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Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version

W. R. Root, CH2M Hill Hanford Group, Inc.
F. M. Mann, Fluor Federal Services
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Abstract: Data package supporting the 2001 Immobilized Low-Activity Waste Performance Analysis. Geology, hydrology, geochemistry, facility, waste form, and dosimetry data based on recent investigation are provided. Verification and benchmarking packages for selected software codes are provided.

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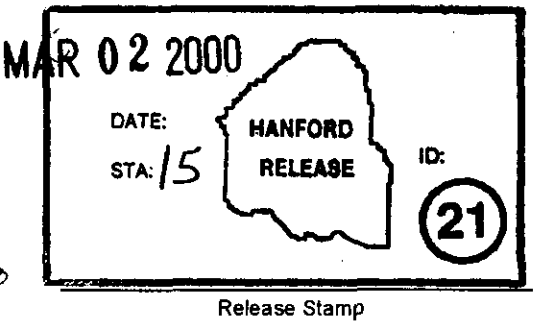

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Rev. 0

DATA PACKAGES FOR THE HANFORD IMMOBILIZED LOW-ACTIVITY TANK WASTE PERFORMANCE ASSESSMENT: 2001 VERSION

Prepared by:
Fred M. Mann and Raymond J. Puigh
Fluor Federal Services

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February 2000

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Executive Summary

This document defines the contents, format, and methods to be used for the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (ILAW PA). This document also provides the data to be used for the supporting calculations. The data are summarized in the main body of the report while the 16 appendices contain the documents used as primary references.

The *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* provides an analysis of the long-term environmental and health impacts of the onsite disposal of Hanford immobilized low-activity tank waste packages. The purpose of the 1998 version[1] was to provide an assessment that would bound the impacts given the limited site-specific and waste-specific data available[2]. The assessment was based on the requirements of DOE Order 5820.2a with the acknowledgment that the order was undergoing revision. This document was conditionally accepted by the Department of Energy and formed part of the basis for the issuance of a Disposal Authorization Statement for the Hanford Site, including the disposal of ILAW.[3]

The next version (known as the 2001 ILAW PA) will use the site-specific and waste form-specific data that have been collected in the past few years. The emphasis of the 2001 ILAW PA will be on how these new data affect the conclusions of the 1998 ILAW PA. These new data and analyses will fulfill the conditions of the DOE headquarters acceptance. The 2001 ILAW PA will also follow the guidance of the new DOE order on radioactive waste management (DOE O 435.1[4]), particularly in the areas of document content and format.

The methods to be used in the performance assessment include the standards (known as performance objectives) against which the impact of the disposal action will be judged, the various scenarios and pathways that will be analyzed, and the tools with which the analyses will be done.

---

[1] F.M. Mann, R.J. Puigh II, P.D. Rittmann, N.W. Kline, J.. Voogd, Y. Chen, C.R. Eiholzer, C.T. Kincaid, B.P. McGrail, A.H. Lu, G.F. Williamson, N.R. Brown, and P.E. LaMont, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment*, DOE/RL-97-69, U.S. Department of Energy, Richland, Washington, March 1998.

[2] F.M. Mann, *Data Packages for the Hanford Low-level Tank Waste Interim Performance Assessment*, WHC-SD-WM-RPT-166, Rev. 0, Westinghouse Hanford Company, Richland, Washington, July 1995.

[3] C.L. Huntoon (Assistant Secretary for Environmental Management), letter to John T. Conway (Chairman, Defense Nuclear Facilities Safety Board) U.S. Department of Energy, Washington, D.C., October 25, 1999.

[4] *Radioactive Waste Management*, DOE O 435.1, U.S. Department of Energy, Washington, D.C., September 1999.

The major data areas covered include:

- Location/geology
- Inventory
- Disposal facility design
- Recharge
- Release rate from the waste form package
- Hydrology
- Geochemistry
- Dosimetry
- Agriculture Use

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Acronyms

BBI	best basis inventory
CA	Composite Analysis
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFEST	Coupled Fluid, Energy, and Solute Transport (computer code)
CFR	Code of Federal Regulations
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
ILAW	Immobilized Low-Activity Waste
ILAW PA	Immobilized Low-Activity Waste Performance Assessment
LFRG	Low-Level Waste Disposal Facility Federal Review Group
NRC	Nuclear Regulatory Commission
PA	Performance Assessment
RCRA	Resource Conservation and Recovery Act
RH	remotely handled (refers to trench disposal facility design)
STORM	Subsurface Transport Over Reactive Multiphases (computer code)
TWRS EIS	Tank Waste Remediation System Environmental Impact Statement
TWRSO&UP	Tank Waste Remediation System Operation and Utilization Plan (Kirkbride 1999)
WAC	Washington Administrative Code

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This document defines the contents, format, and methods to be used for the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (ILAW PA) to be issued in 2001. This document also provides the data to be used for the supporting calculations. The data are summarized in the main body of the report while the 16 appendices contain the documents used as primary references.

1.2 BACKGROUND

The Hanford Site, in south-central Washington State has been used extensively for producing defense materials by the Department of Energy (DOE) and its predecessors, the U.S. Atomic Energy Commission and the U.S. Energy Research and Development Administration. Starting in the 1940s, Hanford Site operations were dedicated primarily to producing nuclear weapons materials. In the 1960s, operations were expanded to producing electricity from a dual-purpose reactor, conducting diverse research projects, and managing waste. In the late 1980s, the Site's original mission ended. This mission left a large inventory of radioactive and mixed waste stored in buried single- and double-shell tanks in the Hanford Site 200 Areas.

Today, the Site's missions are environmental restoration, energy-related research, and technology development. As part of its environmental restoration mission, DOE is proceeding with plans to permanently dispose of the waste stored on site. These plans are based on the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology 1998-1) and the *Record of Decision for the Tank Waste Remediation Systems Environmental Impact Statement* (DOE 1997). These documents call for the waste to be retrieved from the Hanford Site's single- and double-shell tanks, then treated to separate the low-level fraction (now called the low-activity fraction) from the high-level and transuranic fractions. Both fractions will then be immobilized.

The two products (the small volume of high-level immobilized waste and the much larger volume of low-activity waste) will be disposed of in different locations. The high-level waste will be stored on the Hanford Site until sent to a federal geologic repository. The low-activity immobilized waste will be placed in a near-surface disposal system in the 200 East Area of the Hanford Site. On the order of 160,000 m^3 (5,6000,000 ft^3) of low-activity immobilized waste will be disposed of under this plan. This is among the largest amounts of waste in the DOE Complex (DOE 1995) and has one of the largest inventories of long-lived radionuclides at a low-level waste disposal facility.

The DOE is proceeding (DOE-RL 1996a) to procure privatized services for treating and immobilizing the tank waste. In August 1998, DOE placed a contract with BNFL, Inc. (DOE/BNFL 1998) to produce the ILAW with the first delivery currently scheduled in 2008.

The first phase of the effort would extend for about a decade. The contract for the second phase, in which most of the waste will be processed, will be awarded in the second half of the decade.

1.3 PREVIOUS ASSESSMENTS

In 1998, the first version of the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Mann 1998a) was issued and submitted to the Federal Low-Level Waste Review Group (LFRG) for review and action. The Federal Low-Level Waste Review Group has completed their review. Based on this review the DOE has conditionally accepted the ILAW Performance Assessment (DOE 1999f). This acceptance is contingent upon the following actions: providing the LFRG with documentation of the near-term glass activities to provide confidence that the glass performance assumed in the performance assessment can actually be achieved, and addressing the secondary issues identified by the review team in future revisions to the performance assessment.

Most of the data in the 1998 ILAW PA came from the *Data Packages for the Hanford Low-level Tank Waste Interim Performance Assessment (Mann 1995)*, although some data were updated to reflect more current values.

A number of other impact assessments have also been done at the Hanford Site:

- The *Long-Term Performance Assessment of Grouted Phosphate/Sulfate Waste from N Reactor Operations* (Stewart 1987) forms the basis of the environmental assessment (DOE 1986) for the disposal of low-level radioactive waste generated by decontamination operations and other activities associated with N Reactor operations. Because this performance assessment predates the DOE order on radioactive waste management, the DOE review was conducted by reviewing the environmental assessment.

- The *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford* (Kincaid 1995) dealt with disposing of low-level liquid waste from the double-shell tanks. The waste was to be combined with cement, flyash, and clay to form a grout that would be poured into large subsurface vaults located to the east of the 200 East Area. The Peer Review Panel (Wilhite 1994) approved the grout performance assessment in principle. DOE (Lytle 1995) found that the analysis performed in Kincaid (1995) was "technically adequate and provides reasonable assurance that the selected performance objectives would be met." Noting, however, that the grout project had been canceled, DOE also stated that a new or revised performance assessment would be needed for routine disposal of waste in the Grout Disposal Facility.

- The *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* (Wood 1994) dealt with the solid waste from operations at the Hanford Site and other sites. This waste is placed into trenches in the western part of the 200 West Area and then covered with a *Resource Conservation and Recovery Act of 1976* (RCRA)-compliant barrier. The Peer Review Panel found the performance assessment to

be technically acceptable. The 200 West Area performance assessment has been "conditionally accepted" by DOE-Headquarters (Cowan 1996). The conditions were related to added documentation.

- The *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Waste Burial Grounds* (Wood 1996) addresses waste that is similar to that addressed in the 200 West Area performance assessment. However, the disposal trenches for this waste are in the northern part of the 200 East Area. The final performance assessment for this action has also been conditionally approved by DOE-Headquarters (Frei 1997).

- The *Environmental Remediation Disposal Facility Performance Assessment* (Wood 1995) was written to support disposal of waste generated by the cleanup of the Hanford Site. Most of this waste is expected to be contaminated soil. Trenches are planned to be the main means of disposal at the facility. Because the Environmental Remediation Disposal Facility is regulated under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), this performance assessment was not submitted to the Peer Review Panel. However, a remedial investigation and feasibility study report (DOE-RL 1993) was written.

- The *Composite Assessment for Hanford Site* (CA) (Kincaid 1998) was prepared in response to Recommendation 94-2 of the Defense Nuclear Facilities Safety Board to the Secretary of the Department of Energy [DNFSB 1994]. The recommendation noted the need for a risk assessment that investigates the environmental impacts of all radioactive waste disposal actions or leaks at a DOE Site. The CA has undergone headquarters review by the Federal Low-Level Waste Review Group. Based on this review the DOE has conditionally accepted the CA (DOE 1999f). This acceptance is contingent upon the following actions: providing the LFRG by September 30, 2001 with an addendum to the composite analysis that addresses bounding analyses in the 200 Area that include the PUREX tunnels, the chemical separations plants and the CERCLA sites, and resolve the path forward for the Gable Mountain Pond; and address the secondary issues identified in the LFRG review.

- The *Environmental Impact Statement for the Tank Waste Remediation System* (TWRS EIS) (DOE 1996b) analyzed various options to manage the Hanford Site's tank waste with the record of decision issued in 1997 (DOE 1997). Because of the scope of the TWRS EIS, the analyses relied on data less complete and less project-specific than this performance assessment. The record of decision includes the disposal of ILAW in the Hanford Site 200 Areas.

1.4 OTHER RELEVANT HANFORD DATA COLLECTION EFFORTS

Besides the data collection efforts associated with the ILAW PA activity, there are a number of data collection efforts at the Hanford Site that can provide useful data to the ILAW PA activity. Close cooperation with these activities is maintained.

As part of the maintenance program for the Solid Waste Burial Ground Performance Assessments, work on retardation through near-field materials (especially concrete) is being performed.

The maintenance of the Composite Analysis is being undertaken by the Hanford Groundwater / Vadose Zone Integration Project. The Characterization of Systems activity, the Science and Technology activity, and the System Assessment Capability activity will provide (respectively) a centralized data source for Hanford inventory and geotechnical data, improved methods and data, and updated analyses. For the most part, new data will come from other sources.

The Tank Farm Vadose Zone Program has an active program characterizing the vadose zone in and near tank farms. A number of boreholes are planned which will not only provide contaminant concentrations, but also important geologic, geochemical, and hydraulic data in various parts of the 200 Areas.

The 200 Areas Remediation Project will have an active characterization effort in the 200 Areas as it starts planning remediation efforts.

The Hanford Groundwater Project has an active program to monitor groundwater quality at the Hanford Site. This program will be drilling boreholes (in order to replace monitoring wells going dry) from which geotechnical data will be obtained.

1.5 GUIDANCE

Guidance for the performance assessment mainly derives from *Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses* (DOE 1999a) and *Maintenance Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses* (DOE 1999b).

1.6 CONTENTS OF THIS REPORT

Section 2.0 briefly describes the contents and formats of the 2001 ILAW PA. Section 3.0 describes the methods to be used in the PA, including the performance objectives, the scenarios, and the computer codes. Chapter 4.0 summarizes the data to be used, including data on

- Location/geology
- Inventory
- Disposal facility design
- Recharge
- Release rate from the waste form package
- Hydrology

- Geochemistry
- Dosimetry

The appendices contain the documents used as primary references.

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2.0 CONTENTS AND FORMAT

The contents and format for the 2001 ILAW PA is based on the guidance in Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses (DOE 1999a). The structure to be used is displayed in Table 2.1.

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9.0 PREPARERS

10.0 REFERENCES

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3.0 METHODS

3.1 OVERVIEW

This section covers the methods to be used in the 2001 ILAW PA. The methods include the standards (known as performance objectives) against which the effect of the disposal action will be judged, the various scenarios and pathways which will be analyzed, and the tools with which the analyses will be done.

3.2 PERFORMANCE OBJECTIVES

Performance objectives are the standards against which the effect of the disposal action will be done. The manual (DOE 1999d –1) for the new DOE order on radioactive waste management, DOE O 435.1 (DOE 1999c) provides performance objectives for a performance assessment as:

The performance objectives are similar to those used in the 1998 ILAW PA. The major differences are the inclusion of chemicals to support RCRA analyses and explicit comparisons to be done at 1,000 years to support the requirements of the DOE order on radioactive waste management.

(1)(a) "25 mrem in a year total effective dose equivalent from all exposure pathways"
(1)(b) "10 mrem in a year total effective dose equivalent " via the air pathway
(1)(c) "Release of radon shall not exceed 10 mrem in a year total effective dose equivalent"
(2)(g) "include an assessment of impacts to water resources"
(2)(h) "The intruder analysis shall use performance measures for chronic and acute exposures, respectively, of 100 mrem in a year and 500 mrem in a year total effective dose equivalent."
(2)(b) "The point of compliance shall correspond to the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposal waste."
(2) "include calculations for a 1,000 year period after closure"

This performance assessment will also be the technical supporting document for the Resource Conservation and Recovery Act (RCRA) Part B permit and for discussions with the U.S. Nuclear Regulatory Commission (NRC) on the waste classification of ILAW. Therefore, additional items were considered in the establishment of the performance objectives used in the 2001 ILAW PA. Specifically, the RCRA concerns bring in the impacts of hazardous chemicals. The NRC concerns bring in the requirements of 10 CFR 61, which mainly add the requirements for an analysis to 10,000 years after closure.

Therefore, as documented in Appendix A, the various requirements noted above have been merged into an unified set of performance objectives for the 2001 ILAW PA (Mann 1999a). Table 3.1 presents the performance objectives for radionuclides, while Table 3.2 presents the performances objectives for chemicals.

Table 3.1 Radiological Performance Objectives

Protection of General Public and Workers [a, b]	
All-pathways dose from only this facility	25 mrem in a year [d, h]
All-pathways dose including other Hanford Site sources	100 mrem in a year [e, i]
Protection of an Inadvertent Intruder [c, f]	
Acute exposure	500 mrem
Continuous exposure	100 mrem in a year
Protection of Groundwater Resources [b, d, j]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	5 pCi/ℓ
All others (total)	15 pCi/ℓ
Beta and photon emitters	4 mrem in a year
Protection of Surface Water Resources [b, g]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	0.3 pCi/ℓ
All others (total)	15 pCi/ℓ
Beta and photon emitters	1 mrem in a year [k]
Protection of Air Resource [b, f, l]	
Radon (flux through surface)	20 pCi m^{-2} s^{-1}
All other radionuclides	10 mrem in a year

[a] All doses are calculated as effective dose equivalents; all concentrations are in water taken from a well. Values given are in addition to any existing amounts or background.

[b] Evaluated for 1,000 and 10,000 years, but calculated to the time of peak or 10,000 years, whichever is longer.

[c] Evaluated for 500 years, but calculated to 1,000 years.

[d] Evaluated at the point of maximal exposure, but no closer than 100 meters (328 feet) from the disposal facility.

[e] Evaluated at the 200 East Area fence.

[f] Evaluated at the disposal facility.

[g] Evaluated at the Columbia River, no mixing with the river is assumed.

[h] Main driver is DOE Orders on *Radioactive Waste Management* (DOE 1988 and DOE 1999c)

[i] Main driver is DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE 1993).

[j] Main driver is National Primary Drinking Water Regulations (40 CFR 141).

[k] Main driver is Washington State Surface Water Standards (WAC 173-201A)

[l] Main driver is National Emission Standards for Hazardous Air Pollutants (40 CFR 61H and 40 CFR 61Q).

Table 3.2 Performance Goals for Hazardous Materials

Inorganic Compounds/Elements					
Chemical		Groundwater		Surface Waters	
Ammonia				4.0	mg/l
Antimony		0.006	mg/l	0.006	mg/l
Arsenic		0.00005	mg/l	0.05	mg/l
Barium		1.0	mg/l	2.0	mg/l
Beryllium		0.004	mg/l	0.004	mg/l
Cadmium		0.005	mg/l	0.00077	mg/l
Chlorine		250.	mg/l	230.	mg/l
Chromium		0.05	mg/l	0.011	mg/l
Copper		1.0	mg/l	0.0078	mg/l
Cyanide		0.2	mg/l	0.0052	mg/l
Fluoride		4.0	mg/l	4.0	mg/l
Iron		0.3	mg/l		
Lead		0.05	mg/l	0.0015	mg/l
Manganese		0.05	mg/l		
Mercury		0.002	mg/l	0.000012	mg/l
Nickel				0.115	mg/l
Nitrate as N		10.	mg/l	10.	mg/l
Nitrite as N		1.0	mg/l	1.0	mg/l
Nitrite plus Nitrate		10.	mg/l	10.	mg/l
Selenium		0.01	mg/l	0.005	mg/l
Silver		0.05	mg/l		
Sulfate		250.	mg/l		
Thallium		0.002	mg/l		
Zinc		5.0	mg/l	0.072	mg/l
Organic Compounds					
CAS #	Constituent (a)	Groundwater		Surface Waters	
56-23-5	Carbon tetrachloride	0.0003	mg/l	0.005	mg/l
67-66-3	Chloroform	0.007	mg/l		
71-43-2	Benzene	0.001	mg/l	0.005	mg/l
71-55-6	1,1,1-Trichloroethane	0.003	mg/l	0.2	mg/l
75-09-2	Dichloromethane (Methylene Chloride)	0.005	mg/l	0.005	mg/l
79-00-5	1,1,2-Trichloroethane	0.005	mg/l	0.005	mg/l
79-01-6	1,1,2-Trichloroethylene	0.005	mg/l	0.005	mg/l
95-47-6	o-Xylene	0.7	mg/l	0.7	mg/l
100-41-4	Ethyl benzene	0.1	mg/l	0.1	mg/l
106-46-7	1,4-Dichlorobenzene	0.004	mg/l	0.075	mg/l
108-88-3	Toluene	1.0	mg/l	1.0	mg/l
127-18-4	1,1,2,2-Tetrachloroethene	0.005	mg/l	0.005	mg/l

No entry in a cell indicates that no limit was found.

3.3 SCENARIOS AND PATHWAYS

3.3.1 Introduction

The scenarios and pathways are basically unchanged from the 1998 ILAW PA.

The selection of scenarios and pathways for the 2001 ILAW PA is more fully described in Appendix B (Mann 1999b). Possible scenarios were suggested by analyzing the performance objectives given in Section 3.2 and determining which parameters could lead to exposure which is given by the performance objective. The pathways to be analyzed are groundwater, air, and inadvertent intruder. Finally, probable natural events are identified in Section 3.3.5.

In 1992, the Hanford Future Site Uses Working Group (consisting of local, state, and federal officials, representatives of tribal nations, people from agriculture and labor, as well as members of environmental and special interest groups) was charged to determine potential future uses of the various parts of the Hanford Site. Their summary report (HFSUWG 1992-1) states

> *"In general, the Working Group desires that the overall cleanup criteria for the Central Plateau should enable general usage of the land and groundwater for other than waste management activities in the horizon of 100 years from the decommissioning of waste management facilities and closure of disposal areas."*

The DOE along with the U.S. Department of Interior, local governments, and affected tribal nations have recently issued a comprehensive land use plan for the Hanford Site for at least the next 50 years (DOE 1999e). The plan outlines that the 200 Areas (or Central Plateau) would be used exclusively as a waste management area.

Except for the inadvertent intruder scenario, the scenarios described here assume that some controls remain in place to prevent public intrusion into the disposal site. That is, the barriers and markers that have been left are effective in preventing open use of the land directly over the disposal site.

3.3.2 Groundwater Pathway

Past Hanford Site performance assessments (see Section 1.3) have shown that the groundwater pathway to be the most restrictive for the vast majority of radionuclides. Previous assessments have not analyzed the effect of chemicals. Figure 3-1 shows the details of the groundwater pathway. The eight steps are

1) Precipitation (rain or snow) enters the soil. Much of this water returns to the atmosphere by evaporation from the soil surface or transpiration through plant leaves. The remaining water moves down below the surface evapotranspiration zone at a very low rate.

2) The deep water continues to move downward, but some of the water is diverted by any intact sand-gravel capillary barrier.

3) The water that is not diverted away from the waste may be chemically modified by the local environment, interacts with the waste form, and accumulates contaminants.

4) The water (possibly a reduced amount because waste form dissolution and mineral formation consume water) leaves the disposal facility carrying contaminants with it. Some contaminants may interact with the material in the disposal facility, slowing the release of contaminants to the surrounding natural environment.

5) Contaminated water moves through the undisturbed, unsaturated zone (vadose zone) below the disposal facility down to the unconfined aquifer. The contaminants may interact with soil sediments causing further retardation. Changes to the properties of the natural system are considered, but are not major.

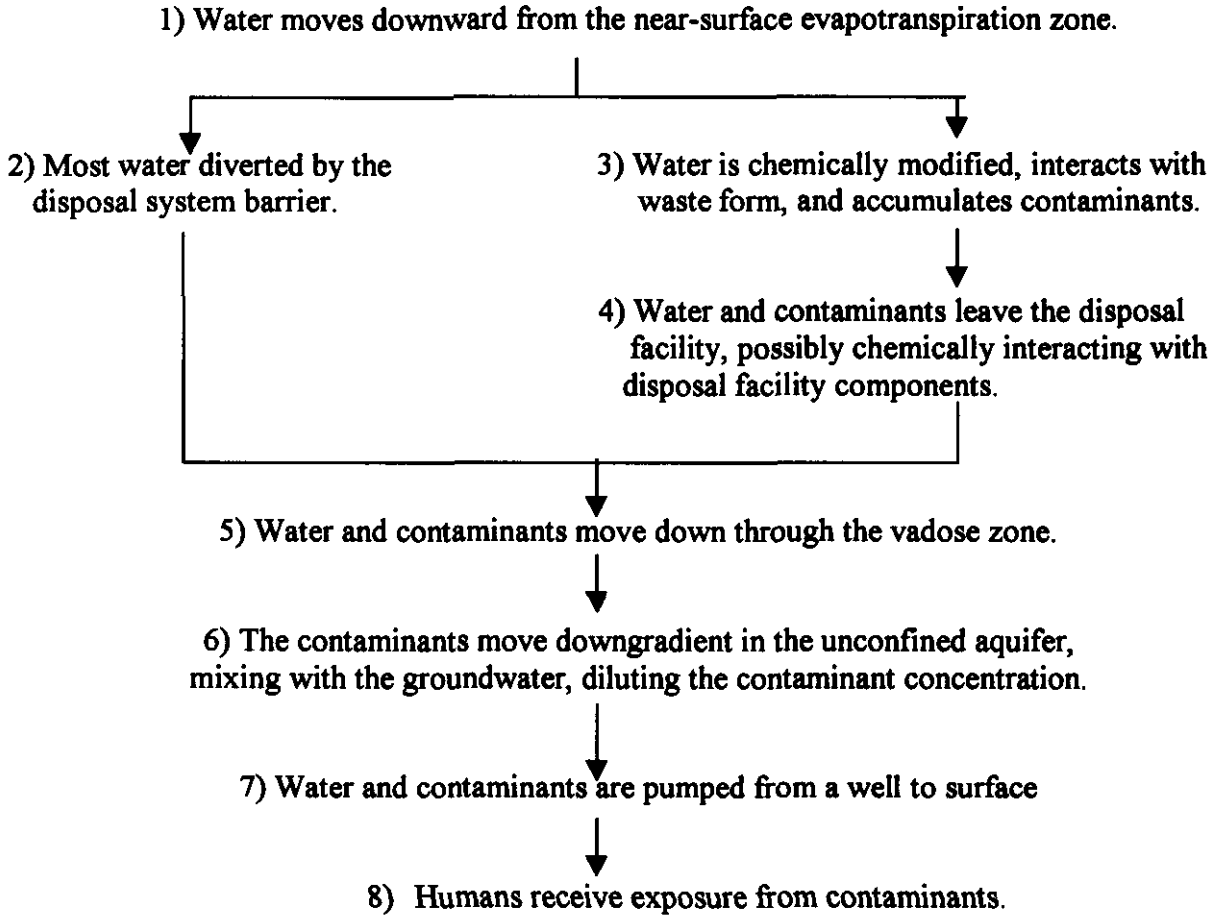
6) The water and contaminants move and mix with the water in the unconfined aquifer until they are extracted from the aquifer and brought to the surface or until they reach the Columbia River.

7) Contaminants are extracted by being carried to the surface with groundwater being pumped through a well.

8) The contaminants result in human exposure through a variety of exposure pathways (ingestion, inhalation, dermal contact, and external radiation).

The 1998 ILAW PA (Mann 1998a) showed that the second most mobile radionuclides (such as uranium and its daughters) peaked at about 50,000 years, a time at which the most mobile radionuclides (technetium, selenium, and many chemicals) were still significant. Explicit numerical simulations will be performed from the present to 100,000 years in the future (i.e., twice the time for the peak all-pathways dose) using best-estimate values for all parameters. Comparisons to the performance objectives will be made at 1,000 years and at 10,000 years after closure of the ILAW disposal facility (which is assumed to be in 2030).

Figure 3-1. Eight Sequential Steps for the Groundwater Pathway



3.3.3 Air Pathway

The previous performance assessment (Mann 1998a) showed that using conservative assumptions that releases to the atmosphere are many orders of magnitude (four in the case of radon releases and nine for other gases) less than performance objectives. As in the 1998 ILAW PA, diffusion of gaseous species will be treated.

3.3.4 Inadvertent Intruder Scenarios

Following the practice of the Nuclear Regulatory Commission (NRC 1988, NRC 1997), three scenarios were considered:

- A basement is excavated which extends into the waste and hence contaminants are brought to the surface,

- A well is drilled through the waste, bringing contaminants to the surface,
- Contaminants that have been brought to the surface are mixed with the surrounding soil as a residential farmer works the soil.

Because the waste will be below (> 5 meters) the levels that basement excavations are dug in the Columbia Basin region, the first scenario (basement excavation) is not treated. The other two scenarios are treated.

3.3.5 Natural Event Scenarios

The main natural events to be expected are 1) erosion of the surface above this disposal units due to wind, 2) subsidence of the engineered barriers or facilities, 3) earthquakes, and 4) flooding due to post-glacial events. As in the 1998 ILAW PA, the first three events will be treated as part of the degradation of the disposal facility, while a simple calculation will estimate the effect of post-glacial flooding.

3.4 COMPUTER CODES

3.4.1 Introduction

Computer codes will be used for four purposes:

Selection processes resulted in newer codes than used in the 1998 ILAW PA.

- calculate contaminant release rates from the waste packages and from the disposal facility,
- calculate moisture flow and contaminant transport in the vadose zone,
- calculate moisture flow and contaminant transport in groundwater, and
- merge the results of the other codes.

For the first three codes, the code selection criteria, code selection, and verification packages have been published and are described below. The code that merges the results will be discussed in the 2001 ILAW PA itself.

3.4.2 Waste Form Release and Near-Field Contaminant Transport Code

The 1998 ILAW PA showed that a key intermediate result is the waste form release rate, which is calculated over thousands of years. The code selection criteria and selection process is documented in *Selection Of A Computer Code For Hanford Low-Level Waste Engineered-System Performance Assessment* (McGrail 1998a), which is included as Appendix C of this document. The needed capabilities were identified from an analysis of the important physical and chemical processes expected to affect LAW glass corrosion and the mobility of radionuclides. The available computer codes with suitable capabilities were ranked in terms of

the feature sets implemented in the code that match a set a physical, chemical, numerical, and functional capabilities needed to assess release rates from the engineered system. The highest ranked computer code was found to be the STORM code developed at PNNL for the U.S. Department of Energy for evaluation of arid land disposal sites. The verification studies for STORM are documented in *Subsurface Transport Over Reactive Multiphases (STORM): A General, Coupled, Nonisothermal Multiphase Flow, Reactive Transport, and Porous Medium Alteration Simulator, Version 1.09, User's Guide* (Bacon et. al. 2000), which is included as Appendix D.

3.4.3 Vadose Zone Moisture Flow and Contaminant Transport Code

The selection process for the vadose zone code was more formal. The code selection criteria were determined (Mann 1998b) and vendors formally submitted proposals which were formally evaluated (Voogd 1999). These latter documented which includes the code selection criteria is attached as Appendix E. The code selection criteria were heavily based on those used in the code selection for the earlier ILAW PAs (Mann 1996) which themselves were based on DOE and NRC criteria. The VAM3DF code, an earlier version of which has been approved by the DOE, EPA, and Washington State Department of Ecology for vadose zone calculations (TPA Milestone 29-2) was selected. Documentation on verification of VAM3DF (Finfrock 2000) can be found in Appendix F.

3.4.4 Groundwater Flow and Contaminant Transport Code

The Richland Operations Office (DOE-RL 1996b) has directed the Hanford Groundwater Program to establish a single groundwater model for the Hanford Site. As a followup to this directive, RL initiated a project in FY 1997 to consolidate multiple groundwater models at the Hanford Site into a single consolidated site-wide groundwater model. The overall recommendations made by RL to select the site-wide groundwater model in the initial phase of the consolidation process are documented in DOE-RL (2000). In this effort, RL initiated an evaluation of computer codes for implementation with the consolidated site-wide groundwater model. Only two computer codes were reviewed in this initial phase of the model-consolidation process: 1) the VAM3D-CG code developed by Hydrogeologic, Inc., in Herndon, Virginia, and 2) the CFEST-96 code developed by the CFEST Co. in Irvine, California. The GWRS model is implemented based on the VAM3D-CG code. The HGWP model is based on the CFEST-96 code. In a qualitative comparison of the two computer codes, both VAM3D-CG and CFEST-96 were found to be technically acceptable because they

- were included in the list of accepted groundwater flow and transport codes identified in Milestone M-29-01 (DOE/RL 1991)
- met the technical capabilities and administrative requirements outlined in the original Milestone M-29-01 document and generally met the technical capabilities and administrative requirement in this report.

In the interest of minimizing initial cost and potential schedule impacts, RL selected the CFEST-96 code as an interim code for implementing the consolidated site-wide groundwater model since it was already implemented with the selected conceptual and numerical model. Documentation of the specific application of the CFEST code to the selected site-wide groundwater flow and transport model at Hanford is provided in Wurstner et al. (1995), Cole et al. (1997), and Kincaid et al. (1998).

RL deferred decisions on final selection of the code until the external peer review of the consolidated site-wide groundwater model and the resulting final refinements and modifications have been completed. When this first phase of the model-consolidation process is completed, RL may consider more in-depth testing and benchmarking of the CFEST-96, VAM3D-0CG, and other applicable codes using the refined and modified site-wide groundwater model before reaching a final decision on selection of a code.

3.5 CALCULATIONAL STRATEGY

The calculational strategy adopted for this performance assessment has been to provide the best estimate for the performance of this disposal action against the performance assessment objectives outlined in section 3.2 of this report. This best estimate calculation is based on the best estimates for the data used in the computer codes to calculate the transport of contaminants from the waste site to the receptors for the various scenarios calculated within this performance assessment.

The authors recognize that there are uncertainties associated with these calculations and the calculational approach. In a broad sense these uncertainties are associated with our understanding of the physical system performance, uncertainty in the models used to approximate the physical system, uncertainty in the codes used to model the transport, and uncertainty in the data input into these codes. An estimate for uncertainty in the data input to the code calculations is provided within the data reports summarized in section 4.0. The other uncertainties are explored through a set of sensitivity calculations where bounding values are used in the calculations for different physical system assumptions. This approach is undertaken in an attempt to convince both the regulators and the public that the proposed disposal action is "acceptable."

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4.0 DATA

4.1 INTRODUCTION

The data to be used in the calculations of the 2001 ILAW PA are described in this section. For most of the topics, the ILAW PA activity has maintained an energetic data gathering and interpretation activity. For other activities (for example, disposal facility design and dosimetry) closely coupled interfaces were developed with those responsible for the information either at the ILAW project level or at the Hanford Site level.

In each subsection, the methods used to generate the values are described and the values for the most important parameters are given. Full details are given in appendices G through N which contain the reports on which this chapter is based. These reports have all undergone Hanford review and several reports (Appendices J, L, M, and N) have undergone external review.

4.2 LOCATION/GEOLOGY

The current plan (Burbank 1999, Taylor 1999a) is to construct new facilities in the south central part of the 200 East Area (Rutherford 1997). Although the existing disposal vaults at the central eastern edge of the 200 East Area are not planned to be used, they will be analyzed as they may be used in the future.

The current plan is to use new facilities in the south-central part of Hanford's 200 East Area. The geology of this area is based on a new borehole as well as reexamining samples from previous holes. The resulting geologic data are more detailed and believed to be more accurate.

The geology of the two disposal sites is given in *Geologic Data Package for the 2001 ILAW PA* (Reidel 1999) which is attached as Appendix G. The Hanford Site lies in the Pasco Basin of the Columbia Plateau. The Columbia Plateau consists of a sequence of thick basalt flows that occurred 5 to 7 million years ago. Overlying the basalt flows are sediments of the late Miocene, Pliocene, and Pleistocene ages, known as the Ringold Formation and (nearer the surface) the Hanford formation. The Hanford formation arises from deposits from post-glacier flooding (between 780,000 years ago and 13,000 years ago) and consists mainly of unconsolidated sand and sandy gravel layers. The unconfined aquifer is near the interface between the Hanford formation and Ringold Formation throughout the Hanford Site and at the disposal sites is about 80-95 meters (262-312 feet) below the surface. Clastic dikes have been observed at the existing disposal site are assumed to exist at the new ILAW site as well.

Data used in the (Reidel 1999) report compilation was obtained from surface geologic studies and from borehole data. The surface geology and geomorphology of the Hanford Site has been mapped and published by Reidel and Fecht (1994a, 1994b). Borehole data consisting of drilling logs, archived samples and geophysical logs are the principal data sets used to interpret the subsurface at the existing disposal site and the new ILAW disposal site. In addition, numerous

reports describing the geology of the area and vicinity are available and are a valuable source of information (e.g., Tallman et al. 1979; DOE 1988; Connelly et al. 1992; Lindberg et al. 1993, Lindsey et al. 1992, 1994b). During the course of this study, archived natural gamma geophysical logs from boreholes at the new ILAW site and surrounding area were located and the logs were incorporated into the interpretations. Geophysical logs include boreholes from surrounding waste disposal sites obtained prior to discharge of effluent and provide a valuable source of information for stratigraphic correlations.

Elevation information were obtained from well completion reports or as-built diagrams if available, or from Chamness and Merz (1993). Because the boreholes are from so many vintages and because several different surveys have been used at the Hanford Site over the years, no attempt was made to assure consistency in the elevation survey data. However, differences among surveys are generally small (<3 feet; 1 m) with respect to other uncertainties associated with the data and, except for water levels in areas with a relatively flat water table, will not affect significantly the information presented in this database.

The methodology used in the process of building the data package followed a series of steps that were designed to insure the data were used properly. First, the main stratigraphic units and contacts were identified in boreholes with geologist's logs and geophysical data. Gross gamma-ray logs were examined with respect to the geologist's logs for geophysical signatures of the stratigraphy. For many boreholes from both sites, chip samples from the Hanford Geotechnical Sample Library were examined to help control the location of contacts and lithologies of stratigraphic units and lateral changes in the percentage of silt, sand, and gravel. Next, boreholes with driller's logs and gross gamma-ray logs were examined and compared to nearby wells and boreholes. At the new ILAW site, the stratigraphy was built out from borehole 299-E17-21 using boreholes with geologist's logs and geophysical logs. Boreholes for which only driller's logs were available were given the least priority for constructing the geologic models.

The stratigraphy at the existing disposal vaults site has the top of the Columbia River Basalt Group at an elevation (above sea level) of approximately 91 m (300 ft). The top of the Ringold Formation ranges between 113-128 m (370-420 ft). The average thickness of the Unit A sequence within the Ringold Formation is 23.7 m (78 ft). The average thickness of the Ringold Formation fine-grain sequence above the Unit A sequence is 5.5 m (18 ft). In some areas beneath the existing disposal site this formation is not present. The Hanford Formation gravel sequence is approximately 31m (102 ft) thick; and the Hanford Formation sand sequence varies from 41 to 67 m (134-220 ft). Finally, recent surface deposits range in thickness between 1.5-4.5 m (5-15 ft). The current water table is in the Ringold Formation fine-grain sequence or in the Hanford Formation gravel sequence.

The stratigraphy at the new ILAW disposal site has the top of the Columbia River Basalt Group at an elevation (above sea level) of approximately 84 m (275 ft). The top of the Ringold Formation ranges between 91-122 m (300-400 ft). The Hanford Formation gravel sequence thickness is approximately 27-46m (88-150 ft) thick; and the Hanford Formation sand sequence varies from 64 to 76 m (210-250 ft). Within the sandy sequence three paleosols were identified. Finally, Eolian deposits cover the southern part of the new ILAW disposal site and range in

thickness between 3 to 15 m (10-50 ft). The current water table is in the Hanford Formation gravel sequence below the new disposal site.

4.3 INVENTORY

The environmental or health impact of each radionuclide or chemical is proportional to the amount of the material at the point of impact. However, normally it is the sum of these impacts over materials at the point of impact that is important. Thus, as shown by the previous Hanford Site performance assessments (see Section 1.3), particularly the last version of the ILAW PA, the significant materials are the most mobile due to the long travel times of the other materials. This section summarizes the data in the *Immobilized Low-Activity Tank Waste Inventory Data Package* report (Wootan 1999) that is included as Appendix H in this document.

Both radionuclide and chemical inventory are given. The radionuclide and inorganic material inventory is based on the current best basis estimates of what is the tank waste inventory corrected for the separation that will occur during the treatment phase as well as contract limits. The organic material inventory is based on RCRA disposal limits.

The ^{99}Tc inventory (5,790 Ci) is lower than in the 1998 ILAW PA because 80% of the Tc will be removed according to the current contract with BNFL.

Both radionuclides and chemicals are considered in this performance assessment. Although DOE O 435.1 only requires performance assessments for radionuclides, the Office of River Protection of DOE along with the Washington State Department of Ecology have determined that the technical analyses should support the Resource Conservation and Recovery Act (RCRA) permitting requirements as well. Thus, one technical analysis will serve as the basis for protection of the public under the requirements of the Atomic Energy Act and RCRA.

Forty-six radionuclides and twenty-five chemicals are explicitly treated in the best basis tank inventories. These materials were selected by the TWRS Characterization Program (Kupfer 1999) as those important for safety, disposal, and processing requirements. This set includes all the radionuclides identified as significant in the 1998 ILAW PA (Mann 1998a) as well as those identified in the screening studies for the ILAW PAs (Schmittroth 1995). The chemicals identified in the 2001 ILAW PA performance objectives (Mann 1999a) that are not listed in the tank inventories should not survive the vitrification process. Therefore, their upper bound concentrations in the waste form were set equal to the concentration limits for land disposal (40 CFR 268).

The nominal ILAW inventories for all the materials explicitly included are based on the *Tank Waste Remediation System Operation and Utilization Plan* (Kirkbride 1999), also known as the TWRSO&UP. The best basis tank by tank inventories (BBI) as of October 1, 1998 were adjusted for waste transfers not accounted for in the BBI, and for non-BBI analytes that are in the waste treatment contract. The BBI inventories were adjusted to a common date (October 1, 1998). The BBI values are based on a tank by tank evaluation of measurements from tank samples as well as modeling results of transfers to and from the tank. The retrieval and feed

delivery process was modeled by estimating liquid and solid partitioning (Hendrickson 1998) and by following the April 1, 1999 DOE guidance (Taylor 1999b) on schedules and contract requirements. Vitrification losses were explicitly included in the model and are described in Kirkbride 1999).

As noted in the 1998 ILAW PA, the previously accepted half-lives of ^{79}Se and ^{126}Sn are now thought to be underestimates. This underestimate for ^{126}Sn has been confirmed (Brodzinski 1999). Thus, inventories for ^{79}Se and ^{126}Sn in the TWRSO&UP have been multiplied by 0.08 and 0.40, respectively.

Table 4.1 provides the total inventory in the tanks and in the ILAW packages as well as the expected average and maximum concentration in the ILAW packages for each radionuclide and chemical considered. The following provide short descriptions of key materials:

- ^{3}H: No tritium is expected to survive the vitrification process to end up in ILAW packages (Kirkbride 1999).
- ^{14}C: No ^{14}C is expected to survive the vitrification process and end up in the ILAW packages (Kirkbride 1999).
- ^{79}Se: Results are based on models, but are considered conservative, since the model neglects previous removals such as disposals to cribs.
- ^{90}Sr: Values are constrained by the current contract (DOE/BNFL 1998) and assumption that this constraint applies to all ILAW waste.
- ^{99}Tc The values are felt to be conservative because the shipments to off-site are neglected. Values are also constrained by the current contract (DOE/BNFL 1998) and assumption that this constraint applies to al ILAW waste.
- ^{126}Sn Results are based on models that overestimate the distribution in tanks 241-AZ-101 and 241-AZ-102.
- ^{129}I The values are felt to be conservative since no credit was taken for losses of iodine to the atmosphere during processing.
- ^{137}Cs Values are constrained by the treatment contract (DOE/BNFL 1998).
- U Many of the values are based on total uranium analysis of samples.
- ^{237}Np The BBI inventory is 30% higher than the global estimate. Two tanks (241-An-103 and 241-AN-105) are thought to have the bulk of the Np, but only "bounding value estimates" are available for those two tanks.
- Pu Values are primarily based on accountability records and samples.

Table 4.1 ILAW Package Inventories (Ci for radionuclide and kg for chemical) and Concentrations (Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Average Package Concentration	Maximum Upper Bound Package Concentration
3-H	2.46E+04	0.00E+00	0.00E+00	4.66E-01
14-C	4.38E+03	0.00E+00	0.00E+00	8.00E+00
59-Ni	8.58E+02	1.67E+02	1.06E-03	6.20E-02

Material	Tank Inventory	ILAW Inventory	Average Package Concentration	Maximum Upper Bound Package Concentration
60-Co	1.99E+04	4.18E+03	2.64E-02	4.39E+00
63-Ni	8.45E+04	1.62E+04	1.02E-01	7.00E+02
79-Se	5.74E+01	4.80E+01	3.03E-04	2.55E-02
90-Sr	5.99E+07	4.50E+06	2.85E+01	7.00E+03
93-Zr	4.12E+03	1.25E+03	7.94E-03	3.32E-01
93m-Nb	2.53E+03	8.36E+02	5.29E-03	4.05E-01
99-Tc	2.89E+04	5.79E+03	3.66E-02	3.00E+00
106-Ru	1.27E+05	8.94E+02	5.65E-03	1.10E+02
113m-Cd	1.67E+04	7.97E+03	5.04E-02	1.34E+00
125-Sb	2.47E+05	5.20E+04	3.29E-01	9.23E+01
126-Sn	4.64E+02	1.69E+02	1.07E-03	3.41E-02
129-I	1.01E+02	2.20E+01	1.39E-04	8.00E-02
134-Cs	8.71E+04	3.76E+02	3.73E-01	3.36E-01
137-Cs	6.37E+07	9.11E+05	5.76E+00	4.60E+03
151-Sm	2.61E+06	7.80E+05	4.93E+00	2.43E+02
152-Eu	1.45E+03	3.07E+02	1.94E-03	5.96E-01
154-Eu	1.83E+05	3.77E+04	2.38E-01	8.92E+01
155-Eu	1.76E+05	3.15E+04	1.99E-01	1.23E+02
226-Ra	1.14E+03	1.03E+03	6.53E-03	9.36E-01
227-Ac	8.75E+01	6.05E-02	3.83E-07	7.63E-03
228-Ra	7.75E+01	3.32E+01	2.10E-04	7.49E-03
229-Th	1.81E+00	3.40E-01	2.15E-06	1.82E-04
231-Pa	1.53E+02	3.37E-01	2.13E-06	1.40E-02
232-Th	4.40E+00	1.28E+00	8.09E-06	6.17E-04
232-U	1.49E+02	3.46E+01	2.19E-04	2.11E-02
233-U	5.72E+02	1.31E+02	8.26E-04	8.18E-02
234-U	3.42E+02	4.41E+01	2.79E-04	4.54E-02
235-U	1.46E+01	1.79E+00	1.13E-05	1.96E-03
236-U	1.24E+01	1.43E+00	9.03E-06	9.60E-04
237-Np	1.85E+02	8.10E+01	5.13E-04	1.46E-03
238-Pu	2.70E+03	1.06E+02	6.72E-04	1.91E-03
238-U	3.28E+02	4.83E+01	3.06E-04	4.12E-02
239-Pu	5.55E+04	3.05E+03	1.93E-02	5.49E-02
240-Pu	1.13E+04	5.25E+02	3.32E-03	9.47E-03
241-Am	1.07E+05	1.08E+04	6.85E-02	1.95E-01
241-Pu	1.66E+05	7.17E+03	4.53E-02	9.28E+00
242-Cm	1.72E+02	5.76E+01	3.64E-04	5.30E+01
242-Pu	1.07E+00	4.49E-02	2.84E-07	8.09E-07
243-Am	1.76E+01	6.89E-01	4.36E-06	1.24E-05
243-Cm	3.47E+01	6.73E+00	4.26E-05	1.21E-04
244-Cm	7.84E+02	1.01E+02	6.36E-04	1.81E-03

Material	Tank Inventory	ILAW Inventory	Average Package Concentration	Maximum Upper Bound Package Concentration
Ag+	1.51E+03	1.08E+02	6.83E-04	1.59E+00
Al(OH)4-	0.00E+00	5.31E+06	3.36E+01	1.53E+03
Al+3	8.27E+06	4.05E+06	2.56E+01	5.29E+02
As+5	2.08E+01	1.76E+01	1.12E-04	1.75E-01
B+3	6.53E+03	6.54E+02	4.14E-03	1.04E+01
Ba+2	1.70E+03	1.86E+01	1.17E-04	1.32E+01
Be+2	1.09E+02	6.14E-01	3.89E-06	1.94E+00
Bi+3	6.31E+05	9.96E+03	6.30E-02	3.27E+02
Ca+2	3.19E+05	4.78E+04	3.03E-01	6.54E+01
Cd+2	4.18E+02	6.30E+01	3.98E-04	6.81E-01
Ce+3	2.38E+05	2.33E+03	1.47E-02	7.93E+02
Cl-	9.37E+05	9.31E+05	5.89E+00	4.67E+01
CN-	1.09E+05	0.00E+00	0.00E+00	2.06E+00
CO3-2	9.46E+06	0.00E+00	0.00E+00	1.79E+02
Cr(OH)4-	0.00E+00	4.05E+05	2.56E+00	2.31E+02
Cr (TOTAL)	6.72E+05	2.74E+05	1.73E+00	9.37E+01
Cs+	1.18E+05	1.12E+03	7.13E-01	5.67E+01
Cu+2	3.15E+02	7.33E-01	4.63E-06	2.19E-01
F-	1.20E+06	9.94E+05	6.28E+00	9.97E+01
Fe+3	1.40E+06	4.48E+04	2.83E-01	2.68E+02
H2O	8.70E+07	0.00E+00	0.00E+00	1.65E+03
Hg+2	2.10E+03	1.92E+02	1.22E-03	1.11E+00
K+	8.75E+05	8.33E+05	5.27E+00	6.57E+01
La+3	5.13E+04	5.06E+02	3.20E-03	9.10E+00
Li+	3.04E+01	3.02E+01	1.91E-04	4.98E-03
Mg+2	3.38E+03	2.84E+02	1.80E-03	1.53E+01
Mn+4	1.96E+05	1.38E+04	8.71E-02	1.79E+01
Mo+6	1.31E+03	6.21E+02	3.93E-03	5.58E-01
Na+	4.90E+07	5.69E+07	3.60E+02	1.01E+03
NH3	5.01E+05	0.00E+00	2.53E+00	9.51E+00
Ni+2	1.80E+05	3.05E+04	1.93E-01	5.25E+01
NO2-	1.26E+07	0.00E+00	0.00E+00	2.40E+02
NO3-	5.25E+07	0.00E+00	0.00E+00	9.96E+02
OH (BOUND)	2.11E+07	0.00E+00	0.00E+00	4.01E+02
OH-	3.66E+06	0.00E+00	0.00E+00	6.95E+01
Pb+2	8.40E+04	7.83E+03	4.95E-02	8.77E+00
PO4-3	5.56E+06	5.16E+06	3.26E+01	7.36E+02
Rh+3	5.19E+01	NA	0.00E+00	6.56E-03
Ru+3	1.21E+00	NA	0.00E+00	1.53E-04
Se+6	6.11E-01	5.33E-01	3.37E-06	6.80E-04
Si+4	9.41E+05	4.20E+05	2.66E+00	1.54E+02

Material	Tank Inventory	ILAW Inventory	Average Package Concentration	Maximum Upper Bound Package Concentration
SO4-2	3.91E+06	3.39E+06	2.15E+01	3.16E+02
Sr+2	4.55E+04	2.20E+03	1.39E-02	8.01E+00
Te+6	3.04E+02	NA	0.00E+00	3.84E-02
Th+4	NA	NA	0.00E+00	4.86E-01
Ti+4	2.60E+02	1.49E+01	9.42E-05	4.00E-01
Tl+3	2.54E+04	NA	0.00E+00	3.21E+00
TOC	2.00E+06	0.00E+00	0.00E+00	3.79E+01
U(TOTAL)	7.61E+04	1.73E+04	1.10E-01	2.85E+01
V+5	1.68E+01	NA	0.00E+00	2.13E-03
W+6	NA	NA	0.00E+00	2.01E+00
Zn+2	2.89E+03	1.98E+03	1.25E-02	3.48E+00
Zr+4	4.65E+05	1.23E+04	7.76E-02	2.07E+01
1,1,1-trichlorethane	NA	0.00E+00	0.00E+00	2.07E-02
1,1,2-trichloro-1,2,2-trifluoroethane	NA	0.00E+00	0.00E+00	1.03E-01
1,1,2-trichloroethane	NA	0.00E+00	0.00E+00	2.07E-02
1,1-dichloroethylene	NA	0.00E+00	0.00E+00	2.07E-02
1,2-dichloroethane	NA	0.00E+00	0.00E+00	2.07E-02
acetone	NA	0.00E+00	0.00E+00	5.51E-01
benzene	NA	0.00E+00	0.00E+00	3.45E-02
carbon tetrachloride	NA	0.00E+00	0.00E+00	2.07E-02
chlorobenzene	NA	0.00E+00	0.00E+00	2.07E-02
chloroform	NA	0.00E+00	0.00E+00	2.07E-02
ethyl acetate	NA	0.00E+00	0.00E+00	1.14E-01
ethyl benzene	NA	0.00E+00	0.00E+00	3.45E-02
hexachorobutadiene	NA	0.00E+00	0.00E+00	1.93E-02
methyl ethyl ketone	NA	0.00E+00	0.00E+00	1.24E-01
methyl isobutyl ketone	NA	0.00E+00	0.00E+00	1.14E-01
methylene chloride	NA	0.00E+00	0.00E+00	1.03E-01
n-butyl alcohol	NA	0.00E+00	0.00E+00	8.96E-03
nitrobenzene	NA	0.00E+00	0.00E+00	4.82E-02
o-dichlorobenzene	NA	0.00E+00	0.00E+00	2.07E-02
pyridine	NA	0.00E+00	0.00E+00	5.51E-02
tetrachloroethylene	NA	0.00E+00	0.00E+00	2.07E-02
toluene	NA	0.00E+00	0.00E+00	3.45E-02
trichloroethylene	NA	0.00E+00	0.00E+00	2.07E-02
trichloromonofluoromethane	NA	0.00E+00	0.00E+00	1.03E-01
vinyl chloride	NA	0.00E+00	0.00E+00	2.07E-02
xylenes-mixed isomers	NA	0.00E+00	0.00E+00	1.03E-01
1,1,2,2-tetrachloroethane	NA	0.00E+00	0.00E+00	2.07E-02
1,1-dichloroethane	NA	0.00E+00	0.00E+00	2.07E-02

Material	Tank Inventory	ILAW Inventory	Average Package Concentration	Maximum Upper Bound Package Concentration
1,2,4-trichlorobenzene	NA	0.00E+00	0.00E+00	6.55E-02
1,2-dichloropropane	NA	0.00E+00	0.00E+00	6.20E-02
1,3-dichlorobenzene	NA	0.00E+00	0.00E+00	2.07E-02
1,4-dichlorobenzene	NA	0.00E+00	0.00E+00	2.07E-02
1,4-dioxane	NA	0.00E+00	0.00E+00	5.86E-01
2-sec-butyl-4,6-dinitrophenol	NA	0.00E+00	0.00E+00	8.61E-03
3-chloropropene	NA	0.00E+00	0.00E+00	1.03E-01
acetonitrile	NA	0.00E+00	0.00E+00	1.31E-01
acetophenone	NA	0.00E+00	0.00E+00	3.34E-02
acrylonitrile	NA	0.00E+00	0.00E+00	2.89E-01
aldrin	NA	0.00E+00	0.00E+00	2.27E-04
benzo(a)pyrene	NA	0.00E+00	0.00E+00	1.17E-02
chloroethane	NA	0.00E+00	0.00E+00	2.07E-02
cis-1,3-dichoropropene	NA	0.00E+00	0.00E+00	6.20E-02
cyanide	NA	0.00E+00	0.00E+00	2.03E+00
dibenzo(a,h)anthracene	NA	0.00E+00	0.00E+00	2.82E-02
dichlorodifluoromethane	NA	0.00E+00	0.00E+00	2.48E-02
dieldrin	NA	0.00E+00	0.00E+00	4.48E-04
dimethylnitrosamine	NA	0.00E+00	0.00E+00	7.92E-03
diphenylamine	NA	0.00E+00	0.00E+00	4.48E-02
endrin	NA	0.00E+00	0.00E+00	4.48E-04
ethylene dibromide	NA	0.00E+00	0.00E+00	5.17E-02
heptachlor	NA	0.00E+00	0.00E+00	2.27E-04
hexachlorobenzene	NA	0.00E+00	0.00E+00	3.45E-02
hexachlorocyclohexane alpha bhc	NA	0.00E+00	0.00E+00	2.27E-04
hexachlorocyclohexane beta bhc	NA	0.00E+00	0.00E+00	2.27E-04
isodrin	NA	0.00E+00	0.00E+00	2.27E-04
lindane (all isomers)	NA	0.00E+00	0.00E+00	2.27E-04
methacrylonitrile	NA	0.00E+00	0.00E+00	2.89E-01
methyl bromide	NA	0.00E+00	0.00E+00	5.17E-02
methyl chloride	NA	0.00E+00	0.00E+00	1.03E-01
p-dinitrobenzene	NA	0.00E+00	0.00E+00	7.92E-03
pentachloronitrobenzene	NA	0.00E+00	0.00E+00	1.65E-02
pentachlorophenol	NA	0.00E+00	0.00E+00	2.55E-02
phenol	NA	0.00E+00	0.00E+00	2.14E-02
polychlorinated biphenyls (PCB)	NA	0.00E+00	0.00E+00	3.45E-02
propionitrile	NA	0.00E+00	0.00E+00	1.24E+00
toxaphene	NA	0.00E+00	0.00E+00	8.96E-03
trans-1,3-dichloropropene	NA	0.00E+00	0.00E+00	6.20E-02
triethylamine	NA	0.00E+00	0.00E+00	2.79E-04

Footnotes:

Inventories for radionuclides are as of 10/1/98.

NA entries refer to components where inventory information is not available.

The ^{90}Sr will have ^{90}Y daughter in equilibrium. The ^{137}Cs will have ^{137m}Ba daughter in equilibrium.

Tank inventories of specific organics are not available. Organics are not expected to survive the vitrification process.

4.4 DISPOSAL FACILITY DESIGN

The design for the ILAW disposal facility (trenches with surface barrier) is based on the mixed waste disposal facility at the Hanford Site. This is a major change from the 1998 ILAW PA which is based on a pre-conceptual design using concrete vaults. Also, conceptual designs have been published for the use of concrete vaults for ILAW.

This section summarizes the data given in *Disposal Facility Data for the Hanford Immobilized Low-Activity Tank Waste* (Puigh 1999), which is included as Appendix I of this document.

The Immobilized Low-Activity Waste (ILAW) disposal planning was to utilize the existing disposal vaults from the grout program suitably modified to receive ILAW packages and new disposal facilities currently in their early design phase. In December 1999 the Department of Energy identified the remote handled trench as the baseline concept for ILAW disposal at Hanford (Taylor 1999a). The 2001 ILAW PA will consider both concepts in assessing long term environmental impacts from the proposed disposal action.

The existing disposal vaults were originally constructed in the late 1980's and early 1990's. These vaults were designed to contain a liquid low-level waste (LLW) grout mixture during the curing and solidification period, and to serve as a disposal structure for the resulting grouted waste monolith. Five vaults were constructed. One vault was filled before termination of the program leaving four empty vaults available for use.

Each vault is 37.6 m (123.5 ft) long and 15.4 m (50.5 ft) wide, with a roof clearance of 10.4 m (34.0 ft), providing 579 m^2 (6,236 ft^2) of floor space. The vaults are constructed of reinforced concrete, and were designed and constructed in compliance with RCRA requirements for both hazardous waste surface impoundments and land disposal units. Each vault is built above a RCRA-compliant leak detection and collection system. The leak detection system consists of a sealed concrete slab sloped to a collection sump fitted with a riser pipe to the surface. The system is capable of collecting, detecting, sampling, and removing any leachate that might escape from the primary vault structure.

A conceptual design activity has been performed to modify the existing disposal vaults to accept and ultimately serve as a disposal facility for the ILAW from the Hanford waste tanks (Pickett 1998a). The existing asphalt layer and concrete "topping" layer above the precast concrete roof slabs will be removed from the four available vaults. For each vault, side wall and end wall extensions 1.8 m (6.0 ft) high will be added to the original top of the side and end walls,

respectively. To support the unloading of ILAW packages from the transportation vehicles, rails for a gantry crane are to be placed on top of the side wall extensions and will run the full length of the vaults.

A conceptual design for the new ILAW disposal facilities (Pickett 1998b) utilizes a long concrete vault concept divided into cells. Each vault will be an underground, open-topped, concrete vault approximately 23 m (76 ft) wide, 207.8 m (686 ft) long, and 8.1 m (26.7 ft) deep below grade. The top of the vault walls will extend 1 m (3.3 ft) above grade. Each vault will be divided into 11 cells, separated by concrete partition walls.

Each vault is built above a RCRA-compliant leak detection and collection system. It consists of a cast-in-place reinforced concrete basin approximately 209.5 m (687.0 ft) long, 24.7 m (81 ft) wide with walls 1.07 m (3.5 ft) high. The basin floor is 0.6 m (2 ft) thick and contains steel reinforcing bars within. The catch basin is lined with two flexible membrane liners, and on top of these lie a layer of gravel with perforated collection pipe routed to sumps, one at each end of a vault. Liquids entering the sump can be removed by use of a portable pump lowered down a riser pipe.

Interim closure for each filled cell in the new disposal facility will consist of using inert backfill material followed by a "controlled density fill," unreinforced concrete. A waterproof membrane will be placed above the "controlled density fill." After all cells in the vault have been filled and interim closed, a closure cap consisting of a capillary break followed by a modified RCRA Subtitle C cap will be placed over the entire vault. A similar closure is assumed for the existing disposal vaults. Each vault will be interim closed using the process used for the cell closure for the new disposal facility. After all vaults have been filled and interim closed, a similar closure cap will be placed over all four vaults.

One trench concept that is receiving additional consideration is the Remote Handled (RH) trench concept. Under the ILAW disposal alternative described below, the disposal facility is a Resource Conservation and Recovery Act (RCRA) compliant landfill (i.e., double lined trench with leachate collection system). Many operational aspects and ancillary activities of the landfill (e.g., leachate collection and disposition, storm water control, installation of surface barrier at closure, etc.) would be similar to that incorporated into the Radioactive Mixed Waste Burial Trench, which was designed and constructed under the Solid Waste Program. However, operational activities related to ILAW package receipt and emplacement in the trench would be modified to accommodate the potentially higher radiation dose rate from remote-handled ILAW.

The RH trench complex would be constructed in the same location as the new ILAW disposal facility. The RH trench internal dimensions 260 m long by 80 m wide by 10 m deep. The trench sides have a 3:1 slope.

The current waste package design consists of a cubic, stainless steel package having outer dimensions of 1.4 m on each side. The package is filled to within 85% capacity with the remaining volume filled with silicate sand. The void volume will be less than 5% (by volume). Current plans for waste loading into each disposal facility design is as follows. Each existing disposal vault would contain seven layers of waste packages with 25 x 10 packages on each

layer. Each cell within the new ILAW disposal facility vault would contain six layers of waste packages with 12 x 14 packages on each layer. Finally, each remote handled trench would have the packing characteristics outlined in Table 4.2.

Table 4.2 Trench Packing Characteristics

Layer	Cells per layer	Matrix size per cell	Packages per layer
1	2	6 x 132	1,584
2	3	6 x 140	2,520
3	4	7 x 150	4,200
4	6	6 x 160	5,760
		Total packages per trench	14,064

The design for the ILAW disposal facilities has not yet been finalized. Facility uncertainty cases have been identified that may impact disposal performance. For example, the following sensitivity cases have been identified: waste form geometry and waste loading into the glass, new facility vault layout with respect to geometry and groundwater flow, different options for closure, inclusion of a capillary break or side wall diverter into the design, and early failure of the system.

4.5 RECHARGE

Recharge rates are based on lysimetry and tracer measurements as well as computer simulations. The recharge rate for the surface barrier (0.1 mm/year) is reduced from the 0.5 mm/year value in the 1998 ILAW PA. Two natural rates (0.9 and 4.2 mm/year) are given based on the type of surface soil. These rates straddle the value used in the 1998 ILAW PA (3.0 mm/year).

The term recharge is used to denote the rate at which moisture flows past the root zone (that is, very near surface) into a region where moisture flow follows simpler models. Recommendations for recharge rates are taken from *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Fayer 1999), that is reproduced in Appendix J of this document. Long-term estimates of moisture flux through the ground surface are needed for a fully functional surface cover, the cover sideslope, the immediate surrounding terrain (Pre-Hanford), as well as for degraded cover conditions. The estimates were derived from lysimeter and tracer measurements collected by the ILAW PA activity and by other projects combined with a modeling analysis.

Values for the recharge are given in Table 4.3. Values are given for two separate surface soils, Rupert sands and Burbank loamy sands. The Rupert sands are located at the site of the existing grout vaults and at the southernmost 60% of the new ILAW disposal site. The Burbank loamy sand is located at the northernmost 40% of the new ILAW disposal site. Impacts from degradation of the barrier, vegetation change, climate change, and irrigation were considered in establishing the best estimate and bounding values.

Table 4.3 Recharge Rate Estimates (mm/year) [a]

Surface feature	Pre-Hanford	Construction	Cover design Life	Post Cover Design Life
Surface cover	na	na	0.1 (0.01, 4.0)	0.1 (0.01,4.0)
Cover sideslope	na	na	50 (4.2, 86.4)	50 (4.2, 86.4)
Rupert sand	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)
Burbank Loamy sand	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)
Construction	na	55.4 (50, 86.4)	na	na
na = not applicable				

a best estimate case given, with values for reasonable bounding cases given in parentheses.

4.6 RELEASE RATE FROM THE WASTE FORM PACKAGE

4.6.1 Introduction

The 1998 ILAW PA showed that the release rate from the waste form was one of the key parameters in the performance assessment. This rate is a major determinant of the impact of disposal as well as setting the temporal structure of that impact. The data for determining the waste form release rate are given in *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment* (McGrail 1999) which is also included as Appendix K to this document.

Key parameters needed to calculate waste form release rates are based on an extensive series of measurements of glasses thought to be in the compositional space of the ILAW product. Data for other needed reaction rates are taken from standard chemical databases. In contrast, the release rate assumed in the base case of the 98 ILAW PA was based on a release rate of 4.4 ppm/year.

The release rate is a function of both the release rate from the glass as well as retardation because of the formation of secondary phases. Because these rates depend on a variety of parameters (amount of moisture, amount of silic acid [the main by-product of dissolved glass] in solution, pH, amount and type of secondary phases) which will vary with time, the release rate must be calculated. However, in order for the calculations to be believed they must be based on an accepted paradigm and an extensive database.

4.6.2 Paradigm for Waste Release

The paradigm for the calculations and the data to support the calculations are given in A Strategy to Conduct an Analysis of the Long-Term Performance of Low-Activity Glass in a Shallow Subsurface Disposal System at Hanford (McGrail 1998b). This document has been favorably reviewed (Wicks 1999) by an internationally known set of experts (Dr. Bernd Grambow, Dr. Etienne Vernaz, Prof. Werner Lutze, Dr. Elmer Wilhite, and Dr. George Wicks) who were selected by the DOE Environmental Science Program.

The main thrust of the paradigm is that there are a few equations, which define the rate-determining step in waste form release. Over the last few decades, a general rate equation has been fashioned to described the dissolution of glass (and more ordered materials) into aqueous solution:

$$k_i = \overset{\mathbf{v}}{k} \nu_i a_{H^+}^{-\eta} e^{\frac{-E_a}{RT}} \left[1 - \left(\frac{Q}{K}\right)^{\sigma}\right] \prod_j a_j \qquad (1)$$

where: k_i = dissolution rate, g/m²/d
$\overset{\mathbf{v}}{k}$ = intrinsic rate constant, g/m²/d
ν_i = the stoichiometric coefficient of element i in the glass (dimensionless)
a_{H^+} = hydrogen ion activity
a_j = activity of the jth aqueous species that acts as an inhibitor or as a catalyst of dissolution
E_a = activation energy, kJ/mol
R = gas constant, kJ/mol·K
T = temperature, K
Q = ion activity product
K = pseudoequilibrium constant
η = pH power law coefficient
σ = Temkin coefficient.

As glass is metastable, the reaction proceeds one way (i.e. glass dissolves).

However, there are a number of reactions, that depending on the amount of constituents and other environmental parameters could go either way. The most important of these are the ion exchange reaction and the formation of secondary phases. The waste form will contain high concentrations of sodium (up to 25 weight percent). At the temperatures of interest, the exchange of sodium in the glass with hydrogen in the water is important as the reaction effectively increases the pH of the solution. Secondary reactions are important because they can strip chemicals from the aqueous solution, affecting the glass corrosion rate or trapping important contaminants.

4.6.3 Waste Form Experiments

The parameters in these equations are established by a set of various experiments, performed at various temperatures and pHs:

- single-pass flow-through test
- product consistency test
- vapor hydration test
- pressurized unsaturated flow-through test.

4.6.3.1 Single-Pass Flow-Through Test

The single-pass flow-through test has solutions of known chemistry flow (at various rates) through a container with glass samples at various temperatures. Such tests determine the intrinsic rate constant (k) of the glass as a function of the various conditions. Many experiments have shown that this rate (also known as the forward rate) is the maximum rate at which glass can dissolve for the given conditions. A limitation of this test is that only very short-term behavior can be determined.

4.6.3.2 Product Consistency Test

The product consistency test was established to compare glasses produced over periods of time (i.e., the consistency of the glass making process). The test, which involves placing a crushed glass in a solution at a fixed temperature, allows long-term testing of glasses to determine how they will behave as the environment surrounding them changes (although in an uncontrolled manner). The major limitations of this test are that the environment changes in an uncontrolled manner and (for ILAW disposal) the test is conducted under saturated conditions.

4.6.3.3 Vapor Hydration Test

The vapor hydration test involves moisture attack at high temperatures (i.e. vapors) which accelerates the dissolution of glasses and the formation of secondary phases. The major limitation of this test is that being performed at much higher temperatures (> 100 °C) than those of interest (14 °C), this test could be emphasizing processes not important at lower temperatures and missing processes important at the lower temperatures.

4.6.3.4 Pressurized Unsaturated Flow-Through Test

The pressurized unsaturated flow-through test involves flowing unsaturated water with known chemistry through glass samples (which may be crushed, fractured, or in some other form). This test can be used to investigate a variety of conditions as the chemical environment can be monitored and controlled. The major limitations of this test are its newness and its complexity. However, this test comes closest to what will happen in the disposal facility.

4.6.4 Other Data Sources

Data for the reactions other than the main glass reactions come mainly from the literature. However, the test conditions described above were used to establish reaction rate constants for the ion exchange reaction and for the important secondary phases.

4.6.5 Data Values for Glasses

The exact glass composition that BNFL, Inc will used for ILAW has not been determined. The ILAW PA activity has worked with BNFL, Inc and the DOE Environmental Science program to investigate a set of glasses in the BNFL, Inc. processing space. For the 2001 ILAW PA, the base analysis case uses LAWABP1 as the reference glass. This glass has the most extensive database of any glass in its compositional space. The composition of LAWABP1 is based on the composition of preliminary BNFL, Inc. glasses. BNFL, Inc. has indicated that the composition of LAWABP1 remains in their design space. Table 4.4 provides a summary of the best-estimate values for parameters important in calculating contaminant release from the LAWABP1 glass waste form.

Table 4.4 Summary of Best Estimate Parameters for LAWABP1 Glass

Parameter	Meaning	Value	Test Method	Evaluation Method
Kinetic Rate Law Parameters				
$\overset{v}{k}$	intrinsic rate constant	3.5×10^{5} g m^{-2} d^{-1}	SPFT	Substitution of regressed coefficients
K_g	apparent equilibrium constant for glass based on activity product $a[AlO_2^-] \cdot a[SiO_2(aq)]$	3.6×10^{-10}	SPFT	Linear regression
η	pH power law coefficent	0.5	SPFT	Linear regression
E_a	activation energy of glass dissolution reaction	75 kJ/mol	SPFT	Nonlinear regression
σ	Temkin coefficient	1		LD6-5412 data
r_x	Na ion-exchange rate	3.5×10^{-6} mol/(m^2·d)	SPFT	Linear regression
Secondary Mineral Phases				
$\log_{10} K_1$	$Al(OH)_3$(am)	-13.10	PCT[a]	log K adjusted to fit PCT data
$\log_{10} K_2$	Analcime	-9.86	PUF[b],VHT[b]	EQ3/6 database
$\log_{10} K_3$	Anatase	-6.64	PCT	log K adjusted to fit PCT data

Table 4.4 Summary of Best Estimate Parameters for LAWABP1 Glass

Parameter	Meaning	Value	Test Method	Evaluation Method
$\log_{10} K_4$	Baddeleyite	-9.29	PCT	EQ3/6 database
$\log_{10} K_5$	Goethite	-11.09	PCT	EQ3/6 database
$\log_{10} K_6$	Herschelite	-40.94	PUF	Polymer model
$\log_{10} K_7$	$La(OH)_3(am)$	22.55	PCT	log K adjusted to fit PCT data
$\log_{10} K_8$	Nontronite-K	-43.70	PUF	EQ3/6 database
$\log_{10} K_9$	Nontronite-Mg	-43.36	PUF	EQ3/6 database
$\log_{10} K_{10}$	Nontronite-Na	-43.33	PUF	EQ3/6 database
$\log_{10} K_{11}$	PuO_2	-5.18		EQ3/6 database
$\log_{10} K_{12}$	Sepiolite	31.29	PCT	EQ3/6 database
$\log_{10} K_{13}$	$SiO_2(am)$	-2.85	PUF,PCT	EQ3/6 database
$\log_{10} K_{14}$	Soddyite	-20.24		EQ3/6 database
$\log_{10} K_{15}$	$Zn(OH)_2(am)$	14.44	PCT	log K adjusted to fit PCT data
$\log_{10} K_{16}$	Na-Zn-Ti-silicate (TBD)	Unknown	PUF	Not evaluated

(a) Solid phases inferred from modeling - not directly observed

(b) Solid phases identified from direct observation of reacted solids

4.7 HYDROLOGY

4.7.1 Overview

Hydrologic processes describe how moisture moves through the subsurface. Because there are distinct regions associated with subsurface flow and transport at the ILAW disposal facilities, the system has been divided into three parts: near-field, far-field, and groundwater.

4.7.2 Near-Field Hydrology Data

The best-estimate and bounding values for the near-field hydrologic parameters were based on literature values as well as measurements done especially for this activity. The values are similar to those of the 1998 ILAW PA.

The processes and data important for moisture flow in the near-field, that is, the zone between the surface and the bottom of the engineered disposal facility is described in *Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999), which is reproduced as Appendix L. Physical and hydraulic properties (particle size distribution, particle density, bulk density, porosity, water retention, and hydraulic conductivity as a function of moisture content) and associated transport parameters (dispersivity and effective diffusion

coefficient) are given for materials of the surface cover, the vault structure, diversion layers, the water conditioning layer, and the backfill materials. Table 4.5 presents best-estimate parameter values for near-field materials. Best estimate values for transport parameters can be found in chapter 5 of *Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* and are not repeated here because of their length.

Table 4.5 Best-Estimate Hydraulic Parameter Values For Near-Field Materials

Material	ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
Silt Loam-Gravel admixture	2.72	1.48	0.456	0.0045	0.0163	1.37	8.4×10^{-5}
Compacted Silt Loam	2.72	1.76	0.353	0.0035	0.0121	1.37	1.8×10^{-6}
Sand Filter	2.755	1.88	0.318	0.030	0.538	1.68	8.58×10^{-5}
Gravel Filter	2.725	1.935	0.290	0.026	8.1	1.78	1.39×10^{-2}
Gravel Drainage	2.725	1.935	0.290	0.006	17.8	4.84	2.0
Asphaltic Concrete	2.63	2.52	0.04	0.000	1.0×10^{-7}	2.0	1×10^{-11}
Vault Concrete	2.63	2.46	0.067	0.00	3.87×10^{-5}	1.29	1.33×10^{-9}
Vault Filler Material	2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}
Glass Waste	2.68	2.63	0.02	0.00	0.2	3	0.01
Diversion Layer Sand	2.8	1.65	0.371	0.045	0.0683	2.08	3.00×10^{-2}
Diversion Layer Gravel	2.8	1.38	0.518	0.014	3.54	2.66	1.85
Backfill	2.76	1.89	0.316	0.049	0.035	1.72	1.91×10^{-3}
Conditioning layer	2.73	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}

ρ_p = particle density ρ_b = dry bulk density θ_s = saturated water content
θ_r = residual water content α,n = van Genutchen fitting parameters
K_s = saturated hydraulic conductivity

A discussion of uncertainty in the estimated parameter values and reasonable bounds for parameter values are also presented in the document.

4.7.3 Far-Field Hydrology

The best-estimate and bounding values for the far-field hydrologic parameters were based on samples from the ILAW boreholes as well as other boreholes in the 100 Area. Laboratory measured data were upscaled using stocastic theory. The values are similar to those of the 1998 ILAW PA.

The processes and data important for moisture flow and contaminant transport in the far-field, that is, the region between the bottom of the engineered disposal facility and the water table are described in *Far-Field Hydrology Data Package for the Immobilized Low-Activity Waste Performance Assessment* (Khaleel 1999), which is reproduced as Appendix M. This document summarizes the hydraulic parameter estimates based on data from the ILAW borehole and data on gravelly samples from the 100 Area boreholes. The document also describes the processes for upscaling such small-scale laboratory measurements to field-scale applications, and provides recommendation for parameter estimates

to be used at that scale. Table 4.6 provides the best estimate values for parameters impacting moisture flow. Best estimate values for transport parameters (bulk density, diffusivity, and dispersivity) are also described in *Far-Field Hydrology Data Package for the Immobilized Low-Activity Waste Performance Assessment*. The document also presents an overall approach for sensitivity and uncertainty analysis for far-field flow and transport predictions.

Table 4.6 Best-Estimate Hydraulic Parameter Values For Far-Field Layers

Formation	Number of samples	θ_s	θ_r	α (1/cm)	n	ℓ	K_s (cm/s)
Sandy	20	0.375	0.041	0.057	1.768	0.5	2.88E-03
Gravelly	15	0.138	0.010	0.021	1.374	0.5	5.60E-04

θ_s = saturated water content
θ_r = residual water content
α,n = van Genutchen fitting parameters
ℓ = pore size distribution factor
K_s = saturated hydraulic conductivity

4.7.4 Groundwater

Groundwater hydrology is an integral part of the Hanford Sitewide model. As was noted in Section 3.4.4, this model is mandated for Hanford Site use. Information on the hydrology used can be found in Cole 1997.

4.8 GEOCHEMISTRY

Geochemical values (solubilities and K_ds) are based on site-specific samples for the most part, but in a few cases depend on literature values or chemical similarity. Values are given for 5 zones (having different soil properties and impacts from released waste). These values are similar to the values used in the 1998 ILAW PA.

Geochemical effects are based on the discussion and values presented in *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Kaplan 1999), provided in Appendix N of this document. The geochemistry is described using two parameters, the distribution coefficient (K_d value) and the solubility product of a specified solid. The distribution coefficient is a thermodynamic construct. It is the ratio of the concentration of a species reversibly adsorbed/exchanged to a geomedia's surface site divided by the concentration of the species in solution. Parameters are given for five zones:

1) Near-Field: inside the disposal facility (K_d and solubility values)
2) Degraded Concrete Vault (K_d and solubility values)
3) Chemically Impacted Far-Field in Sand Sequence (K_d values only)
4) Chemically Impacted Far-Field in Gravelly Sequence (K_d values only)

5) Far Field in Gravel Sequence (K_d values only).

Values are based on site-specific samples for the most part, but in a few cases depend on literature values or chemical similarity. The document describes corrections due to the amount of gravel or moisture present. Since the tables are quite extensive, the only full table displayed is the one for K_d values in the gravel sequence of the far-field zone (see Table 4.7). Other important geochemical data (e.g., near-field field values for important radionuclides) are displayed in Table 4.8. Other information is provided in *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment.*

Table 4.7 Best-Estimate K_d Values For Far-Field Gravel Sequence (a)

Radionuclide	Reasonable Conservative Kd_{gc} (mL/g)	"Probable" Kd_{gc} (mL/g)	Kd_{gc} Range (mL/g)
Ac	6.	30.	6. to 130.
Am	6.	30.	6. to 130.
C	0.05	0.5	0.05 to 100.
Ce	6.	30.	6. to 130.
Cl	0.	0.	0. to 0.06
Cm	6.	30.	6. to 130.
Co	100.	200.	100. to 1250.
Cs	50.	200.	50. to 400.
Eu	6.	30.	6. to 130.
^3H	0.	0.	0. to 0.06
I	0.	0.01	0.0 to 1.5
Nb	5.	30.	5. to 250.
Ni	5.	30.	5. to 250.
Np	0.2	1.5	0.2 to 2.5
Pa	0.2	1.5	0.2 to 2.5
Pb	800.	600.	800. to 8000.
Pu	5.	15.	5. to 200.
Ra	0.5	1.4	0.5 to 20.
Ru	1.	2.	1. to 100.
Se	0.3	0.7	0.3 to 1.5
Sn	5.	30.	5. to 250.
Sr	0.5	1.4	0.5 to 20.
Tc	0.	0.	0. to 0.06
Th	4.	100.	4. to 250.
U	0.05	0.06	0.01 to 8.
Zr	4.	100.	4. to 250.

(a) The aqueous phase is untainted Hanford groundwater except for trace levels of radionuclides; the solid phase is composed of the unaltered gravel-dominated sequence material. Kd_{gc} is the gravel-corrected K_d value.

Table 4.8 Other Important Geochemical Values

Element	Reasonable Conservative	"Best" Value	Range	Zone
Tc	0.1	1	0.1 to 1.2	Zone 1: Near-Field K_d (mL/g)
U	5	20	10 to 800	Zone 1: Near-Field K_d (mL/g)
U	1×10^{-6}	1×10^{-7}		Zone 1: Near Field Solubility (M)
I	1	2	1 to 5	Zone 2: Degraded Aged Concrete K_d (mL/g)
U	70	100	70 to 250	Zone 2: Degraded Aged Concrete K_d (mL/g)
U	1×10^{-6}	1×10^{-7}		Zone 2: Degraded Aged Concrete Solubility (M)

4.9 DOSIMETRY

Dosimetry values are based on Hanford Site standards and have been approved by the Hanford Environmental Dose Oversight Panel.

Dosimetry scenarios and parameter values are based on the discussion and values presented in *Dosimetry Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Rittmann 1999), also Appendix O of this document. The scenarios for human exposure to the hazardous materials associated with the ILAW glass are defined in Appendix B (Mann 1999b). Table 4.9 provides the unit dose factors for the intrusion scenario where a post-intrusion resident lives near the exhumed waste associated with a well drilled through the disposal site. Internal and external contributions are separated because the glass matrix will prevent a portion of the exhumed waste from contributing to the internal dose. All of the exhumed activity contributes to the external dose.

Table 4.10 provides unit dose factors for exposure scenarios that use contaminated groundwater. The first four columns of unit dose factors are based on a well near the disposal facility. The last column is based on groundwater entering the Columbia River.

The first column of unit dose factors," HSRAM Industrial," are for employees of a business that uses well water for drinking and showering. The second column of numbers," HSRAM Residential," are for people in a suburban setting who obtain a portion of their diet from a garden that is irrigated with well water. The third column of numbers, "All Pathways Farmer," adds animal products, such as milk and meat to the exposure scenario. The fourth column of numbers, "Native American Subsistence Resident," can be considered a bounding case in that all intake parameters are maximized. The last column of numbers, "Columbia River Population," give the collective dose to 5 million people living near the Columbia River between the Hanford Site and the Pacific Ocean.

Table 4.9 Unit Dose Factors for Post-Intrusion Resident (mrem per Ci exhumed)

Nuclide	External	Internal
H-3	0	1.46E+02
Se-79	4.24E-02	1.24E+02
Sr-90+D	5.15E+01	2.00E+04
Tc-99	1.69E-01	7.93E+02
Sn-126+D	2.41E+04	1.05E+02
I-129	2.58E+01	6.70E+03
Cs-137+D	6.80E+03	1.23E+03
Pa-231	4.78E+02	3.81E+04
U-233	3.21E+00	2.74E+03
U-234	9.04E-01	2.68E+03
U-235+D	1.66E+03	2.51E+03
U-236	4.81E-01	2.54E+03
U-238+D	2.61E+02	2.45E+03
Np-237+D	2.30E+03	2.39E+04
Pu-239	6.48E-01	1.18E+04
Pu-240	3.34E-01	1.18E+04
Am-241	9.98E+01	1.23E+04

Table 4.10 Total Unit Dose Factors for Low-Water Infiltration Cases

Nuclide	HSRAM Industrial*	HSRAM Residential*	All Pathways Farmer*	Native American Sustenance Resident*	Columbia River Population**
H-3	1.62E-5	4.92E-5	4.58E-5	1.03E-4	2.29E-1
Se-79	2.18E-03	7.26E-03	1.15E-02	3.10E-02	5.03E+01
Sr-90+D	3.83E-02	1.30E-01	1.19E-01	3.38E-01	5.53E+02
Tc-99	3.65E-04	1.31E-03	3.54E-03	1.23E-02	1.46E+01
Sn-126+D	5.28E-03	4.07E-02	5.63E-02	1.20E-01	2.36E+02
I-129	6.90E-02	2.31E-01	3.77E-01	1.21E+00	1.64E+03
Cs-137+D	1.25E-02	4.84E-02	7.53E-02	2.14E-01	3.25E+02
Pa-231	2.68E+00	8.87E+00	7.08E+00	1.84E+01	3.40E+04
U-233	7.51E-02	2.45E-01	2.19E-01	5.77E-01	1.04E+03
U-234	7.35E-02	2.40E-01	2.14E-01	5.65E-01	1.02E+03
U-235+D	6.93E-02	2.28E-01	2.03E-01	5.34E-01	9.62E+02
U-236	6.99E-02	2.28E-01	2.04E-01	5.37E-01	9.65E+02
U-238+D	6.95E-02	2.27E-01	2.03E-01	5.34E-01	9.60E+02
Np-237+D	1.12E+00	3.72E+00	2.97E+00	7.73E+00	1.42E+04
Pu-239	8.94E-01	2.96E+00	2.36E+00	6.14E+00	1.13E+04
Pu-240	8.94E-01	2.96E+00	2.36E+00	6.14E+00	1.13E+04
Am-241	9.19E-01	3.05E+00	2.43E+00	6.32E+00	1.17E+04

* Annual dose in mrem for a groundwater concentration of 1 pCi/l

** Annual dose in person-rem per Columbia River concentration of 1 pCi/l

4.10 AGRICULTURE USE

The future application of Hanford land for potential agriculture use is presented and described in *Determining Reasonable Future Agriculture Land Use on the Hanford Site* (Evans 2000), also Appendix P of this document.

Potential land use and economic scenarios on the Hanford Site favor intensive, large-scale agricultural development growing high-value orchard, vineyard, and vegetable crops. Such large enterprises would be able to afford to import clean water and use high-level water management to minimize deep drainage. It is highly probable that any future irrigation development on the Hanford Site would be pressurized irrigation systems because of the site's very sandy soils and undulating topography. Water would be supplied to the fields by pressurized pipelines rather than canals or ditches. Because of the light soils and widely variable topography of the Hanford Site, new advances in micro-irrigation and self-propelled irrigation (i.e., linear move and center pivot systems) will probably have the most promise for future irrigation.

A reasonable estimate of deep percolation in 50 years would be the current best achievable levels of the best technology: from 2% to 15% of the applied water, not including water applied for frost protection or other non-irrigation uses. Recharge from irrigation would probably range from 50 to 500 mm/yr compared to historical estimated natural recharge rates, even with the expected improved technologies and systems. Wine grapes would have the least recharge, while field crops would potentially have the greatest deep percolation losses. Small acreage, irrigated ranchette development would probably contribute about twice the recharge to the unconfined aquifer systems as large scale irrigation.

Washington State Department of Ecology well data records were reviewed for the area surrounding the Hanford Site. Average screened lengths for the wells in the region ranged from 4.6 to 9.7 m.

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[1. Appendix D lists the activities and associated milestones. Activities 45 (closure of single-shell tanks), 50 (pretreatment processing), 60 (vitrification of Hanford low-level waste), and 90 (disposal of the immobilized low-activity waste) cover areas of concern for this performance assessment.]

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[1. Page 9 discusses use the central plateau wisely for waste management.]

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APPENDIX A

PERFORMANCE OBJECTIVES

FOR THE

HANFORD IMMOBILIZED LOW-ACTIVITY WASTE (ILAW) PERFORMANCE ASSESSMENT

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List of Acronyms

ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
EDE	effective dose equivalent
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ILAW	immobilized low-activity waste
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Agency
PA	performance assessment
RCRA	Resource Conservation and Recovery Act
TWRS	Tank Waste Remediation System
TWINS	TWRS Information System
WAC	Washington Administrative Code

1.0 OVERVIEW

The purpose of the next version of the *Hanford Immobilized Low-Activity Tank Waste* (ILAW) *Performance Assessment* (ILAW PA) is to provide an updated estimate of the long-term human health and environmental impact of the disposal of ILAW and to compare these estimates against performance objectives. Since the previous performance assessment (Mann 1998) was issued, considerable additional data on waste form behavior and soil geotechnical properties have been collected. Such a radiological performance assessment is required by U.S. Department of Energy (DOE) Orders on radioactive waste management (DOE 1988a and DOE 1999a).

The ILAW PA will also support other activities necessary for the disposal of ILAW. The Nuclear Regulatory Commission (NRC) has required (Paperiello 1997) that the original ILAW PA (Mann 1998) and updates be supplied in order to support DOE's request that ILAW be classified as incidentalwaste, that is, wastethat is produced in association with reprocessing and meets three criteria (Paperiello 1997):

1) the "wastes have been processed (or will be further processed) to remove key radionuclides to the maximum extent that is technically and economically practical,"

2) the "waste will be incorporated in a solid physical form at a concentration that does not exceed the applicable concentration for Class C [low-level waste] as set out in 10 CFR 61," and

3) the "wastes are managed, pursuant to the Atomic Energy Act, so that safety requirements comparable to the performance objectives set out in 10 CFR Part 61, Subpart C are satisfied."

The NRC expects that the analyses in the ILAW PAs show that the disposal system will meet performance requirements at least as protective as those required by the NRC. In their review of the *Hanford Low-Level Tank Wastes Interim Performance Assessment* (Mann 1997a), the staff of the NRC (Paperiello 1997) indicated that meeting the performance objectives in the interim performance assessment (which are the same as the ones in this document) would indeed meet the performance objectives of the NRC regulations (10 CFR 61).

DOE will also use the 2001 ILAW PA as part of the technical basis for permits required by the State of Washington in its regulation of the disposal of mixed waste. Mixed waste is waste that is both radioactive and dangerous (or radioactive and hazardous if federal terminology is used). The previous version of the ILAW PA only estimated long-term impacts from radionuclides. It must be emphasized that this document provides the performance objectives for the 2001 ILAW PA and that the standards to be used in the permits issued by the State of Washington may have a different basis.

The initial step in performing an assessment of the long-term impact of disposing of low-level waste from Hanford tanks is the determination of criteria by which success or failure will be judged. These criteria, known as performance objectives, are based on

- DOE requirements (primary source),
- NRC requirements,
- EPA land disposal restrictions,
- State of Washington requirements,
- Programmatic requirements, and
- Public involvement

The DOE requirements not only include the regulation directing the creation of the PA, but also regulations that are directly and indirectly cited in that regulation. In addition, other PAs produced in the DOE Complex and "case law" offer precedents that indicate what may constitute a successful performance assessment.

This document updates the performance objectives (Mann 1995) created for the *Hanford Low-Level Tank Wastes Interim Performance Assessment* (Mann 1997) and the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Mann 1998). These performance objectives will be used in the next revision of the performance assessment which is scheduled for 2001.

These performance objectives are only for the long-term assessment of the public health and environmental impacts from the disposal of immobilized low-activity tank waste. The TWRS Immobilized Waste Program, of which the ILAW performance assessment activity is a part, has additional objectives that relate to other parts of the Immobilized Waste Program. Thus, for example, worker and public safety during construction and active facility operation are not considered here. Although reviewed by others performing Hanford Site assessments, it must be emphasized that these performance objectives deal only with the ILAW disposal effort and not with the performance objectives of other Hanford Site disposal actions.

As described in the following sections,

2. Introduction
3. Regulations and Other Performance Assessments
4. Programmatic Requirements
5. Public Involvement,

performance objectives have been determined for both radioactive and chemical species. The radiological objectives are shown in Table 1.0 and are unchanged from those radiological performance objectives (Mann 1995) defined for the earlier ILAW PAs. Because the DOE orders on radioactive waste management specify only radiological performance objectives, the chemical goals are displayed in the appendix, Appendix A.

Table 1.0 Radiological Performance Objectives
(These are Unchanged from Mann 1995)

Protection of General Public and Workers [a, b]	
All-pathways dose from only this facility	25 mrem in a year [d, h]
All-pathways dose including other Hanford Site sources	100 mrem in a year [e, i]
Protection of an Inadvertent Intruder [c, f]	
Acute exposure	500 mrem
Continuous exposure	100 mrem in a year
Protection of Groundwater Resources [b, d, j]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	5 pCi/ℓ
All others (total)	15 pCi/ℓ
Beta and photon emitters	4 mrem in a year
Protection of Surface Water Resources [b, g]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	0.3 pCi/ℓ [j]
All others (total)	15 pCi/ℓ [j]
Beta and photon emitters	1 mrem in a year [k]
Protection of Air Resource [b, f, l]	
Radon (flux through surface)	20 pCi m^{-2} s^{-1}
All other radionuclides	10 mrem in a year

[a] All doses are calculated as effective dose equivalents; all concentrations are in water taken from a well. Values given are in addition to any existing amounts or background.
[b] Evaluated for 1,000 and 10,000 years, but calculated to the time of peak or 10,000 years, whichever is longer.
[c] Evaluated for 500 years, but calculated to 1,000 years.
[d] Evaluated at the point of maximal exposure, but no closer than 100 meters (328 feet) from the disposal facility.
[e] Evaluated at the 200 East Area fence.
[f] Evaluated at the disposal facility.
[g] Evaluated at the Columbia River, no mixing with the river is assumed.
[h] Main driver is DOE Orders on *Radioactive Waste Management* (DOE 1988a and DOE 1999a)
[i] Main driver is DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE 1993).
[j] Main driver is National Primary Drinking Water Regulations (40 CFR 141).
[k] Main driver is Washington State Surface Water Standards (WAC 173-201A)
[l] Main driver is National Emission Standards for Hazardous Air Pollutants (40 CFR 61H and 40 CFR 61Q).

2.0 INTRODUCTION

2.1 General Requirements

Before low-level waste may be disposed of, a performance assessment must be written and then approved by the DOE (DOE 1988a, DOE 1999a). The performance assessment is to determine whether "reasonable assurance" exists that the performance objectives of the disposal facility will be met. The DOE requirements for waste disposal (DOE 1988a, DOE 1999a) require (see Appendix B)

- The protection of public health and safety; and
- The protection of the environment.

Although quantitative limits are sometimes stated (for example, the all-pathways exposure limit is 25 mrem/year), usually the requirements are stated in a general nature. Quantitative limits were established by:

- investigating all potentially applicable regulations as well as interpretations of the review panels which DOE has established to review performance assessments,
- interacting with program management to establish the additional requirements of the program, and
- interacting with the public (i.e., the Hanford Advisory Board members; as well as affected Tribal Governments) to understand the values of residents in the Pacific Northwest.

Because of space considerations, not all radionuclides and dangerous chemicals are listed in this document. The radionuclides listed here are those which were explicitly treated in the ILAW PA (Mann 1998). The dangerous chemicals listed here are those most often detected in Hanford tank waste as documented in the *Regulatory Data Quality Objectives Supporting Tank Waste Remediation System Privatization Project* (Wiemers 1998).

2.2 1998 ILAW PA

Presently, there are about 54 million gallons of high-level waste stored in underground tanks located in the central plateau area of the Hanford Site. The present plans are to retrieve these wastes, separate the wastes into streams, and then vitrify each stream. The high-level waste stream would contain relatively little volume, but it would contain the bulk of the radionuclides. The vitrified high-level waste will be stored onsite until it is shipped to a federally approved geological repository. The low-activity waste stream will contain most of the material, but relatively few radionuclides. The vitrified (or immobilized) low-activity waste is planned to be disposed of in near-surface underground vaults in the 200 East Area (which is part of Hanford's central plateau).

The 1998 ILAW PA (Mann 1998) only analyzed the impacts of radionuclides. The most restrictive performance objective was for beta and gamma emitters in groundwater (estimated impact = 2.0 mrem/yr compared to a performance objective of 4.0 mrem/yr). The main radionuclides contributing to this result was ^{99}Tc and ^{79}Se. The next most restrictive performance objective was the all-pathways scenario (estimated impact = 6.4 mrem/yr compared to a performance objective of 25 mrem/yr). The performance objective for alpha emitters in ground water (15 pCi/liter) was more easily met (estimated impact = 1.7 pCi/liter). Performance objectives for surface water protection, air emissions, and protection of inadvertent intrusion were all met by at least a factor of ten.

2.3 Programmatic Uses of the ILAW PA

The TWRS Immobilized Waste Program will use the ILAW PA in a variety of ways. The design of the disposal facilities is in the conceptual model stage. The results of the PA (particularly the sensitivity cases) will be used to optimize the design using subsequent design stages in order to keep doses as low as reasonable achievable. Similarly, the selection of the waste form formulation and processing are in the early stages. The ILAW PA data collection activities as well as the analyses for the document are aiding DOE and BNFL, Inc. in optimizing waste form performance. As the total cost of the retrieval, separation, vitrification, and disposal activities is many 10's of billions of dollars, optimization can have large financial impacts.

3.0 REGULATIONS AND OTHER PERFORMANCE ASSESSMENTS

3.1 Introduction

A number of federal and state regulations are potentially applicable to the determination of how well the public health, safety and the environment must be protected. Table C.1 in Appendix C lists the regulations that were reviewed and that were judged potentially relevant to this proposed disposal action. Quantitative limits from such regulations are contained in the remaining tables of Appendix C.

Other regulations and general environmental acts were not included in Table C.1 because:

- Requirements fall under other parts of the TWRS Immobilized Waste Program (i.e., the National Environmental Policy Act – NEPA);
- Requirements are for different environmental actions (for example, the Comprehensive Environmental Response, Compensation, and Liability Act – CERCLA);
- Requirements deal with general environmental concerns (e.g., Endangered Species Act) and such concerns are thought to be adequately addressed for the long-term by regulations presented here; or
- The regulations are only at a preliminary stage and are likely to change. Examples are the Radiation Site Cleanup Regulation (proposed 40 CFR 196) and Environmental Radiation Standards for Management and Disposal of Low-Level Waste (proposed 40 CFR 193) from the U.S. Environmental Protection Agency. The development of these proposals will be closely followed.

This is not the first performance assessment concerning the disposal of low-level waste in the DOE complex. In fact, it is not the first one concerning Hanford wastes. Such prior assessments provide "case law" interpretations. Table D.1 in Appendix D lists the performance objectives of the other performance assessments in the DOE complex.

3.2 Protection of the General Public

For this assessment, the performance objective for the protection of the general public is 25 mrem (effective dose equivalent [EDE]) in a year. This value is used consistently in the regulations (DOE 1988a, DOE 1999a, and 10 CFR 61) and was used in the past performance assessments. However, the EnvironmentalProtection Agency has issued a guidance for CERCLA cleanup actions (EPA 1997) that 15 mrem/yr should be used. Although other methods are available for determining body dose (Mann 1995), the effective dose equivalent method was selected because regulations normally use this method.

The Defense Nuclear Facilities Safety Board (DNFSB 1994) noted that a member of the public could receive exposures from several sources at a DOE site. Guidance from DOE-Headquarters (DOE 1996a) is that protection of the general public from multiple sources should be based on *Radiation Protection of the Public and the Environment*, DOE Order 5400.5 (DOE 1993-1). This order sets a limit of 100 mrem in a year from all sources. In addition, the order requires that if the dose is above 30 mrem in a year, then an additional analysis is required. For the Hanford Site, this is considered to be a fence surrounding the present Hanford Site 200 Areas. The *Composite Analysis for the Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (Kincaid 1998) shows compliance with this requirement.

Little guidance is provided on the interpretation of ALARA (as low as reasonably achievable). The philosophy of the new DOE Order on Radioactive Waste Management is that results from the performance assessment are to be used to minimize potential impacts by better disposal facility designs and better disposal operational practices. The Immobilized Waste Program is integrating design and safety (including environmental considerations) into a single program so that the exposure effects can be minimized. The iterative approach uses environmental and safety analyses of preconceptual designs (see Mann 1996), followed by preliminary and detailed designs using the results of those analyses, followed by more complete environmental and safety analysis (for example, successors to this document). Disposal facility components will be incorporated whenever their inclusion significantly adds protection to human health or to the environment.

The compliance time for this performance assessment is 10,000 years. (The compliance time is the time starting 100 years from the time of closure over which the predicted dose must remain below the performance objectives.) However, the calculation will be carried out to the time of maximum impact if that time is longer than 10,000 years. This compliance time is significantly longer than that included in the guidance for draft DOE Order 435.1 (1,000 years).

The compliance time used is, however, consistent with the compliance time used by the NRC [see, for example, the *Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities* (NRC 1997)]. Because the waste being disposed of is derived from high-level waste, the NRC has indicated that DOE must protect the public and the environment consistent with NRC standards (Paperiello 1997). Thus, the more conservative time of compliance is used in this performance assessment. The time of compliance used here is consistent with that used in the other Hanford Site performance assessments: the Grout Performance Assessment (Kincaid 1995), the 200 West Area Solid Waste Performance Assessment (Wood 1995), and the 200 East Area Solid Waste Performance Assessment (Wood 1996). Results at 1,000 years will also be presented to compare the impacts to the performance objectives at the DOE time of compliance.

The point of compliance will be the point of maximum exposure at least 100 meters down gradient from the disposal facilities. This follows the requirements of the new DOE manual on radioactive waste management (DOE 1999b). Under the Resource Conservation and Recovery Act (RCRA), the point of compliance for a disposal facility is at the fenceline for the facility. However, no fenceline has yet been established. Moreover, as shown in the previous

ILAW PA (Mann 1998), because of the physical extent of the disposal facilities, doses at closer locations are not significantly higher than at a point of compliance at 100 meters.

3.3 Protection for Workers

For this performance assessment, as for others performed under DOE orders on radioactive waste management, worker health is not explicitly addressed. Rather , the more restrictive requirements for the general public are used. Protection for workers during construction and operations will be addressed in the safety analysis report that will be prepared for the Immobilized Waste Program.

3.4 Protection of the Inadvertent Intruder

The exposure limits for protecting a hypothetical inadvertent intruder are consistent with the regulations (DOE 1988a, DOE 1999a, and 10 CFR 61) and with earlier performance assessments. As shown in Table D.1. These limits are 500 mrem (EDE) for a one-time (acute) exposure and 100 mrem (EDE)/year for a continuous exposure.

The compliance time for protecting an inadvertent intruder is defined differently from the time of compliance for protecting the general public or the environment. The inadvertent intrusion time of compliance differs slightly between regulations. Current DOE guidance (Alm 1997) is that active institutional control shall occur for at least 100 years, but notes that longer times can be used if justified. DOE intends to control the Hanford Site 200 Areas as long as necessary to protect the public (DOE 1996b). The Hanford Site grout performance assessment (Kincaid 1995) used the 500-year compliance time based on the assumption that passive barriers and markers would be present. The performance assessments for the disposal of solid radioactive waste on the Hanford Site (Wood 1995 and Wood 1996) also have used a compliance time of 500 years. This is consistent with the NRC requirement for Class C waste (10 CFR 61) that inadvertent intruders be protected for 500 years.

Following the precedent of the other Hanford Site performance assessments, the 500-year compliance time was used in this assessment because passive barriers and markers are planned for this proposed disposal action. Therefore, protection of an inadvertent intruder shall be considered met if the exposure limits are met at 500 years after closure. Calculations will be run from 100 years to 1,000 years after the time of disposal to obtain the doses as a function of time.

3.5 Protection of Ground Water Resources

The protection of ground water resources is the most complicated requirement to determine. The level of protection for groundwater is usually based on its intended use. However, predicting future groundwater use is highly subjective given the long time frames involved in a performance assessment. The quantities being limited (decay rate and dose) differ

in the various regulations. Moreover, different regulatory agencies approach the protection of groundwater resources using a variety of methods. In addition, earlier DOE performance assessments have taken different approaches. The guidance under the new DOE order on radioactive waste management (see Appendix B) is to use the site's groundwater protection management plan. However, the Hanford Site's plan (DOE-RL 1995) focuses only on short-term activities and does not address the metrics to apply for the long-term protection of groundwater.

Previous performance assessments have generalized the requirements from the "National Primary Drinking Water Regulations" (40 CFR 141) for determining if the disposal action meets the groundwater protection requirement. The scenario used is based on a public drinking water system serving at least 25 people and located at the point of compliance of the disposal facility. The previous performance assessments set a limit for the total exposure from all radionuclides for an individual drinking the water at less than 4 mrem (EDE) in a year. The "National Primary Drinking Water Regulations," however, use the limit of 4 mrem in a year not for all radionuclides, but for just beta and gamma emitters. The distance of 100 meters from the disposal facility is given in the manual for the new DOE order on radioactive waste management (DOE 1999b). Four mrem (EDE) in a year was chosen for two reasons. First, the value corresponds to the risk-based limit found in the "National Primary Drinking Water Regulations." Second, for most of the radionuclides, the value is more restrictive (see Table C.9) than decay rate concentration limits specified in the Washington State regulations (WAC 173-200).

The requirements for alpha emitters are the same in both the Washington State (WAC 173-200) and Federal (10 CFR 141) regulations. Both regulations limit alpha emitters by decay rate concentration limits, not annual dose. In addition, both sets of requirements limit the same subsets of alpha emitters (^{226}Ra, total radium, and other) and set the same quantitative limits. These decay rate concentration limits (Table 1.0) are used for this performance assessment.

Washington State's requirements for beta emitters are based on a screening level previously used by the EPA. These screening levels were selected because the requirements are easily verified in the field. (The current EPA regulations are based on risk limitation.) The current state screening level ensures that even for beta emitters emitting high-energy gamma radiation, the dose limit will be met. However, for low-energy beta emitters, the state screening level is conservative by a factor of about 100. This high degree of conservatism exists for radionuclides, such as ^{99}Tc, that are important in this performance assessment.

For this performance assessment, the Federal standards are used. This means that the current EPA regulation governing drinking water (40 CFR 141) is used to protect groundwater. The "Maximum Contaminant Level Goals" subpart of 40 CFR 141 (40 CFR 141, Subpart F) and the "National Secondary Drinking Water Standards" (40 CFR 143) were not used because they are stated only as goals. This follows the precedent set in the *Tank Waste Remediation System Environmental Impact Statement* (TWRS EIS) (DOE 1996c), a joint publication of the Washington State Department of Ecology and DOE. Thus, the performance objective is an EDE of 4 mrem in a year for beta/photon emitters and a concentration of 15 pCi per liter for

alpha emitters. Although uranium is not restricted by the regulations, for this analysis it is included under other alpha emitters. The values are displayed in Table 1.0. A dose of 4 mrem (EDE) in a year for 70 years corresponds to an incremental health risk of 0.0001 (EPA 1989b).

To ensure compliance with the intent of Federal and State groundwater regulations, the limits shown in Table 1.0 are applied to a well 100 meters downgradient from the disposal facility for a time period of 10,000 years after closure (the same time of compliance as for protection of the general public). Calculations will also be done for a location at the future Hanford Site boundary (DOE 1996b) and for 1,000 years after closure to compare the results at the DOE time of compliance. The hypothetical well from which the water is drawn is sized to provide the minimum public drinking water system that serves 25 people (40 CFR 141).

Performance goals for chemicals were chosen by selecting the most restrictive of the Federal and State groundwater regulations. All inorganic chemicals found in the regulations are included in Table A.1. However, for organic chemicals only those organic chemicals that have been detected frequently in tank waste (Wiemers 1998) are included in Table A.2.

3.6 Protection of Surface Water Resources

Federal (40 CFR 141) and State requirements (WAC 173-201A) for surface water protection are similar in scope and objectives. Both are directed at preventing degradation of surface water quality and preservation of highest priority water uses. The point of compliance for performance assessment purposes is where the groundwater is predicted to reach the Columbia River. The concentration of radionuclides in the groundwater at the point where it enters the Columbia River should meet all the standards listed in Table 1.0.

The 1.0 mrem (EDE) dose in a year (one quarter of the EPA drinking water standard) value is used because it meets the Washington State regulation while minimizing reporting requirements. The Washington State regulation (WAC 173-201A) mandates a dose limit that is the lesser of the EPA drinking water standard and explicit limits for each radionuclide contained in the State regulation. For the major radionuclides of interest, the explicit limits when converted to dose are greater than 1.3 mrem in a year. Using 1.0 mrem in a year for the sum of all beta/photon emitters is restrictive.

The compliance time for protecting surface water resources is selected as 10,000 years, the same compliance time as for protecting groundwater resources. Calculations will also be done for 1,000 years after closure to compare the results at the DOE time of compliance.

Performance goals for chemicals were chosen by selecting the more restrictive of the Federal and State groundwater regulations. All inorganic chemicals found in the regulations are included in Table A.1. However, for organic chemicals only those organic chemicals that have been detected frequently in tank waste are included in Table A.2.

3.7 Protection of Air Resources

Air emissions limits were taken from the draft DOE manual on radioactive waste management (DOE 1999b) which are the same limits found in Parts H and Q of the "National Emissions Standards for Hazardous Air Pollutants" (40 CFR 61H and 40 CFR 61Q). Based on these standards, emissions (except radon) are limited to 10 mrem (EDE) in a year with radon emissions limited to 20 pCi/m^2s.

4.0 PROGRAMMATIC REQUIREMENTS

The TWRS Immobilized Waste Program has mandated that all wastes to be disposed of and/or stored in the facility shall meet NRC Class C concentration limits (10 CFR 61). In addition, the immobilized waste form will meet Resource Conservation and Recovery Act [RCRA] (40 CFR 261, 40 CFR 264, and 40 CFR 268) concentration limits as well as the requirements of the ILAW treatment contract (BNFL 1998). Table C.8 lists these limits in the immobilized waste form.

Although the ILAW performance assessment is being created to meet the DOE Order (DOE 1988a, DOE 1999a) requirement to prepare a radiological performance assessment, the TWRS Immobilized Waste Program will also use the ILAW PA to support permits required by the Washington State Department of Ecology and the Washington State Department of Health. Therefore, performance goals for concentrations of chemicals have also been established (using the same procedures as for the radionuclides). These performance goals are shown in Appendix A.

5.0 PUBLIC INVOLVEMENT

It is important that Hanford stakeholders have the opportunity to affect the scenarios analyzed in the ILAW performance assessment. Public comments were requested on the original version of this document (Mann 1994) as well as revision 2 (Mann 1999).

A summary of the initial version of the scenarios was sent to each member and alternate of the Hanford Advisory Board, to selected Hanford Site contractor employees, and to selected members of the DOE's Peer Review Panel and Performance Assessment Task Team. Their comments and corresponding responses to the previous version of this document are available for review (Murkowski 1995).

Revision 2 of this document was made available for public review following the public involvement procedures established by the Hanford Groundwater / Vadose Zone Integration Project (that is, announcements were made at biweekly meetings, the review period was noted on the published list of Integration Project activities, and the documents were available on the Integration Project's web site). Only the Oregon Office of Energy submitted comments (Blazek 1999) and these mainly dealt with waste classification, the extent of public announcement, and other general program activities. Because of the nature of the comments, no changes were made to revision 2 based on these comments. The comments from the Oregon Office of Energy as well as the responses (Taylor 1999) to them by the Department of Energy's Office of River Protection are available on request.

Comments on this version of the document should be sent to:

Frederick M. Mann
Fluor Daniel Northwest
Mail Stop H0-22
Post Office Box 1050
Richland, Washington 99352

Since calculations for the performance assessment will begin in October 1999, to be effective the comments should be sent as soon as possible.

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Appendix A Dangerous Materials Performance Goals

Chemical concentration limits for groundwater protection and surface water protection are determined by identifying the Federal and State regulations dealing with chemicals in the environments and applying the most restrictive limit. Although organic compounds are not expected to be measurably present in the immobilized product resulting from a vitrification process, organic compounds are listed here.

Table A.1 Performance Goals for Inorganic Materials

Chemical	Groundwater	Surface Waters
Ammonia		4.0 mg/l
Antimony	0.006 mg/l	0.006 mg/l
Arsenic	0.00005 mg/l	0.05 mg/l
Barium	1.0 mg/l	2.0 mg/l
Beryllium	0.004 mg/l	0.004 mg/l
Cadmium	0.005 mg/l	0.00077 mg/l
Chlorine	250. mg/l	230. mg/l
Chromium	0.05 mg/l	0.011 mg/l
Copper	1.0 mg/l	0.0078 mg/l
Cyanide	0.2 mg/l	0.0052 mg/l
Fluoride	4.0 mg/l	4.0 mg/l
Iron	0.3 mg/l	
Lead	0.05 mg/l	0.0015 mg/l
Manganese	0.05 mg/l	
Mercury	0.002 mg/l	0.000012 mg/l
Nickel		0.115 mg/l
Nitrate as N	10. mg/l	10. mg/l
Nitrite as N	1.0 mg/l	1.0 mg/l
Nitrite plus Nitrate	10. mg/l	10. mg/l
Selenium	0.01 mg/l	0.005 mg/l
Silver	0.05 mg/l	
Sulfate	250. mg/l	
Thallium	0.002 mg/l	
Zinc	5.0 mg/l	0.072 mg/l

No entry in a cell indicates that no limit was found.

Table A.2 Performance Goals for Organic Materials

CAS #	Constituent (a)	Groundwater	Surface Waters
56-23-5	Carbon tetrachloride	0.0003 mg/l	0.005 mg/l
67-66-3	Chloroform	0.007 mg/l	
71-43-2	Benzene	0.001 mg/l	0.005 mg/l
71-55-6	1,1,1-Trichloroethane	0.003 mg/l	0.2 mg/l
75-09-2	Dichloromethane (Methylene Chloride)	0.005 mg/l	0.005 mg/l
79-00-5	1,1,2-Trichloroethane	0.005 mg/l	0.005 mg/l
79-01-6	1,1,2-Trichloroethylene	0.005 mg/l	0.005 mg/l
95-47-6	o-Xylene	0.7 mg/l	0.7 mg/l
100-41-4	Ethyl benzene	0.1 mg/l	0.1 mg/l
106-46-7	1,4-Dichlorobenzene	0.004 mg/l	0.075 mg/l
108-88-3	Toluene	1.0 mg/l	1.0 mg/l
127-18-4	1,1,2,2-Tetrachloroethene	0.005 mg/l	0.005 mg/l

(a) Greater than 100 analytical detects in tank waste or greater than 20 analytical detects in TWINS Solid/Liquid Hits. Taken from Wiemers 1998.

No entry in a cell indicate that no limit was found.

Appendix B. DOE Orders on Low-Level Waste Disposal

B.1 DOE Order 5820.2A (DOE 1988a) (effective 09/26/88)

This is the DOE Order currently governing the disposal of low-level waste (5820.2A). A new order (435.1 [see section B.2 below]) will replace this order. Chapter III, Section 3a states that the objectives are to

1) "Protect public health and safety in accordance with standards specified in applicable EH orders and other DOE orders.
2) Assure that external exposure to the waste and concentrations of radioactive material which may be released into surface water, ground water, soil, plants, and animals results in effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.
3) Assure that the committed effective dose equivalents received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/year for continuous exposure or 500 mrem for a single acute exposure.
4) Protect ground water resources, consistent with Federal, State, and local requirements."

B.2 DOE Order 435.1 (DOE 1999a)

B.2.1 DOE Order 435.1 (*Radioactive Waste Management*)

DOE Order 435.1 is the DOE order on radioactive waste management which should be effective when the next version of the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* is prepared and submitted.

DOE Order 435.1 requires

(4a) "DOE radioactive waste management activities shall be systematically planned, documented, executed, and evaluated."

(4b). "Radioactive waste shall be managed to

(1) Protect the public from exposure to radiation from radioactive materials. Requirements for public protection are in DOE O 5400.5, *Radiation Protection of the Public and the Environment.*
(2) Protect the environment. Requirements for environmental protection are in DOE O 5400.1, *General Environmental Protection Program,* and DOE O 5400.5, *Radiation Protection of the Public and the Environment.*
(3) Protect the work force. Requirements for radiation protection of workers are in 10 CFR 835; requirements for industry safety are in DOE O 440.1, *Worker Protection Management for DOE Federal and Contractor Employees.*
(4) Comply with applicable Federal, state, and local laws and regulations. These activities shall also comply with applicable Executive Orders and other DOE directives."

(4c) "All radioactive waste shall be managed in accordance with the requirements in DOE M 435.1, *Radioactive Waste Management Manual.*" [DOE 1999b]

B.2.2 *Radioactive Waste Management Manual* (DOE M 435.1)

The document that implements DOE Order 435.1 is DOE M 435.1, *Radioactive Waste Management Manual* (DOE 1999b). This manual requires (Chapter I, 1D) the following regulations and DOE directives for all DOE radioactive waste management facilities, operations, and activities.

(1D) **"Analysis of Environmental Impacts**. Radioactive waste management facilities, operations, and activities shall meet the requirements of 10 CFR 1021, *National Environmental Policy Act Implementing Procedures*; and DOE O 451.1A, National Environmental Policy Act Compliance Program."

(1E10) "**Mixed Waste**. Radioactive waste that contains a hazardous waste component is also subject to the *Resource Conservation and Recovery Act* (RCRA) as amended." Note hazardous waste is termed "dangerous waste" in Washington State requirements.

(1E13) **"Radiation Protection.** Radioactive waste management facilities, operations, and activities shall meet the requirements of 10 CFR 835, *Occupational Radiation Protection,* and DOE O 5400.5, *Radiation Protection of the Public and the Environment.*"

(1E18) **"Site Evaluation And Facility Design.** New radioactive waste management facilities, operations, and activities shall be sited and designed in accordance with DOE O 420.1, *Facility Safety*, and DOE O 430.1, *Life Cycle Asset Management.*"

(1E21) **"Worker Protection.** Radioactive waste management facilities, operations, and activities shall meet the requirements of DOE O 440.1, *Worker Protection Management for DOE Federal and Contractor Employees.*"

Section P of Chapter IV of the DOE *Radioactive Waste Management Manual* has additional requirements for low-level waste disposal facilities.

(1) **"Performance Objectives**. Low-level waste disposal facilities shall be sited, designed, operated, maintained, and closed so that reasonable assurance exists that the following performance objectives will be met for waste disposed of after September 26, 1988:

(a) Dose to representative members of the public shall not exceed 25 mrem (0.25 mSv) in a year total effective dose equivalent from all exposure pathways, excluding the dose from radon and its progeny in air.
(b) Dose to representative members of the public via the air pathway shall not exceed 10 mrem (0.10 mSv) in a year total effective dose equivalent, excluding the dose from radon and its progeny.
(c) Release of radon shall be less than an average flux of 20 $pCi/m^2/s$ (0.74 $Bq/m^2/s$) at the surface of the disposal facility. Alternatively, a limit of 0.5 pCi/l (0.185 Bq/l) of air may be applied.

(2) **Performance Assessment**. A site-specific radiological performance assessment shall be prepared and maintained for DOE low-level waste disposal facilities which received waste after September 26, 1988. The performance assessment shall include calculations of potential dose to representative future members of the public and potential releases from the facility to provide reasonable expectation that the performance objectives identified in this Chapter will not be exceeded over a period of 1,000 years after facility closure.

(a) Analyses performed to demonstrate compliance with the performance objectives in this chapter, and to establish limits on performance measures for inadvertent intruders in this chapter shall be based on reasonable activities in the critical group of exposed individuals. Unless otherwise specified, the assumption of average living habits and exposure conditions in representative critical groups of individuals projected to receive the highest dose is appropriate. ...
(b) The point of compliance shall correspond to the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposed waste. A larger or smaller buffer zone may be used provided adequate justification is provided.
(c) Performance assessments shall address reasonably foreseeable natural processes that might disrupt barriers against release and transport of radioactive materials.

(d) Performance assessments shall use DOE-approved dose coefficients (dose conversion factors) for internal and external exposure of reference adults.

(e) The performance assessment shall include an estimate of the maximum projected dose, flux, or concentration and the time of the maximum, in the sensitivity/uncertainty analysis.

(f) Performance assessments shall include a demonstration that projected releases of the radionuclides to the environment shall be maintained as low as reasonably achievable (ALARA).

(g) For the purpose of establishing limits on radionuclides that may be disposed near-surface, the performance assessment shall include an assessment of impacts to water resources.

(h) For purposes of establishing limits on concentration of radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts calculated for a hypothetical person assumed to inadvertently intrude into the low-level waste disposal facility. For intruder analyses, institutional controls shall be assumed to be effective in deterring intrusion for at least 100 years following closure. The intruder analyses shall use performance measures of 100 mrem (1 mSv) in a year total effective dose equivalent for chronic exposure and 500 mrem (5 mSv) total effective dose equivalent for acute exposure."

B.2.3 *Implementation Guide for DOE M 435.1* (DOE G 435.1)

The Department of Energy has also issued an implementation guide (DOE 1999c) on how the *Radioactive Waste Management Manual* is to be used.

Section IV.P(1) provides guidance on the performance objectives.

(1) The use of the phrase 'representative members of the public' is "to indicate that overly conservative assumptions such as age, sex, or assumed activities of persons, are not made."

(2) The air-pathway objective (10 mrem in a year) "is for all sources on the DOE site, not just the disposal facility."

(3) Sources of radon include the "constituent of waste at the time of disposal or produced by radioactive decay following disposal."

- "In most cases, the ground surface emanation limit for radon of 20 $pCi/m^2/s$ should be used. However, in cases where the disposed waste radiologically resembles uranium or thorium mill tailings, the limit on air concentration may be warranted. The radon dose can also be calculated as part of the total air dose, in which case, radon does not need to be addressed separately."

Section IV.P.(2) provides guidance on the performance assessment. "Detailed guidance on conducting performance assessments has been developed and is contained in *Format and Content Guide for U.S. Department of Energy Low-Level Disposal Facility Performance Assessments and Composite Analyses*" (DOE 1999d). Guidance explicitly in the implementation guide includes

(1) The compliance time period is 1,000 years after the disposal facility has been closed. "This time was selected to encompass rates of processes likely to govern migration of radiochemical species most likely to contribute to calculated dose. Longer times of assessments are not to be used to assess compliance because of the inherent large uncertainties in extrapolating calculations over long time frames."

(2) "Performance assessment analyses should be based on reasonable activities of the portion of the exposed population likely to receive the highest dose (i.e., the critical group). The performance assessment analyses should not be based on "worst case" assumptions. Rather, the analyses should be based on scenarios that represent reasonable actions of a typical group of individuals performing activities that are consistent with regional social customs, work, and housing practices, and expected regional environmental conditions at the time of the exposure scenario."

(3) "The concept of a buffer zone is inherent in defining a low-level waste disposal facility. The disposal facility is comprised of a number of disposal units." "Setting the extent of the buffer zone at 100 meters is somewhat arbitary, but 100 meters is considered to be sufficient, but not unreasonably large, for the stated purposes." "In certain cases, e.g. if the disposal facility is located adjacent to the current DOE site boundary, it may be more appropriate to use a smaller buffer zone. In other cases, e.g., where the disposal facility is located far from the DOE site boundary, and the site's land use planning does not envision relinquishing control of the site, a larger buffer zone could be considered."

(4) Natural processes "might disrupt the intended performance of the disposal facility, but such consideration should be limited to those processes which are foreseeable." Examples of such natural processes are corrosion which "will, in time, breach most containers; environmental conditions, will, in time, consume the capacity of chemical buffers, and burrowing animals and root intrusion will eventually breach disposal facility caps." "Other processes or events, although not regularly occurring, are, nonetheless, reasonably foreseeable. Such events would include severe weather such as flooding (e.g., 100 year flood, probable maximum flood), and seismic events. Other processes, such as climate change, are considered to be too speculative for consideration in the performance assessment."

(5) Dose calculations are "for adults (i.e., Reference Man). The actual dose to a particular individual from a given exposure to radioactive material is dependent on a number of characteristics, including age and sex. However, doses are not to be predicted for specific individuals or classes of persons. Rather, the calculations are to represent potential exposures to hypothetical future members of the public."

(6) "Performance assessments should include ALARA assessment that focus on alternatives for low-level waste disposal. The alternatives considered might consider the use of different disposal unit covers, waste forms, containers, or other alternatives (e.g. concrete vaults versus earthen trenches) consistent with the situation being addressed. The rigor of the ALARA assessment and its analysis of alternatives should be commensurate with the magnitude of the risk and decisions to be made."

(7) "The hierarchy for establishing water resource protection performance measures is:

- First, the DOE LLW disposal facility must comply with any applicable State or local law, regulation, or legally applicable requirements for water resource protection.

- Second, the DOE LLW disposal facility should comply with any formal agreement applicable to water resource protection that is made with appropriate State or local officials.
- Third, if neither the above conditions apply, the site should select assumptions for use in the performance assessment based on criteria established in the site groundwater protection management program and any formal land-use plans.
- If none of the above conditions apply, the site should identify a performance measure for protection of water resources that is consistent with the use of water as a drinking water source. Examples of this type of performance measure would be the assumption of the concentration limits in 40 CFR 141 or a dose limit of 4 mrem per year above background from the ingestion of water."

(8) "Although DOE is committed to retaining control of land containing residual radioactive material, such as disposed low-level waste, it is nonetheless appropriate to consider the impacts of potential inadvertent intrusion. Intrusion can be considered either as an accident scenario which could occur during lapses of institutional control or as a hypothetical situation assumed simply to provide a basis for establishing control over the concentration of radioactive material acceptable in a near-surface disposal facility."

"Institutional control should be assumed to be effective in preventing intrusion for 100 years following disposal facility closure. Longer periods may be assumed with justification (e.g. land-use planning, passive controls)."

"Development of intruder scenarios should be based on the following assumptions

- Intruders could carry out activities for no more than about a year before discovery.
- An intruder performs reasonable activities consistent with regional social customs and well drilling, excavation, and construction practices, and the regional environmental conditions projected for the time that intrusion is assumed to occur.
- Intrusion events involve random contact with waste.
- An intruder will take reasonable, investigative actions upon discovery of unusual materials.
- Intrusion events that contact waste should normally be assumed to be limited to drilling or simple extraction scenarios involving use of relatively unsophisticated tools and commonplace machinery.
- Doses calculated for an intruder will depend on waste disposal facility design and operating practices, and may be reduced by practices such as disposal below depths normally associated with common construction activities, use of intruder barriers or durable waste forms or containers, or distributed disposal of higher activity waste."

"The inadvertent intruder assessment should, at a minimum, include consideration of an acute construction scenario, an acute well drilling scenario, and a chronic agricultural scenario."

B.2.4 *Technical Basis for DOE M 435.1*

Further information is given in the *Technical Basis for DOE M 435.1* (DOE 1999e). In particular, the sections on the performance objectives and performance assessment given justification for the approach taken and the values used.

1) The requirement of an all-pathways effective dose equivalent "is consistent with established radiation protection practice that allocates a fraction of the 100 mrem/yr public dose to a particular practice or activity. It is also consistent with the regulatory practice of the NRC to require all-pathways assessments, and this is consistent with the NRC low-level waste disposal facility licensing regulations at 10 CFR 61."

2) The requirement on groundwater protection "provides defense in depth to the all pathways performance objective." "Guidance developed for this requirement describes a tiered structure for its application. The guidance is based on a recognition that at the current time, there are no applicable Federal regulations. Therefore, the emphasis is to be consistent with the site's groundwater protection

management program. Also, the role of future use commitments between DOE and other authorities in the management of water resources may provide a sound basis for making decisions."

3) The time period for compliance (1,000 years after closure) "was selected after consideration of the times used in other regulations (e.g. 10 CFR 191, 40 CFR 192), and recognition of the uncertainties and hypothetical nature of long-term projections." "based on the study, *Comparison of Low-Level Waste Disposal Programs of DOE and Selected International Countries* (DOE/LLW-236) [DOE 1996d] two countries (Canada and Sweden) have established a time of compliance of 10,000 years. The other two countries (France and the United Kingdom) have not specified a time of compliance. Similarly, to date, DOE, NRC, and EPA have not specified a time of compliance for low-level waste disposal facility performance assessments. A team composed of primarily of DOE contractor performance assessment staff evaluated the options for a time of compliance. In its progress report, *Performance Assessment Task Team Progress Report* (DOE/LLW-157, Rev. 1) [Wood 1994], the team recommended a time of compliance of 10,000 years. This time was consistent with the time specified on 10 CFR 191 for high-level and transuranic waste disposal, and was considered to be conservative in that no longer times had been seriously proposed. This time or longer times had been used in DOE disposal facility performance assessments conducted up to that time. Subsequently, EPA asked agency reviewers for their opinions on the use of 10,000, 1,000, or some other time frame as the time of compliance for low-level waste disposal facility performance assessments. DOE responded that its position was that 1000 years was an appropriate time."

4) The "point of compliance is consistent with regulatory positions included in 40 CFR 192.32 and 40 CFR 264.95. The NRC regulation at 10 CFR 61.52(a)(8) states that a 'buffer zone of land must be maintained between any buried waste and the disposal site boundary ...' In NUREG-1200, section 4.3.6 [NRC 1988] it is recommended that this buffer be at least 30 m wide. The Performance Assessment Task Team recommended a point of compliance of 100 meters in the *Performance Assessments Task Team Progress Report* (DOE/LLW-157, Rev. 1). [Wood 1994] In the *Draft Recommendations on Prospective Assessments for Long-Term Management of Low-Level Radioactive Waste* (memorandum, R. Beube, dated September 5, 1996) [DOE 1996e], the DOE Office of Environment recommended that the point of compliance should be at the point of public access. Therefore the point of compliance would be the site boundary. The Office of Environment recommendations further acknowledged that it may be prudent to use a closer point of assessment if there is uncertainty about the future location of the site boundary. 40 CFR 192.32 permits the establishment of alternative concentration limits that are as low as reasonable and meet the standards of 40 CFR 264.94(a) at all points at a greater distance than 500 meters from the edge of the disposal area and/or outside the site boundary."

5) "The rationale for using standard adult dose conversion factors comes from the fact that in a performance assessment one is calculating a postulated dose to a hypothetical future person assumed to be engaged in a set of 'normal' activities over a period of years. Consequently, performing calculations as if real people of known age were being impacted by releases from the facility is not reasonable."

6) "in addition to calculations over the time of compliance (1000 years), performance assessments also are to present calculations of maxima relative to each of the performance objectives. The results of these calculations are part of the sensitivity and uncertainty analysis which would support a conclusion that the model is providing a reasonable projection. These longer calculations address the need to ensure that there are no unexpected significant increases shortly after the time of compliance and provide a mechanism for understanding the model performance and significance of modelling parameters. The calculation of maxima does present the possibility that there may be results that exceed the performance objectives. The significance of these results must be handled with caution and judgement. The further out in time that the maxima occurs, the less significant is the relationship to the performance objective."

"This requirement represents a DOE policy decision; it derives in part from IAEA Fundamental Principles of Radioactive Waste Management."

7) "The use of the ALARA concept in long-term assessments is a best management practice that contributes defense-in-depth to the possible exposures from a disposal facility. Application of the ALARA principle for managing current operational exposures has practical and measurable merit in that real doses are being avoided or reduced. This concept is extended here by addressing projected releases of materials well into the future which may result in doses."

8) "The concept of protection of inadvertent intrusion is consistent with national and international practice (NRCP, ICRP, IAEA). The NRC included the protection of inadvertent intruders as one of the performance objectives in 10 CFR 61. Other international and national organizations have and continue to include the protection of inadvertent intruders as one of the elements of radiation protection."

"Since the intent of the Department is to control the use of the land where low-level waste is disposed until the land can be released, inadvertent intruder calculations provide defense-in-depth by limiting the concentration of waste that can be disposed of in the near surface. With each performance assessment evaluating and developing limits for near-surface disposal, DOE is more cost-effective in managing waste and is consistent with the philosophy of using performance based requirements."

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Appendix C Supporting Tables

Table C.1 List of Relevant Regulations

REGULATION	COMMENT
Radioactive Waste Management (DOE Order 5820.2A) [DOE 1988a]	Current DOE order covering disposal of low-level waste.
Radioactive Waste Management (DOE Order 435.1) [DOE 1999a]	New DOE order covering disposal of low-level waste, released July 9, 1999.
Licensing Requirements for Land Disposal of Radioactive Wastes (10 CFR 61)	Requirements of the Nuclear Regulatory Commission for the land disposal of low-level radioactive waste
Radioactive Waste – Licensing and Disposal (WAC 246-250)	Sets requirements for disposal of low-level radioactive wastes in the State of Washington
General Environmental Protection Program (DOE Order 5400.1) (DOE 1990)	Lists executive orders, laws, and regulations which DOE actions must meet
Radiation Protection of the Public and the Environment (DOE Order 5400.5) (DOE 1993)	Provides exposure limits for general activities
Department of Energy Radiological Health and Safety Policy (DOE 1996a)	Establishes basis of DOE's radiological control programs
Occupational Radiation Protection (10 CFR 835)	Establishes radiation protection standards, limits, and programs for protecting individuals from ionizing radiation from the conduct of DOE activities
Standards for Protection Against Radiation (10 CFR 20)	Establishes standards for protection against ionizing radiation resulting from activities conducted under licenses issued by the NRC.
Radiation Protection Standards (WAC 246-221)	Sets radiation protection standards for the state of Washington
National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities (40 CFR 61.192)	Establishes maximum exposure to public via air pathway for non-radon radionuclides
National Emission Standards for Radon Emissions from Department of Energy Facilities (40 CFR 61.192)	Establishes maximum exposure to public of Ra-222 via air pathway
Ambient Air Quality Standards and Emission Limits for Radionuclides (WAC 173-480)	Sets emission standards into air for radionuclides in the state of Washington
Radiation Protection – Air emissions (WAC 246-247)	Sets radioactive air emissions standard
National Primary Drinking Water Regulations (40 CFR 141)	Sets drinking water standards
Water Quality Standards for Ground Waters of the State of Washington (WAC 173-200)	Sets standards for ground waters in the State of Washington

REGULATION	COMMENT
Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A)	Sets standards for surface waters in the State of Washington
Identification and Listing of Hazardous Waste (40 CFR 261)	Establishes which wastes are subject to RCRA
Land Disposal Restrictions (40 CFR 268)	Limits disposal options for hazardous wastes
Dangerous Waste Regulations (WAC 173-303)	Implements RCRA in the State of Washington

Table C.2 Requirements Of Relevant General Radioactive Waste Regulations

DOE Order 5820.2a: (DOE 1988a)	
All pathways	25 mrem/year
ALARA	See footnote
Intruder (100 years)	100 mrem/year (continuous)
Intruder (100 years)	500 mrem (single event)

DOE M 435.1 (DOE 1999b)	
All pathways (<1,000 years)	25 mrem/year
ALARA	See footnote
Intruder (> 100 years or larger)	100 mrem/year (continuous)
Intruder (> 100 years or larger)	500 mrem (single event)

DOE Order 5400.5 (DOE 1993)	
All pathways (from all DOE facilities at the site)	100 mrem/year (analysis performed by a separate document)

WAC 246-221-060	
All pathways	2 mrem/hour
All pathways	100 mrem/year

10 CFR 61. 41	
All pathways (whole body)	25 mrem/year
All pathways (thyroid)	75 mrem/year
All pathways (other organs)	25 mrem/year
Only Class C disposal	See Table C.8

WAC 246-250-170	
All pathways (whole body)	25 mrem/year
All pathways (thyroid)	75 mrem/year
All pathways (other organs)	25 mrem/year

Following DOE Order 435.1 guidance, ALARA restrictions are taken to require sensitivity studies showing the significance of various design options.

Table C.3 Requirements of Relevant Worker Protection Regulations

10 CFR 835	
All pathways (effective dose equivalent)	5,000 mrem/year
Sum of deep dose equivalent for external exposures and the committed dose equivalent to any organ or tissue other than the lens of the eye	50,000 mrem
Lens of the eye (dose equivalent)	15,000 mrem
Shallow dose equivalent to the skin or any extremity	50,000 mrem
WAC 246-221-010	
All-Pathways	5,000 mrem/year
Sum of deep dose equivalent for external exposures and the committed dose equivalent to any organ or tissue other than the lens of the eye	50,000 mrem
Lens of the eye (annual limit)	15,000 mrem
Shallow dose equivalent to the skin or any extremity (annual limit)	50,000 mrem

Table C.4 Requirements of Relevant Air Regulations

DOE O 435.1	
Air emissions (except radon)	10 mrem/year
Air emissions (radon)	20 pCi/m^{2}s

DOE Order 5400.5 (DOE 1993)	
Air emissions (except radon)	10 mrem/year

40 CFR 61.92	
Air emission (except radon)	10 mrem/year

40 CFR 61.192	
Air emissions (radon)	20 pCi/m^{2}s

WAC 173-480-040	
Air emissions (except radon) (whole body)	25 mrem/year
Air emissions (except radon) (critical organ)	75 mrem/year

WAC 173-480-060
Best available radionuclide control technology

WAC 246-247-040
References WAC 173-480 and 40 CFR 61

Table C.5 Requirements of Relevant Drinking Water Regulations

DOE Order 5400.5 (DOE 1993)	
Radionuclides	4 mrem/year
Ra-226 plus Radium-228	$5x10^{-9}$ μCi/ml (= 5 pCi/l)
Alpha emitters (but not Rn nor U)	$1.5x10^{-8}$ μCi/ml (=15 pCi/l)

40 CFR 141.11	
Arsenic	0.05 mg/l

40 CFR 141.12	
Trihalomethanes	0.10 mg/l

40 CFR 141.15	
Ra-226+Ra-228	5 pCi/l
Alpha activity (except Ra and U)	15 pCi/l

40 CFR 141.16	
Beta and photon activity (2 L/d)	4 mrem/year
H-3	20,000 pCi/l
Sr-90	8 pCi/l

40 CFR 141.61		
CAS #	Constituent (a)	Limit
56-23-5	Carbon tetrachloride	0.005 mg/l
71-43-2	Benzene	0.005 mg/l
71-55-6	1,1,1-Trichloroethane	0.2 mg/l
75-09-2	Dichloromethane (Methylene Chloride)	0.005 mg/l
79-00-5	1,1,2-Trichloroethane	0.005 mg/l
79-01-6	1,1,2-Trichloroethylene	0.005 mg/l
95-47-6	o-Xylene	0.7 mg/l
100-41-4	Ethyl benzene	0.1 mg/l
106-46-7	1,4-Dichlorobenzene	0.075 mg/l
108-88-3	Toluene	1.0 mg/l
127-18-4	1,1,2,2-Tetrachloroethene	0.005 mg/l

40 CFR 141.62			
Antimony	0.006 mg/l	Barium	2.0 mg/l
Beryllium	0.004 mg/l	Cadmium	0.005 mg/l
Chromium	0.1 mg/l	Cyanide	0.2 mg/l
Fluorine	4.0 mg/l	Mercury	0.002 mg/l
Nitrate (as N)	10. mg/l	Nitrite (as N)	1. mg/l
Nitrate + Nitrite (as N)	10. mg/l	Selenium	0.05 mg/l
Thallium	0.002 mg/l		

a Greater than 100 analytical detects in tank waste or greater than 20 analytical detects in TWINS Solid/Liquid Hits. Taken from Wiemers 1998.

Table C.6 Requirements of Relevant Groundwater Regulations

40 CFR 264.94			
Arsenic	0.005 mg/l	Barium	1.0 mg/l
Cadmium	0.01 mg/l	Chromium	0.05 mg/l
Lead	0.05 mg/l	Mercury	0.002 mg/l
Selenium	0.01 mg/l	Silver	0.05 mg/l

WAC 173-200-040	
Alpha emitters	15 pCi/l
Beta emitters	50 pCi/l
H-3	20,000 pCi/l
Sr-90	8 pCi/l
Ra 226 plus Ra-228	5 pCi/l
Ra 226	3 pCi/l

Chemical	**WAC 173-200-040**	**WAC 173-303-645**
Arsenic	0.00005 mg/l	0.05 mg/l
Barium	1 mg/l	1 mg/l
Cadmium	0.01 mg/l	0.01 mg/l
Chlorine	250. mg/l	
Chromium	0.05 mg/l	0.05 mg/l
Copper	1. mg/l	
Fluorine	4. mg/l	
Iron	0.30 mg/l	
Lead	0.05 mg/l	0.05 mg/l
Manganese	0.05 mg/l	
Mercury	0.002 mg/l	0.002 mg/l
Selenium	0.01 mg/l	0.01 mg/l
Silver	0.05 mg/l	0.05 mg/l
Zinc	5. mg/l	
Sulfate (SO_4)	250. mg/l	
Nitrate (as N)	10. mg/l	

CAS #	Constituent (a)	**WAC 173-200-040**
56-23-5	Carbon tetrachloride	0.0003 mg/l
67-66-3	Chloroform	0.007 mg/l
71-43-2	Benzene	0.001 mg/l
71-55-6	1,1,1-Trichloroethane	0.003 mg/l
75-09-2	Dichloromethane (Methylene Chloride)	0.005 mg/l
106-46-7	1,4-Dichlorobenzene	0.004 mg/l
117-81-7	Bis(2-ethylhexyl)phthalate	0.006 mg/l

a Greater than 100 analytical detects in tank waste or greater than 20 analytical detects in TWINS Solid/Liquid Hits. Taken from Wiemers 1998.

Table C.7 Requirements Of Relevant Surface Water Regulations

WAC 173-201A-040			
Ammonia	4.0 mg/l	Arsenic	0.19 mg/l
Cadmium (a)	0.00077 mg/l	Chlorine	230. mg/l
Copper (a)	0.0078 mg/l	Chromium	0.011 mg/
Cyanide	0.0052 mg/l	Lead (a)	0.00146 mg/l
Mercury	0.000012 mg/l	Nickel (a)	0.115 mg/l
Selenium	0.005 mg/l	Zinc (a)	0.072 mg/l

a based on Columbia River at Pasco having a mean hardness of 73 mg/l (DOE 1988b)

WAC 173-201A-050	
Radionuclides	0.01 of WAC 246-221-290 Or EPA drinking water standards (40 CFR 141, see Table C.5 above)
Radionuclide (a)	0.01 of WAC 246-221-290
H - 3	200. pCi/l
Se- 79	3. pCi/l
Sr- 90	8. pCi/l
Zr- 93	3. pCi/l
Nb- 93m	8. pCi/l
Tc- 99	20. pCi/l
Sn-126	0.2 pCi/l
I -129	0.04 pCi/l
Cs-137	0.6 pCi/l
Ra-226	0.003 pCi/l
Ra-228	0.005 pCi/l
Th-232	0.000005 pCi/l
Pa-231	0.000006 pCi/l
U –233	0.005 pCi/l
U –234	0.005 pCi/l
U –235	0.006 pCi/l
U –236	0.005 pCi/l
U –238	0.006 pCi/l
Np-237	0.00002 pCi/l
Pu-239	0.00003 pCi/l
Pu-240	0.00003 pCi/l
Am-241	0.00003 pCi/l
Am-243	0.00003 pCi/l

Table C.8 Requirements of Relevant Regulations for Concentrations in Waste

BNFL Contract (BNFL/DOE 1998)			
Sr 90	3 Ci/m^3	Tc 99 (a)	0.1 Ci/m^3
Cs 133	3 Ci/m^3		
	On average, 80% of Tc99 delivered from vendor shall be removed		

10CFR61.55 (limits given are for isotope in activated metal)			
C - 14	8. Ci/m^3	Ni- 59	220. Ci/m^3
Ni - 63	700. Ci/m^3	Nb-94	0.2 Ci/m^3
Sr - 90	7000. Ci/m^3	I-129	0.08 Ci/m^3
Cs - 137	4600. Ci/m^3		
Alpha emitters (with half-lives greater than 5 years)			100 nCi/g
Pu – 241	3500 nCi/g	Cm-242	20000 nCi/g

40 CFR 261.24 (a)			
Arsenic	5 mg/l	Barium	100 mg/l
Cadmium	1 mg/l	Chromium	5 mg/l
Lead	5 mg/l	Mercury	0.2 mg/l
Selenium	1mg/l	Silver	5 mg/l
`CAS #	Constituent (b)		
56-23-5	Carbon tetrachloride		0.5 mg/kg
67-66-3	Chloroform		6.0 mg/kg
78-93-3	2-Butanone (Methyl ethyl ketone)		200. mg/kg
79-00-5	1,1,2-Trichloroethane		0.5 mg/kg
106-46-7	1,4-Dichlorobenzene		7.5 mg/kg
110-86-1	Pyridine		5. mg/kg
127-18-4	1,1,2,2-Tetrachloroethene		0.7 mg/kg

40 CFR 268.40 (a)			
Arsenic	5.0 mg/l	Barium	100 mg/l
Cadmium	1.0 mg/l	Chromium (total)	5.0 mg/l
Cyanide	590 mg/kg	Lead	5.0 mg/l
Mercury	0.02 mg/l	Selenium	5.7 mg/l
Silver	5.0 mg/l		
CAS #	Constituent (b)		Waste limit
56-23-5	Carbon tetrachloride		6.0 mg/kg
67-56-1	Methyl alcohol		0.75 mg/l
67-64-1	2-Propanone (Acetone)		160. mg/kg
67-66-3	Chloroform		6.0 mg/kg
71-36-3	n-Butyl alcohol		2.6 mg/kg
71-43-2	Benzene		10. mg/kg
71-55-6	1,1,1-Trichloroethane		6. mg/kg
74-87-3	Chloromethane (Methyl Chloride)		30. mg/kg
75-05-8	Acetonitrile		38. mg/kg

75-09-2	Dichloromethane (Methylene Chloride)	30. mg/kg
75-69-4	Trichlorofluoromethane	30. mg/kg
75-71-8	Dichlorodifluoromethane	7.2 mg/kg
76-13-1	1,2,2-Trichlorotrifluoroethane	30. mg/kg
78-93-3	2-Butanone (Methyl ethyl ketone)	36. mg/kg
79-00-5	1,1,2-Trichloroethane	6. mg/kg
79-01-6	1,1,2-Trichloroethylene	6. mg/kg
95-47-6	o-Xylene	30. mg/kg
100-41-4	Ethyl benzene	10. mg/kg
106-46-7	1,4-Dichlorobenzene	6.0 mg/kg
107-12-0	Propionitrile (Ethyl Cyanide)	360. mg/kg
108-10-1	4-Methyl-2-pentanone (Methyl isobutyl ketone)	33. mg/kg
108-88-3	Toluene	10. mg/kg
108-94-1	Cyclohexane	0.75 mg/l
110-86-1	Pyridine	16. mg/kg
117-81-7	Bis(2-ethylhexyl)phthalate	28. mg/kg
127-18-4	1,1,2,2-Tetrachloroethene	6. mg/kg

40 CFR 268.48 (Universal Treatment Standards)(a)			
Antimony	1.15 mg/l	Arsenic	5.0 mg/l
Barium	21. mg/l	Beryllium	0.014 mg/l
Cadmium	0.11 mg/l	Chromium (total)	0.60 mg/l
Cyanide (total)	590. mg/kg	Lead	0.75 mg/l
Mercury	0.025 mg/l	Nickel	11.0 mg/l
Selenium	5.7 mg/l	Silver	0.14 mg/l
Thallium	0.078 mg/l	Vanadium	0.23 mg/l
Zinc	5.3 mg/l		

CAS #	Constituent (b)	
56-23-5	Carbon tetrachloride	6.0 mg/kg
67-56-1	Methyl alcohol	0.75 mg/l
67-64-1	2-Propanone (Acetone)	160. mg/kg
67-66-3	Chloroform	6.0 mg/kg
71-36-3	n-Butyl alcohol	2.6 mg/kg
71-43-2	Benzene	10. mg/kg
71-55-6	1,1,1-Trichloroethane	6. mg/kg
74-87-3	Chloromethane (Methyl Chloride)	30. mg/kg
75-05-8	Acetonitrile	38. mg/kg
75-09-2	Dichloromethane (Methylene Chloride)	30. mg/kg
75-69-4	Trichlorofluoromethane	30. mg/kg
75-71-8	Dichlorodifluoromethane	7.2 mg/kg
76-13-1	1,2,2-Trichlorotrifluoroethane	30. mg/kg
78-93-3	2-Butanone (Methyl ethyl ketone)	36. mg/kg
79-00-5	1,1,2-Trichloroethane	6. mg/kg
79-01-6	1,1,2-Trichloroethylene	6. mg/kg

95-47-6	o-Xylene	30. mg/kg
100-41-4	Ethyl benzene	10. mg/kg
106-46-7	1,4-Dichlorobenzene	6.0 mg/kg
107-12-0	Propionitrile (Ethyl Cyanide)	360. mg/kg
108-10-1	4-Methyl-2-pentanone (Methyl isobutyl ketone)	33. mg/kg
108-88-3	Toluene	10. mg/kg
108-94-1	Cyclohexane	0.75 mg/l
110-86-1	Pyridine	16. mg/kg
117-81-7	Bis(2-ethylhexyl)phthalate	28. mg/kg
127-18-4	1,1,2,2-Tetrachloroethene	6. mg/kg

WAC 173-303-090 (a)			
Arsenic	5 mg/l	Barium	100 mg/l
Cadmium	1 mg/l	Chromium	5 mg/l
Lead	5 mg/l	Mercury	0.2 mg/l
Selenium	1 mg/l	Silver	5 mg/l
CAS #	Constituent (b)		
56-23-5	Carbon tetrachloride		0.5 mg/kg
67-66-3	Chloroform		6.0 mg/kg
78-93-3	2-Butanone (Methyl ethyl ketone)		200. mg/kg
79-00-5	1,1,2-Trichloroethane		0.5 mg/kg
106-46-7	1,4-Dichlorobenzene		7.5 mg/kg
110-86-1	Pyridine		5. mg/kg
127-18-4	1,1,2,2-Tetrachloroethene		0.7 mg/kg

a where unit is "mg/l", then concentration is established by a TCLP test.

b Greater than 100 analytical detects in tank waste or greater than 20 analytical detects in TWINS Solid/Liquid Hits. Taken from Wiemers 1998.

Table C.9 Conversion between Water Concentration and Dose [*]

Nuclide (Taken from ILAW PA [Mann 1998])	Concentration (pCi/l)	Dose (mrem/year)
H-3	20,000. [a,b,g,s]	0.92 [g,s]
C-14	50 [a] 3 [c]	0.076 [g] 4. [b] 0.015 [s]
Se-79	50. [a] 3. [c]	0.3 [g] 4. [b] 0.2 [s]
Sr-90	8. [a,b,g] 3. [c,s]	0.82 [g] 0.31 [s]
Zr-93	50. [a] 3. [c]	0.06 [g] 4. [b] 0.012 [s]
Nb-93m	50. [a] 8. [c]	0.02 [g] 4. [b] 0.004 [s]
Tc-99	50. [a,g] 20. [c]	0.05 [g] 4. [b] 0.02 [s]
Sn-126	50. [a] 0.2 [c]	0.8 [g] 4. [b] 0.003 [s]
I-129	50. [a] 19.6 [g] 2,000. [c,s]	10. 4. [b,g] 400. [s]
Cs-137	50. [a,g] 110. [s] 200. [c]	1.8 [g] 4. [b,s] 7.3
Sm-151	50. [a] 10. [c]	0.014 [g] 4. [b] 0.003 [s]
Ra-226	3. [a,g] 5. [b] 0.3 [c,s]	2.4 [g] 4. 0.24 [s]
Ra-226+Ra-228	5. [a,b,g] 0.3 [c,s]	4.1 [g] 0.24 s
Th-232	15. [a,b,g,s] 20. [c]	31. [g,s] 7.8
U-232	15. [a,b,g,s] 300. [c]	14. [g,s] 71.

Nuclide (Taken from ILAW PA [Mann 1998])	Concentration (pCi/l)	Dose (mrem/year)
U-233	15. [a,b,g,s] 300. [c]	3.0 [g,s] 59.
U-234	15. [a,b,g,s] 300. [c]	2.8 [g,s] 57.
U-235	15. [a,b,g,s] 300. [c]	2.7 [g,s] 55.
U-236	15. [a,b,g,s] 300. [c]	2.7 [g,s] 55.
U-238	15. [a,b,g,s] 400. [c]	2.7 [g,s] 71.
Np-237	15. [a,b,g,s] 30. [c]	43. [g,s] 140.
Pu-239	15. [a,b,g,s] 50. [c]	47. [g,s] 160.
Pu-240	15. [a,b,g,s] 50. [c]	47. [g,s] 160.
Am-241	15. [a,b,g,s] 40. [c]	49.g,s 131.
Am-243	15. [a,b,g,s] 40. [c]	49.g,s 130.

* Conversion performed by assuming 2/d per day water consumption and EPA internal dose conversion coefficients (EPA 1988)
a Washington State ground water standard (WAC 173-200)
b National drinking water standard (40 CFR 141)
c Washington State surface water standard from WAC 246-221-290 Table (using 0.01 of value found in table)
g Ground water standard, minimum of state and national standards
s Surface water standard, minimum of state and national standards

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Appendix D. Performance Objectives of Previous DOE Performance

Table D.1 Performance Objectives of Previous DOE Performance
(Status Given in Owendoff 1999)

Hanford Site: *Performance Assessment of Grouted Double Shell Tank Waste Disposal at Hanford* (Kincaid 1993)		
All-Pathways	<10,000 yr	25 mrem/yr
Drinking Water	<10,000 yr 100 m downgradient	4 mrem/yr
Air emissions (radon)		20 pCi/m^{2}s
Inadvertent Intruder	>500 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
ALARA	<10,000 yr	500 persons-rem/yr
Status	Found "technically acceptable" by Peer Review Panel, but new mission (ILAW) has made PA moot.	

Hanford Site: *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Burial Grounds* (Wood 1995)		
All-Pathways	<10,000 yr	25 mrem/yr
Drinking Water	<10,000 yr 100 m downgradient	4 mrem/yr
Air emissions (radon)		20 pCi/m^{2}s
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

Hanford Site: *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Burial Grounds* (Wood 1996)		
All-Pathways	<10,000 yr	25 mrem/yr
Drinking Water	<10,000 yr 100 m downgradient	4 mrem/yr
Air emissions (radon)		20 pCi/m^{2}s
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

Hanford Site: *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Mann 1998)		
All-Pathways	<10,000 yr	25 mrem/yr
Drinking Water Beta emitters	<10,000 yr 100 m downgradient	 4 mrem/yr 15 pCi/l
Air emissions all but radon radon	<10,000 yr	 10 mrem/yr 20 pCi/m^{2}s
Inadvertent Intruder	>500 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Submitted to DOE	

Idaho National Engineering And Environmental Laboratory: *Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment* (Maheras 1994)		
All-Pathways (but air)		25 mrem/yr
Drinking Water all alpha emitters (other than U and Rn)	100 m downgradient	 4 mrem/yr 15 pCi/l
Air emissions		10 mrem/yr
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

Los Alamos National Laboratory: *Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G* (Hollis 1997)		
All-Pathways	<10,000 yr	25 mrem/yr
Drinking Water	<10,000 yr 100 m downgradient	4 mrem/yr
Air emissions (all LANL facilities) all but radon radon		 10 mrem/yr 20 pCi/m^{2}s
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Submitted	

Nevada Test Site: *Performance Assessment / Composite Analysis for the Area 3 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada* (Schott 1997)		
All-Pathways	<1,000 year 100 m downgradient	25 mrem/yr
Drinking Water Beta/gamma emitters Gross alpha Ra-226 + Ra-228	<1,000 year 100 m downgradient	 4 mrem/yr 15 pCi/l 5 pCi/l
Air emissions All but radon radon	 100 m down gradient waste cap	 10 mrem/yr 20 pCi/m^2s
Inadvertent Intruder	> 100 year < 1,000 year	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Submitted	

Nevada Test Site: *Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada* (Schott 1998)		
All-Pathways	<1,000 year	25 mrem/yr
Drinking Water Beta/gamma emitters Gross alpha Ra-226 + Ra-228	<1,000 year 42,000 m downgradient	 4 mrem/yr 15 pCi/l 5 pCi/l
Air emissions All but radon radon	<1,000 year 100 m down gradient waste cap	 10 mrem/yr 20 pCi/m^2s
Inadvertent Intruder	> 100 year <1,000 year	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Submitted	

Oak Ridge National Laboratory: *Performance Assessment for Continuing and Future Operations Solid Waste Storage Area 6* (MMES 1994)		
All-Pathways		25 mrem/yr
Drinking Water	100 m downgradient	4 mrem/yr
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

Savannah River Site: *Radiological Performance Assessment for the Z-Area Saltsone Disposal Facility* (WSRC 1992)		
All-Pathways		25 mrem/yr
Drinking Water		4 mrem/yr
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

Savannah River Site: *Radiological Performance Assessment for the E-Area Vaults Disposal Facility* (WSRC 1994)		
All-Pathways		25 mrem/yr
Drinking Water	100 m downgradient	EPA Standards U: 20 g/l
Air emissions (radon)		20 pCi/m^2s
Inadvertent Intruder	>100 yr	Continuous: 100 mrem/yr Acute: 500 mrem/yr
Status	Approved by DOE	

APPENDIX B

SCENARIOS

FOR THE

HANFORD IMMOBILIZED LOW-ACTIVITY WASTE (ILAW) PERFORMANCE ASSESSMENT

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Acronyms

ALARA	as low as reasonable achievable
CFR	Code of Federal Register
DOE	Department of Energy
HFSUWG	Hanford Future Site Uses Working Group
ILAW	immobilized low-activity waste
NRC	Nuclear Regulatory Commission
PA	performance assessment
WAC	Washington Administrative Code

1.0 OVERVIEW

The purpose of the next version of the *Hanford Immobilized Low-Activity Tank Waste* (ILAW) *Performance Assessment* (ILAW PA) is to provide an updated estimate of the long-term human health and environmental impact of the disposal of ILAW and to compare these estimates against performance objectives displayed in Tables 1, 2, and 3 (Mann 1999a). Such a radiological performance assessment is required by U.S. Department of Energy (DOE) Orders on radioactive waste management (DOE 1988a and DOE 1999a). This document defines the scenarios that will be used for the next update of the PA that is scheduled to be issued in 2001. Since the previous performance assessment (Mann 1998) was issued, considerable additional data on waste form behavior and site-specific soil geotechnical properties have been collected. In addition, the 2001 ILAW PA will benefit from improved computer models and the experience gained from the previous performance assessment. However, the scenarios (that is, the features, events, and processes analyzed in the performance assessment) for the next PA are very similar to the ones in the 1998 PA.

The scenarios analyzed as part of the base case studies are chosen to represent likely situations to demonstrate compliance with the performance objectives. Other scenarios are chosen to represent situations that demonstrate the uncertainties or sensitivities of key parameters surrounding the best case. Finally, reasonably bounding scenarios are chosen to provide an understanding of the limits of performance.

The scenarios are based on guidance from the Department of Energy (1999a, 1999b, 1999c, 1999d, and 1999e) and from the U.S. Nuclear Regulatory Commission (NRC 1988 and NRC 1997). The scenarios are also based on those used in the 1998 ILAW PA (Mann 1998) and other Hanford Site performance assessments (Kincaid 1995, Wood 1995, and Wood 1996). This document updates the document (Mann 1994) which defined the scenarios used in the 1998 ILAW PA.

This document provides a general description of the scenarios that will be analyzed. A series of documents (data packages) [Fayer 1999, Kaplan 1999, Khaleel 1999, Meyer 1999, McGrail 1999, Prosser 1999, Puigh 1999, Reidel 1999, Rittmann 1999, and Wootan 1999] that cover each of the various data areas important to the performance assessment will be published later this year. These data packages will provide the values for all of the parameters used in the analyses as well as the associated uncertainty information. Each of these data packages will have a formal review plan that will include external review.

Chapter 2 provides background information about the ILAW disposal. The next three chapters,

3. All-Pathways and Groundwater
4. Releases to the Atmosphere
5. Inadvertent Intruder,

define the scenarios for each set of performance objectives. Since contamination transport to surface water (such as the Columbia River) will be through the groundwater pathway, that

pathway is also described in Chapter 3. Chapter 6 describes the public involvement process used for this document.

Table 1.1 Radiological Performance Objectives

Protection of General Public and Workers [a, b]	
All-pathways dose from only this facility	25 mrem in a year [d, h]
All-pathways dose including other Hanford Site sources	100 mrem in a year [e, i]
Protection of an Inadvertent Intruder [c, f]	
Acute exposure	500 mrem
Continuous exposure	100 mrem in a year
Protection of Groundwater Resources [b, d, j]	
Alpha emitters	
$^{226}Ra + ^{228}Ra$	5 pCi/ℓ
All others (total)	15 pCi/ℓ
Beta and photon emitters	4 mrem in a year
Protection of Surface Water Resources [b, g]	
Alpha emitters	
$^{226}Ra + ^{228}Ra$	0.3 pCi/ℓ [j]
All others (total)	15 pCi/ℓ [j]
Beta and photon emitters	1 mrem in a year [k]
Protection of Air Resource [b, f, l]	
Radon (flux through surface)	20 pCi m^{-2} s^{-1}
All other radionuclides	10 mrem in a year

[a] All doses are calculated as effective dose equivalents; all concentrations are in water taken from a well. Values given are in addition to any existing amounts or background.
[b] Evaluated for 1,000 and 10,000 years, but calculated to the time of peak or 10,000 years, whichever is longer.
[c] Evaluated for 500 years, but calculated to 1,000 years.
[d] Evaluated at the point of maximal exposure, but no closer than 100 meters (328 feet) from the disposal facility.
[e] Evaluated at the 200 East Area fence.
[f] Evaluated at the disposal facility.
[g] Evaluated at the Columbia River, no mixing with the river is assumed.
[h] Main driver is DOE Orders on *Radioactive Waste Management* (DOE 1988a and DOE 1999a)
[i] Main driver is DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE 1993).
[j] Main driver is "National Primary Drinking Water Regulations (40 CFR 141).
[k] Main driver is "Washington State Surface Water Standards (WAC 173-201A)
[l] Main driver is "National Emission Standards for Hazardous Air Pollutants (40 CFR 61H and 40 CFR 61Q)

Table 1.2 Performance Goals for Inorganic Materials

Chemical	Groundwater	Surface Waters
Ammonia		4.0 mg/l
Antimony	0.006 mg/l	0.006 mg/l
Arsenic	0.00005 mg/l	0.05 mg/l
Barium	1.0 mg/l	2.0 mg/l
Beryllium	0.004 mg/l	0.004 mg/l
Cadmium	0.005 mg/l	0.00077 mg/l
Chlorine	250. mg/l	230. mg/l
Chromium	0.05 mg/l	0.011 mg/l
Copper	1.0 mg/l	0.0078 mg/l
Cyanide	0.2 mg/l	0.0052 mg/l
Fluoride	4.0 mg/l	4.0 mg/l
Iron	0.3 mg/l	
Lead	0.05 mg/l	0.0015 mg/l
Manganese	0.05 mg/l	
Mercury	0.002 mg/l	0.000012 mg/l
Nickel		0.115 mg/l
Nitrate as N	10. mg/l	10. mg/l
Nitrite as N	1.0 mg/l	1.0 mg/l
Nitrite plus Nitrate	10. mg/l	10. mg/l
Selenium	0.01 mg/l	0.005 mg/l
Silver	0.05 mg/l	
Sulfate	250. mg/l	
Thallium	0.002 mg/l	
Zinc	5.0 mg/l	0.072 mg/l

No entry in a cell indicates that no limit was found.

Table 1.3 Performance Goals for Organic Compounds [a]

CAS #	Constituent (a)	Groundwater	Surface Waters
56-23-5	Carbon tetrachloride	0.0003 mg/l	0.005 mg/l
67-66-3	Chloroform	0.007 mg/l	
71-43-2	Benzene	0.001 mg/l	0.005 mg/l
71-55-6	1,1,1-Trichloroethane	0.003 mg/l	0.2 mg/l
75-09-2	Dichloromethane (Methylene Chloride)	0.005 mg/l	0.005 mg/l
79-00-5	1,1,2-Trichloroethane	0.005 mg/l	0.005 mg/l
79-01-6	1,1,2-Trichloroethylene	0.005 mg/l	0.005 mg/l
95-47-6	o-Xylene	0.7 mg/l	0.7 mg/l
100-41-4	Ethyl benzene	0.1 mg/l	0.1 mg/l
106-46-7	1,4-Dichlorobenzene	0.004 mg/l	0.075 mg/l
108-88-3	Toluene	1.0 mg/l	1.0 mg/l
127-18-4	1,1,2,2-Tetrachloroethene	0.005 mg/l	0.005 mg/l

(a) Greater than 100 analytical detects in tank waste or greater than 20 analytical detects in TWINS Solid/Liquid Hits. Taken from Wiemers 1998.

No entry in a cell indicates that no limit was found.

BACKGROUND

To better understand the scenarios selected, some background information is presented for

- the disposal action,
- the Hanford Site,
- the expected future land use.

Only a summary is given here. More information is provided in the *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Mann 1998).

2.1 ILAW Disposal Action

In the 200 Areas of the Hanford there are presently 54 million gallons of high-level radioactive and hazardous waste stored in 177 underground tanks (See Figure 1). These wastes are the by-products of the production of special nuclear material for the U.S. defense effort. The inventory in the underground tanks (Kupfer 1998) for the radionuclides found most important in the 1998 ILAW PA is displayed in Table 2.1.

Table 2.1 Most Important Radionuclides in Tanks (from Kupfer 1998)

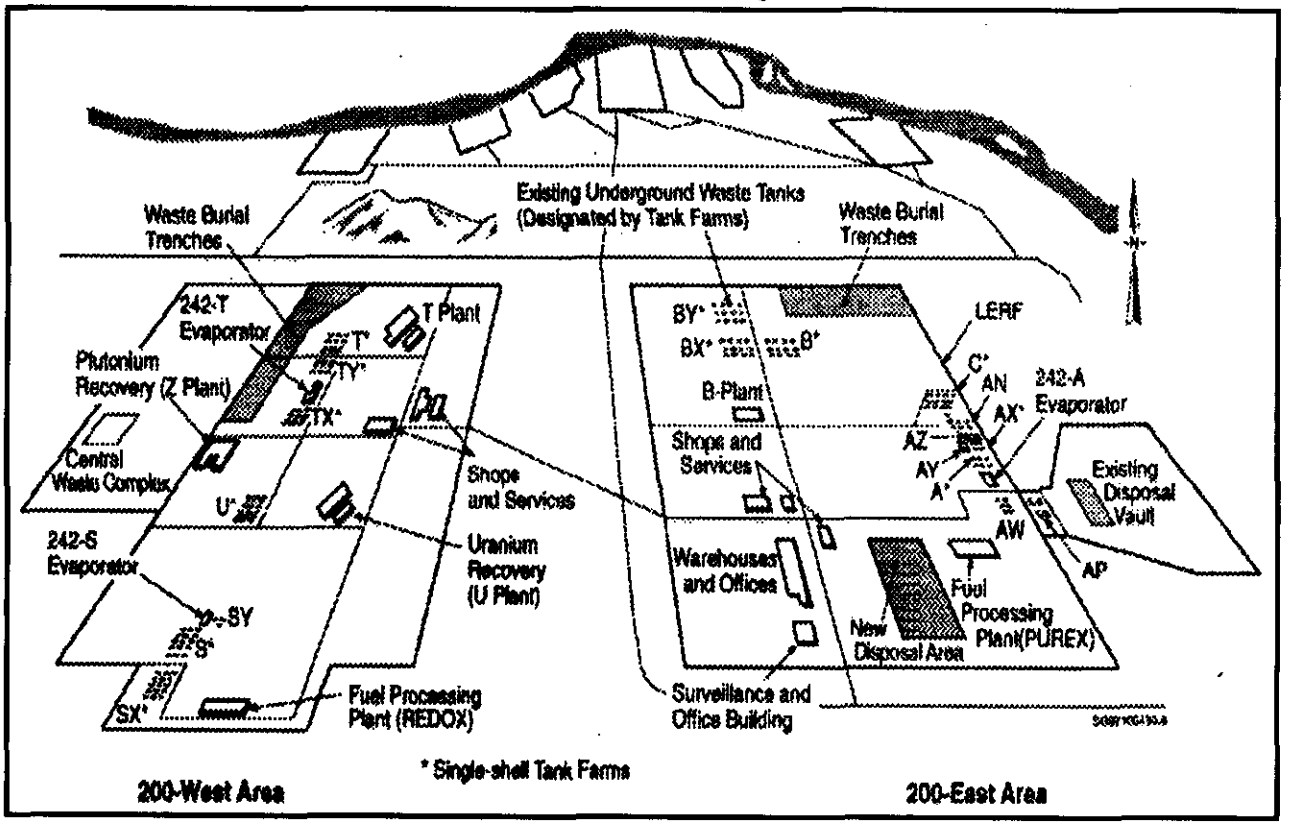
Radionuclide	Amount (Curies) (Decayed to 1/1/1994)
H - 3	34,000
Se- 79	773
Sr - 90	71,600,000
Tc - 99	32,600
Sn- 126	1,190
I - 129	63
Cs -137	46,400,000
U -235	15
U - 238	322
Pu - 239	39,000

Over the next 30 years, it is planned to retrieve the waste from the tanks and separate it into two waste streams, which will then be immobilized (TPA 1996). The high-level waste stream will contain most of the radionuclides. The immobilized high-level waste will be stored at the Hanford Site until it is transferred to a federally licensed geologic repository. The low-activity waste will contain most of the non-radioactive chemical constituents of the tank waste. The immobilized low-activity waste (about 200,000 cubic meters) will be disposed of on site in steel containers.

The Department of Energy (DOE) has entered into a contract with BNFL, Inc. (BNFL/DOE 1998) for tank waste treatment and immobilization services. Vitrification is the required method of immobilization for both the high-level and low-activity waste streams. However, the initial glass formulations have not yet been determined. The ILAW steel containers (about a meter in length in each dimension) are to last a minimum of 50 years. The long-term contaminant release rate is expected to be a few parts per million per year.

The current plans are to dispose of the ILAW containers in large underground concrete vaults (on the order of 20 to 40 meters long by 10 meters wide by 10 meters high). A surface barrier will be placed over the vault with the top of the waste being about 5 meters below the resulting ground surface. Four vaults, constructed as part of the Double-Shell Tank Waste Grout Disposal Program and are located at the eastern edge of the 200 East Area, could store about 4% of the ILAW. The remaining waste is planned to be disposed in new facilities in the south central part of the 200 East Area (Rutherford 1997) (See Figure 2.1). However, on-going engineering studies may indicate the benefits of other disposal options.

Figure 2.1 Location of the Disposal Vaults

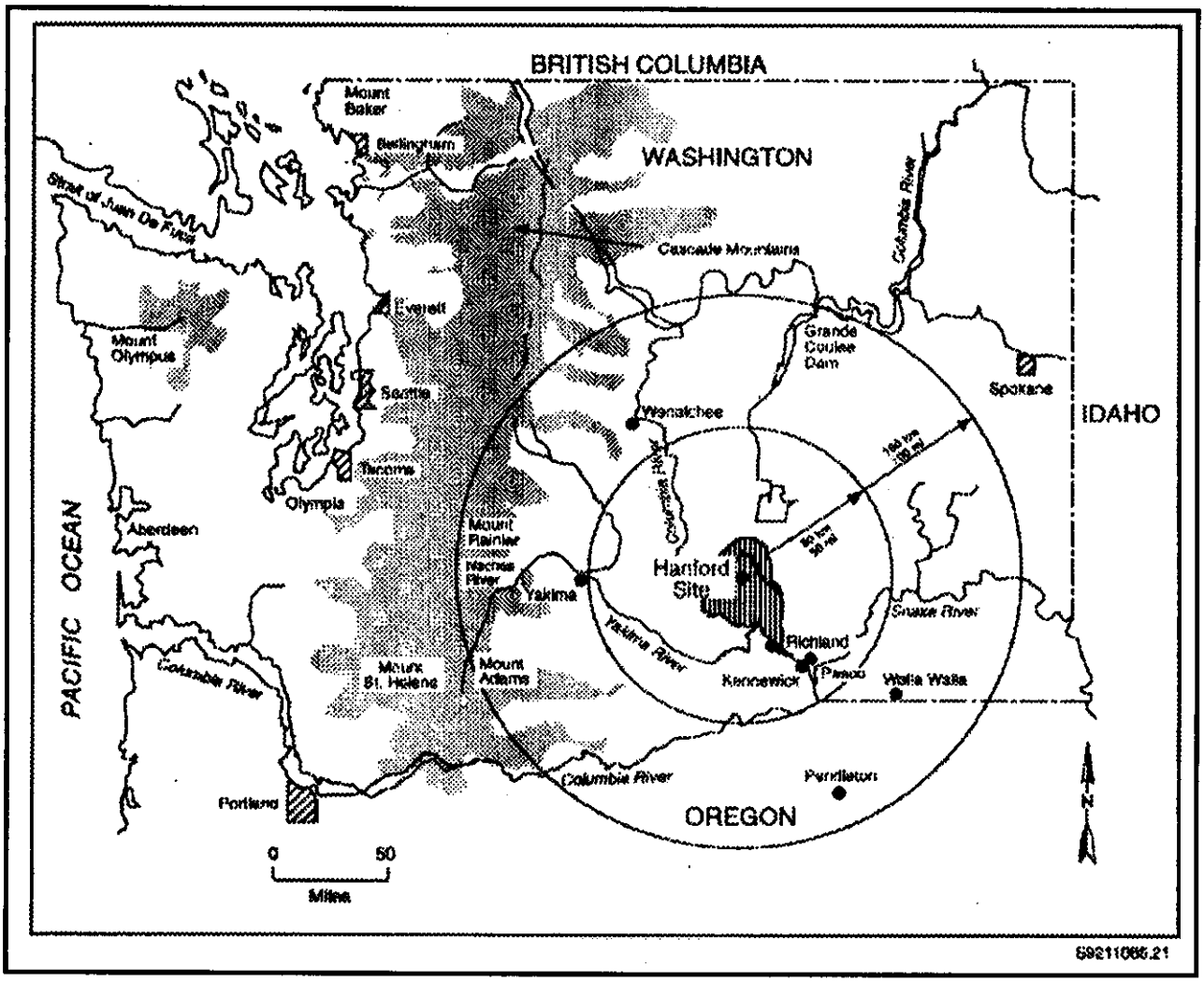


(The four existing disposal vaults are located at the just east of the AP Tank. The new disposal facility is located in the south-central part of the 200 East Area. The tank farms are identified by their letter names, e.g. AP)

2.2 Hanford Site

The Hanford Site is located in south central Washington State (See Figure 2.). Because this site lies in the rain shadow of the Cascade Mountains, there is little precipitation most of which is removed from the soil by evaporation and plant transpiration. Thus, the Hanford Site is characterized by having a very small average moisture infiltration rate to the water table.

Figure 2.2 Location of the Hanford Site



The Hanford Site lies in the Pasco Basin of the Columbia Intermontane Province. This province is the product of the Miocene continental flood, basalt volcanism, and regional deformation that occurred 6 to 17.5 million years ago. Glacier-related flooding has had a major impact on the physical geography. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington. The last series of major floods occurred about 13,000 years ago, during the late Pleistocene Epoch. Interconnected flood channels, giant current ripples, and giant flood bars are among the landforms created by the floods. These formations resulted in heterogeneous and discontinuous characteristics for sediments ranging in size from silts to coarse gravels.

The top three geologic strata at the disposal site locations (the Holocene deposits, the Hanford formation, and, the Ringold Formation) have important roles in the performance assessment. More details are given in Mann 1998.

During the Holocene Epoch (the last 11,000 years), winds have locally reworked the flood sediments. The winds deposited dune sands in the lower elevation and loess (very fine wind-blown silts) around the margins of the Pasco Basin. Generally, anchoring vegetation has stabilized sand dunes. There is little potential for landslides, flooding, volanicism, or earthquakes at the disposal sites.

The Hanford formation was deposited by the catastrophic ice age flooding. The formation consists of pebble-to-boulder sized gravel, fine- to coarse-grained sand, and silt. It can be divided into two main facies: coarse-grained or gravelly deposits and fine-grained or sandy and silty deposits. The gravelly facies consists of coarse-grained sand and granule-to-boulder sized gravel. These gravels often lack matrix material and have an open framework appearance. The gravelly facies was deposited by high-energy floodwaters in flood bars and along channelways. The sand and silt facies consist of silt and fine- to coarse-grained sand that commonly display normally graded rhythmites a few centimeters to several tens of centimeters thick in outcrop (Myers 1979, DOE 1988b). These sediments were deposited under slackwater conditions and in backflooded areas (DOE 1988b). Clastic dikes are vertical features occasionally seen in the Hanford formation. In clastic dikes coarser Hanford formation materials surround a vertical hexagonal structure of very-fine grained sand. At the location of the disposal facilities, the Hanford formation is about 90 to 105 m (300 to 345 ft) thick and consists predominantly of sands and gravelly sands. The sandy sequence is interpreted to lie between a slightly gravelly sand and a lower sandy gravel to gravelly sand. The Hanford formation thickens both to the north and south of the site of the new disposal facilities.

The Ringold Formation is assigned to a late Miocene to Pliocene age (Fecht 1987, DOE 1988b) and consists of clay, silt, compacted mud, fine- to coarse-grained sand, and granular to cobble gravel. In general, it tends to be finer-grained, or siltier, in the upper parts just below the Hanford formation. At the existing vaults site, the Ringold Formation starts about 90 meters (300 feet) below the unperturbed surface. At this location, the Ringold Formation is about 25 to 32 meters (82 to 105 feet) thick. At the site of the new disposal facilities, the Formation begins at about 100 meters (330 feet) and is about 30 to 38 meters (100

to 125 feet) thick. In both cases the Ringold Formation lies atop the Columbia River Basalt Group.

2.3 Future Land Use

In 1992, DOE, EPA, and Ecology gathered a group of stakeholders to study future land use of the Hanford Site. This Hanford Future Site Uses Working Group issued a summary (HFSUWG 1992a) and a detailed report (HFSUWG 1992b) of its findings. The draft *Hanford Remediation Action Environmental Impact Statement and Comprehensive Land Use Plan* (DOE 1996) is heavily based on the work of the Hanford Future Site Uses Working Group. However, DOE's land use planning extends for only 50 years instead of the 100 years forecast by the working group.

HFSUWG (1992a) contains the following statement about near-term use of the 200 Areas, called the Central Plateau in the report.

> "The presence of many different types of radionuclides and hazardous constituents in various forms and combinations throughout the site poses a key challenge to the Hanford cleanup. To facilitate cleanup of the rest of the site, wastes from throughout the Hanford site should be concentrated in the Central Plateau...Waste storage, treatment, and disposal activities in the Central Plateau should be concentrated within this area as well, whenever feasible, to minimize the amount of land devoted to, or contaminated by, waste management activities. This principle of minimizing land used for waste management should specifically be considered in imminent near-term decisions about utilizing additional uncontaminated Central Plateau lands for permanent disposal of grout."

The report continues on the subject of future use options (HFSUWG 1992a),

> "In general, the Working Group desires that the overall cleanup criteria for the Central Plateau should enable general usage of the land and groundwater for other than waste management activities in the horizon of 100 years from the decommissioning of waste management facilities and closure of waste disposal areas."

Based on conversations of the working group, no definition of "general use" could be agreed on. For the "foreseeable future" the working group developed options involving waste treatment, storage, and disposal of DOE low-level radioactive waste. The differences among the options are whether offsite waste (radioactive and/or hazardous) would be allowed to be disposed of on the Hanford Site.

Finally (HFSUWG 1992a),

> "The working group identified a single cleanup scenario for the Central Plateau. This scenario assumes that future uses of the surface, subsurface and groundwater in and immediately surrounding the 200 West and 200 East Areas would be exclusive...Surrounding the exclusive area would be a temporary surface and subsurface exclusive buffer zone composed of at least the rest of the Central Plateau...As the risks from the waste management activities decrease, it is expected that the buffer zone would shrink commensurately."

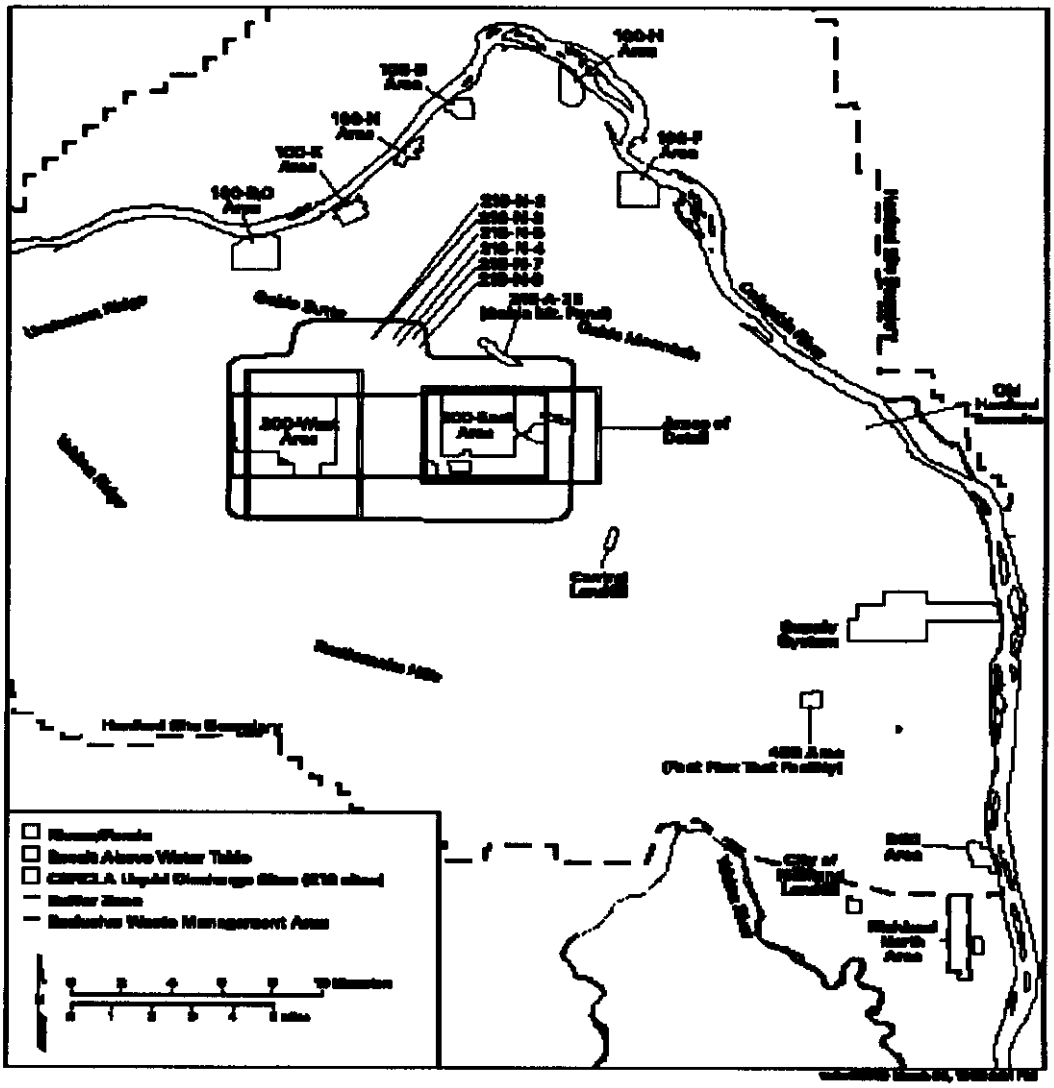
For nearer term land use planning, as part of the Washington State Growth Management Act of 1991, Benton County is identifying land uses for the Hanford Site. This plan treats the 200 Areas as industrial areas surrounded by "critical areas." By state law, "critical areas" are defined as land to be protected from use because of wildlife habitat or geologic or environmental conditions. Only the following areas were found suitable for development:

> The McGee Ranch area to the northwest of the 200 West Area (at least 6 km [4 mi] away), where farming would be allowed
>
> The area to the east of the 200 East Area (a minimum of 5 km [3 mi] away), where research and development activities would be allowed.

However, any formal land use planning is not expected to be accurate over the hundreds to hundreds of thousands of years covered in this analysis.

The future site boundary is shown in Figure 2.3.

Figure 2.3 Location of the Future Site Boundary



3.0 ALL-PATHWAYS AND GROUNDWATER

Previous Hanford Site performance assessments (Kincaid 1995, Mann 1998, Wood 1995, Wood 1996) have shown that the main pathway that results in exposure will involve the following eight steps

1) Precipitation (rain or snow) falls on the ground with much of the water lost to the atmosphere due to evaporation or transpiration through plant leaves. The remaining water infiltrates the soil below the surface at a very low rate.

2) The water moves downward, but some of the water is diverted by any intact sand-gravel capillary barrier.

3) The water that is not diverted away from the waste may be chemically modified by the local environment, interacts with the waste form, and accumulates contaminants.

4) The water (possibly a reduced amount because waste form dissolution and mineral formation consumes water) leaves the disposal facility carrying contaminants with it. Some contaminants may interact with the material in the disposal facility, slowing the release of contaminants to the surrounding natural environment.

5) Contaminated water moves through the undisturbed, unsaturated zone (vadose zone) below the disposal facility down to the unconfined aquifer. The contaminants may interact with soil sediments causing further retardation. Changes to the properties of the natural system are considered, but are not major.

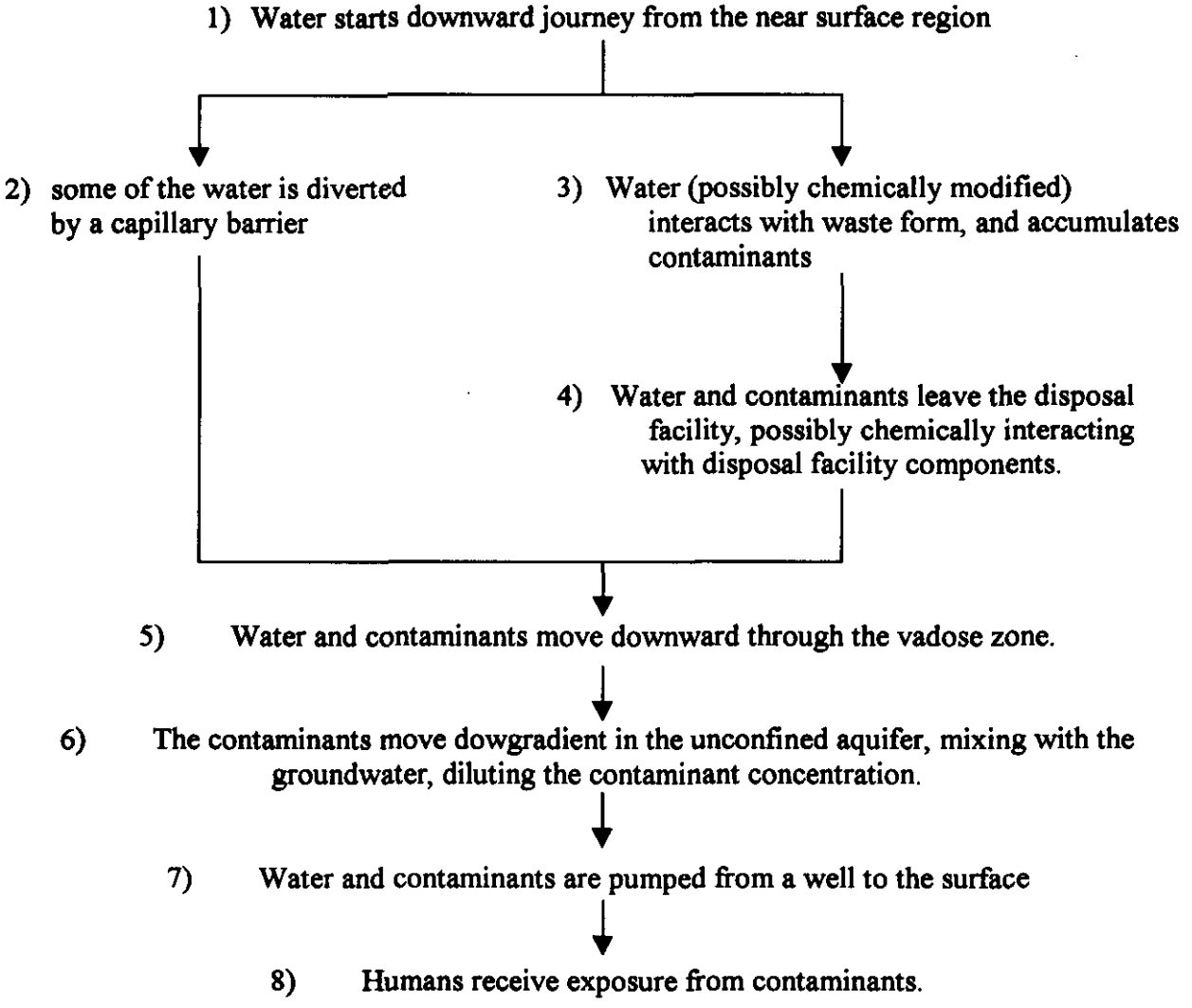
6) The water and contaminants move and mix with the water in the unconfined aquifer until they are extracted from the aquifer and brought to the surface or until they reach the Columbia River.

7) Contaminants are extracted by being carried to the surface with groundwater being pumped through a well.

8) The contaminants result in human exposure through a variety of exposure pathways (ingestion, inhalation, dermal contact, and external radiation).

Figure 3.1 shows these eight steps (which remain unchanged from the previous ILAW PA) as a flow chart.

Figure 3.1 Sequential Steps for Groundwater Pathway



3.1 Base Case

3.1.1 General Description

The general description of the base case scenario is the one described immediately above and displayed in Figure 3.1. Explicit numerical simulations will be performed from the present to 100,000 years in the future using best-estimate values for all parameters. Such extended calculations are required because of the overlapping in time of the various contaminant plumes. The 1998 ILAW PA (Mann 1998) showed that the second most mobile radionuclides (such as uranium and its daughters) peaked at about 50,000 years, a time at which the most mobile radionuclides (technetium, selenium, and many chemicals) were still significant. Comparisons to the performance objectives will be made at 1,000 years and at 10,000 years after closure of the ILAW disposal facility (which is assumed to be in 2030).

Details for important categories of information are in the following subsections. Sections 3.2 through 3.5 contain the uncertainty, sensitivity, and reasonably bounding cases.

3.1.2 End State

The Department of Energy intends to retain the 200 Areas as long as necessary to protect human health (DOE 1996). Nonetheless, the new DOE Order on radioactive waste management (DOE 1999a) requires that the compliance point be the point of maximum exposure not nearer than 100 meters downgradient. Calculations of contaminant transport will determine the point of maximum exposure. Calculations will also be performed at the future site boundary as well as near the Columbia River. The calculations will consider the spatial overlap of the two disposal locations, but will not consider the overlap with other Hanford Site activities. The *Composite Analysis for the Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (Kincaid 1998 and revisions) calculates the effect of any overlap with other Hanford Site actions.

Scattered residential farms are assumed. Much of the area surrounding the Hanford Site contains irrigated farming sites. However, because of the low groundwater flow, because of the large vertical and horizontal distances from the Columbia River, and because of the difficulty to obtain water rights (Prosser 1999), it is unlikely that irrigated farming will occur and thus a dry land farming scenario is assumed. Parameters describing well construction and use will be taken from *Future Hanford Site Farming Scenarios* (Prosser 1999).

3.1.3 Engineered Facility

Immobilized low-activity waste is planned to be disposed at the two locations stated in Chapter 2. At each location, the waste will be disposed in subsurface concrete vaults that are topped by surface barriers designed to reduce water infiltration. The important parameters in modeling moisture flow, contaminant release, and contaminant transport at the disposal facility location are the elements of the disposal facility design governing moisture flow, the amount of

water entering the facility (the infiltration rate), how the water moves in the facility (hydraulic processes and properties), and how contaminants interact with the disposal structure (geochemical processes and parameters).

Only conceptual models for the disposal facilities (FDNW 1998a, FDNW 1998b) are available. The parameters to be used to describe the disposal facility in the modeling shall be taken from *Disposal Facility Parameters to be Used in the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (Puigh 1999) which is based on these conceptual models.

The infiltration rate through the surface barrier will be taken from the *Recharge Data Package for the Immobilized Low-Activity Tank Waste 2001 Performance Assessment* (Fayer 1999). These estimates will be based on long-term lysimeter measurements, measurements of Cl and ^{36}Cl tracers, and detailed modeling of surface barriers. Values will be a function of space (under the surface barrier, near the barrier, and far from the barrier) and of time (intact and degraded surface barriers).

Hydraulic properties for the materials in the engineered facilities will be taken from the *Near-Field Hydrology Data Package for thee Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999). The properties will be based on both existing literature and laboratory measurements including some laboratory measurements as a function of pH. Both advection and diffusion are considered. Degradation of the components of the engineered system will be accounted for by varying the hydraulic parameters as a function of time.

Chemical parameters will be taken from *Geochemical Data Package for the Hanford Low-Activity Tank Waste Performance Assessment* (Kaplan 1999). The properties will be based on, in part, laboratory measurements of geochemical reactions as a function of pH and ionic strength. Time-dependent effects will be explicitly considered in many of the performance assessment calculations.

3.1.4 Inventory

Impacts to the receptor are directly proportional to the inventory of key contaminants (e.g. ^{99}Tc). There will be a different inventory in the various ILAW packages as there is a significant variation in the waste in the various Hanford single- and double-shell tanks. ILAW package inventories will be taken from the *Immobilized Low-Activity Tank Waste Inventory Data Package* (Wootan 1999) which will be based on the best basis global and tank-by-tank inventories of the TWRS Characterization Program (Kupfer 1998) and on chemical separation efficiencies of the BNFL, INC. treatment process. The estimate will also reflect maximum concentrations required by NRC Class limits (10 CFR 61), by RCRA restrictions (10 CFR 261, 10 CFR 264, 10 CFR 269, and WAC 173-303), and by the contract between BNFL, Inc. and DOE (BNFL/DOE 1998). It is assumed that these requirements will not change with time. Inventories of hazardous materials that are part of the engineered disposal facility will be identified in *Disposal Facility Parameters to be Used in the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (Puigh 1999).

3.1.5 Immobilized Low-Activity Waste

Based on the results of the previous ILAW PA (Mann 1998), the release rate from the waste form is a critical parameter. Such release rates depend on the waste form, the surrounding moisture content, the presence of key compounds (e.g. silic acid and secondary phases), as well as other environmental conditions (e.g. pH). Thus the release rate will depend on both the location of the waste form in the facility and will vary with time.

The waste form calculations will not only represent the initial release of contaminants from the glass, but also how the contaminants interact with secondary phases and with components of the engineered system. The calculations will also determine the amount of water consumed during these reactions.

Waste Form Release Data Package for the 2001 Immobilized Low-Activity Tank Waste Performance Assessment (McGrail 1999) will provide the data for calculating glass matrix dissolution, for the release of sodium from the glass matrix through ion exchange reactions, and for the creation and destruction of secondary phases. Such data are based on extensive experiments performed by both Argonne and Pacific Northwest National Laboratories following the research strategy contained in *A Strategy to Conduct an Analysis of the Long-Term Performance of Low-Activity Waste Glass in a Shallow Subsurface Disposal System at Hanford* (McGrail 1998). These experiments include the Product Consistency Test (PCT), Pressurized Unsaturated Flow (PUF) test, Single Pass Flow Through (SPFT) test, and Vapor Hydration Test (VHT).

The incoming moisture flow will come from simulations of the engineered system. Hydraulic parameters for filler material and the degraded waste form will come from the *Near-Field Hydrology Data Package for thee Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999). The chemical interactions between the contaminants and the engineered materials are documented in Kaplan 1999. Impurities in the water entering the waste zone will be explicitly calculated.

3.1.6 Geotechnical Data

Transport in the vadose zone provides a significant delay in the time required before released contaminants will reach the biosphere. Transport in the groundwater further dilutes the contaminants. Although the underlying parameters in these models do not change with time as these parameters describe the properties of a stable system, vadose zone and groundwater calculations are time-dependent because the boundary conditions (recharge, groundwater inflow, and contaminant inflow) do change with time.

Inputs of moisture flow and contaminant release come from the engineered system moisture flow and from the waste form calculations. Hydraulic parameters for the vadose zone will come from the *Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment* (Khaleel 1999). The chemical interactions between the contaminants and the vadose zone soil sediments are documented in Kaplan 1999. Both the

geohydrologic and the geochemical parameters are derived from site-specific subsurface samples as well as other Hanford Site samples, corrected for upscaling from laboratory-size measurements to field-scale use. The hydraulic and geochemical data are expected to depend on the startigraphic strata. The strata will be defined in the *Geologic Data Package for 2001 Immobilized Low-Activity Tank Waste Performance Assessment* (Reidel 1999).

The contaminant flux from the vadose zone will be fed into the groundwater calculations. The Hanford Site is developing a site wide aquifer model for calculating groundwater flow and contaminant transport for impact assessments. The aquifer model and its associated database will be used for the groundwater calculations.

3.1.7 Receptor

As noted in section 3.1.2, a dry land residential farming scenario is assumed. Parameters for such a farming scenario will be taken from *Future Hanford Site Farming Scenarios* (Prosser 1999). Dosimetry parameters will follow standard Hanford Site practices (DOE 1995) and will be taken from *Data and Assumptions for Estimates of Radiation Doses for the Immobilized Low-Activity Hanford Tank Waste Performance Assessment* (Rittmann 1999).

3.2 ALARA Cases

The DOE Orders on Radioactive Waste Management (DOE 1988a and DOE 1999a) require that sensitivity calculations be performed to show that the design for the disposal action achieves impacts that are as low as reasonably achievable (ALARA). This version of the ILAW PA will analyze three areas:

- Facility design
- Inventory
- Waste Form.

The ALARA cases will also determine the effect on impacts from the uncertainty of key parameters in these three areas.

3.2.1 Facility Design

As noted in subsection 3.1.3, only conceptual designs (FDNW 1998a, FDNW 1998b) are available for the disposal facilities. Therefore, a major goal of the performance assessment is that the results of the PA will be used to optimize the disposal facility design. Sensitivity cases will be taken from *Disposal Facility Parameters to be Used in the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (Puigh 1999), the *Recharge Data Package for the Immobilized Low-Activity Tank Waste 2001 Performance Assessment* (Fayer 1999), the *Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999), and the *Geochemical Data Package for the Hanford Low-Activity Tank Waste Performance Assessment* (Kaplan 1999). Among the items to be investigated are

- different surface barriers
- presence of hydraulic diverters (both horizontal and vertical)
- different filler materials between the ILAW packages and between the ILAW packages and the disposal structure
- different material degradation rates
- subsidence of the ILAW packages
- different facility layouts.

3.2.2 Inventory

The uncertainty of the inventory of ILAW packages in a disposal facility arises from

- uncertainty in the inventory of each tank (and in the global inventory)
- uncertainty in the order in which the waste will be retrieved from the tanks
- uncertainty in how BNFL, Inc. will treat the waste (i.e. separate tank waste into low-activity and high-level fractions and how much waste will go into the product).

Uncertainty cases will be based on the uncertainty data presented in the *Immobilized Low-Activity Tank Waste Inventory Data Package* (Wootan 1999). The emphasis will be on contaminants (such as Tc) with the greatest impacts and on processes (such as off-site transfers and waste treatment) that have large impacts and are most susceptible to modification.

3.2.3 Waste Form

BNFL, Inc. has not yet determined the waste form that will be used during production. Uncertainty cases will be taken from *Parameters for the Calculation of Waste Form Release for the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (McGrail 1999). The emphasis will be on different waste form formulations, waste loadings, and cooling rates as well as uncertainty in extrapolating laboratory measurements to long-term performance.

3.3 Uncertainty Cases

3.3.1 Geotechnical Alternatives

Our understanding of the vadose zone and the unconfined aquifer is incomplete. The uncertainty in vadose zone parameters will be taken the *Geologic Properties for the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (Reidel 1999), the *Estimated Hydrologic Properties for the 2001 Hanford Low-Activity Tank Waste Performance Assessment* (Khaleel 1999), and the *Geochemical Data Package for the Hanford Low-Activity Tank Waste Performance Assessment* (Kaplan 1999). Key parameters to be investigated include hydraulic properties, diffusion parameters, dispersion parameters, chemical retardation parameters, and initial moisture conditions. Uncertainty cases in groundwater modeling will be defined in consultation with the Hanford Site Consolidated Groundwater Program.

3.3.2 Different Future End States

The future is by its nature quite uncertain. Therefore general conditions will be varied. Irrigation will be considered in various parts of the Hanford Site. In particular, irrigation over the disposal site shall be investigated. Other differences that are likely to be investigated include different well parameters.

3.3.3 Different Receptor Scenarios

Predicting future human activities is quite uncertain. Uncertainty cases will be taken from the *Future Hanford Site Farming Scenarios* (Prosser 1999) and from the *Data and Assumptions for Estimates of Radiation Doses for the Immobilized Low-Activity Hanford Tank Waste Performance Assessment* (Rittmann 1999). In particular, Prosser 1999 will provide uncertainties in well parameters, while Rittmann 1999 will provide uncertainties in dosimetry conversion factors. Rittmann 1999 will also provide alternative receptor scenarios, including Native American and industrial work scenarios.

4.0 ATMOSPHERIC RELEASES

The previous performance assessment (Mann 1998) showed that using conservative assumptions that releases to the atmosphere are many orders of magnitude (four in the case of radon releases and nine for other gases) less than performance objectives.

The release rate of gases from the waste form will be taken as the same as the dissolution rate of the glass (see subsection 3.1.5). The gases would then diffuse up through the disposal facility without taking credit for any intact-engineered barriers (such as metal containers or concrete structures). Diffusion parameters will be taken from the *Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999).

5.0 INADVERTENT INTRUDER

Following the practice of the Nuclear Regulatory Commission (NRC 1998, NRC 1997), three scenarios were considered:

- A basement is excavated which extends into the waste and hence contaminants are brought to the surface
- A well is drilled through the waste, bringing contaminants to the surface,
- Contaminants that have been brought to the surface are mixed with the surrounding soil as a residential farmer works the soil.

Because the waste will be below (> 5 meters) the levels that basement excavations are dug in the Columbia Basin region, the first scenario (basement excavation) is not treated. The other two scenarios are treated.

5.1 Drilling

A likely occurrence is that a borehole will be drilled in order to obtained water either from the unconfined aquifer or, more likely, from the more voluminous confined aquifer. Because of the large gravels underlying the Hanford Site, robust drilling tools are likely to be used. Well parameters are taken from the *Future Hanford Site Farming Scenarios* (Prosser 1999). Exposure parameters are taken from the *Data and Assumptions for Estimates of Radiation Doses for the Immobilized Low-Activity Hanford Tank Waste Performance Assessment* (Rittmann 1999). No credit is taken that the driller would recognize that large blocks of glass would be brought to the surface (an unnatural occurrence). It is assumed that drilling fractures the waste form into rock-size chunks, consistent with that typically produced by ordinary drilling techniques.

5.2 Residential Farmer

After the driller leaves, with the contaminated soil still present, a residential farmer with his family occupies the land. The family is exposed to contaminants by direct irradiation from the soil, and by eating crops and animals raised on the contaminated soil. Use of contaminated groundwater is not considered as part of this scenario (because following DOE guidance for DOE O 435.1 the intruder and all-pathways scenarios are separated) as it is considered under the all pathways/groundwater scenarios. Again, credit is taken that the waste form brought to the surface will still be coarsely divided.

5.3 Uncertainty Cases

Uncertainty cases will be based on uncertainties developed in the *Future Hanford Site Farming Scenarios* (Prosser 1999) and the *Data and Assumptions for Estimates of Radiation Doses for the Immobilized Low-Activity Hanford Tank Waste Performance Assessment* (Rittmann 1999). Cases that will be included will be the volume of waste taken from the disposal facility, the type of contaminants in that volume, how intact the retrieved waste form is, and the various exposure scenarios.

6.0 PUBLIC INVOLVEMENT

It is important that Hanford stakeholders have the opportunity to affect the scenarios analyzed in the ILAW performance assessment. Public comments were requested on the original version of this document (Mann 1994) as well as revision 2 (Mann 1999b).

A summary of the initial version of the scenarios was sent to each member and alternate of the Hanford Advisory Board, to selected Hanford Site contractor employees, and to selected members of the DOE's Peer Review Panel and Performance Assessment Task Team. Their comments and corresponding responses to the previous version of this document are available for review (Murkowski 1995).

Revision 2 of this document was made available for public review following the public involvement procedures established by the Hanford Groundwater / Vadose Zone Integration Project (that is, announcements were made at biweekly meetings, the review period was noted on the published list of Integration Project activities, and the documents were available on the Integration Project's web site). Only the Oregon Office of Energy submitted comments (Blazek 1999) and these mainly dealt with waste classification, the extent of public announcement, and other general program activities. Because of the nature of the comments, no changes were made to revision 2 based on these comments. The comments from the Oregon Office of Energy as well as the responses (Taylor 1999) to them by the Department of Energy's Office of River Protection are available on request.

Comments on this version of the document should be sent to:

Frederick M. Mann
Fluor Daniel Northwest
Mail Stop H0-22
Post Office Box 1050
Richland, Washington 99352

Since calculations for the performance assessment will begin in October 1999, to be effective the comments should be sent as soon as possible.

7.0 REFERENCES

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- Subpart C, "Performance Objectives," Sections 40 through 44.
- Subpart D, "Technical Requirements for Land Disposal Facilities," Sections 50 through 59.

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- Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities, Section 92.
- Subpart Q, "National Emission Standards for Radon Emissions from Department of Energy Facilities," Section 192.

40 CFR 141, "National Primary Drinking Water Regulations," 40 CFR 141, U.S. Environmental Protection Agency, Washington, D.C. December 24, 1975.

- Subpart B, "Maximum Contaminant Levels," Sections 11 through 16.
- Subpart G, "National Revised Primary Drinking Water Regulations: Maximum Contaminant Levels," Part 60 to 63.

40 CFR 261, "Identification and Listing of Hazardous Waste, "U. S. Environmental Protection Agency, Washington, D.C., August 31, 1993.

- Subpart B, "Criteria for Identifying the Characteristics of Hazardous Waste and for Listing Hazardous Waste," Sections 10 and 11.
- Subpart C, "Characteristics of Hazardous Waste," Sections 20 through 24.

40 CFR 264, "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," U.S. Environmental Protection Agency, Washington, D.C., February 16, 1993.

- Subpart F, "Release from Solid Waste Management Units," Sections 90 to 101."

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- Part 1, Section C, Item 2.2.2 contains the Immobilized Low-Activity Waste product requirements.

Code of Federal Regulations. See reference under XX CFR YYY.

DOE Orders

DOE O 435.1, "Radioactive Waste Management," see DOE 1999a.
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DOE Order 5400.5, "Radiation Protection of the Public and the Environmental," see DOE 1993.

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APPENDIX C

Selection of A Computer Code for Hanford Low-Level Waste Engineered-System Performance Assessment

B. P. McGrail
D. H. Bacon

March 1998

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Pacific Northwest National Laboratory
Richland, Washington 99352

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SUMMARY

Planned performance assessments for the proposed disposal of low-activity waste (LAW) glass produced from remediation of wastes stored in underground tanks at Hanford, Washington will require calculations of radionuclide release rates from the subsurface disposal facility. These calculations will be done with the aid of computer codes. The available computer codes with suitable capabilities at the time Revision 0 of this document was prepared were ranked in terms of the feature sets implemented in the code that match a set a physical, chemical, numerical, and functional capabilities needed to assess release rates from the engineered system. The needed capabilities were identified from an analysis of the important physical and chemical processes expected to affect LAW glass corrosion and the mobility of radionuclides. This analysis was repeated in this report but updated to include additional processes that have been found to be important since Revision 0 was issued and to include additional codes that have been released. The highest ranked computer code was found to be the STORM code developed at PNNL for the U.S. Department of Energy for evaluation of arid land disposal sites.

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1.0 INTRODUCTION

The Tri-Party agreement (Ecology 1996) between the State of Washington Department of Ecology, the U.S. Department of Energy (DOE), and the U.S. Environmental Protection Agency (EPA) specifies vitrification as the encapsulation technology for low-activity wastes (LAW). The DOE and its contractors are currently obligated to meet DOE Order 5820.2A on radioactive waste management. However, it is anticipated that DOE Order 435.1 will become the primary regulation governing management and disposal of radioactive waste at DOE facilities. Before the low-activity radioactive waste can be disposed of, DOE-Headquarters must issue a Disposal Authorization Statement to the Richland Operations Office. The issuance of this Disposal Authorization Statement is predicated on many analyses, including a performance assessment, which investigates the ability of the disposal system to provide long-term environmental, public health, and safety protection.

The Hanford Low-Activity Tank Waste Disposal Project currently plans to issue a performance assessment for the disposal facility in 2001. The performance assessment will be based on as much site and materials-specific data as possible to demonstrate a high likelihood that the facility will meet regulatory requirements, and therefore, support a decision to begin construction of vitrification facilities.

Performance assessments for the disposal of Hanford LAW will require calculating radiation dose to a future population as result of any release and transport of radionuclides to the unconfined aquifer located approximately 70 m below the disposal facility. The processes controlling release and transport of radionuclides to the unconfined aquifer are expected to be simulated by using computer models. However, the specific processes to be simulated by computer codes are not well defined because facility design, waste form selection, and data collection needs are currently undecided. However, three major functions will be modeled by computer codes:

1. release of contaminants from the vitrified waste form,
2. transport of those contaminants through the engineered system, and
3. transport through the vadose zone and groundwater.

This document describes the rationale and approach used to select a computer code suitable for simulating major functions 1 and 2. For reasons which are discussed in detail in the following sections, functions 1 and 2 cannot be readily decoupled. As a result, functions 1 and 2 are discussed in this report in combination as an engineered-system release model.

1.1 CODE SELECTION CRITERIA

The following general criteria (Mann 1994) were used to identify codes suitable for modeling engineered-system release:

1. The theoretical framework of the selected computer code shall be based on appropriate scientific principles (for example, conservation of mass, momentum, and energy) and well established engineering equations (for example, Darcy's law and Fick's law).

2. The selected code shall be documented in a technical report and contain descriptions of
   a) model theory, governing equations, and assumptions
   b) computational techniques and algorithms
   c) example applications.

3. The selected code shall be maintained under a software quality management program that assures that modifications and updates are traceable, auditable, and documented. Audits by the Project Hanford Management Contractor (PHMC) and other organizations may occur.

4. The selected code shall allow the use of site- and facility-specific data/standards/guidelines as appropriate. For example, the ability to use site-specific vadose zone parameters is required rather than parameters for a generic soil type.

5. Because some simulations are expected to be conducted for long-time periods (e.g., tens of thousands of years), diagnostic monitoring capability of the simulation during actual run-time or else a restart option as a minimum is required.

The following desirable features were also considered:

1. The selected code should be certified (that is, simulation results compared with field and/or laboratory data) for a system similar to that being modeled.

2. The degree of complexity of the selected code shall be consistent with the quantity and quality of data and the objectives of the computation. Screening calculations and sensitivity analyses should be used to simplify conceptual models and ultimately direct code selection.

3. Computer hardware requirements for the selected code should be consistent with available platforms and be affordable. Compatibility among computing platforms is highly desirable.

4. Proprietary codes should be used only if they provide a distinct advantage over public domain codes; and only if the author(s)/custodian(s) allow inspection and verification of the source code. If a proprietary code is used,

   a) the source code must be made available by lease or purchase to the PHMC and
   b) the executable version must be made available by lease or purchase to interested parties.

5. Consideration must be given to the ease of interfacing code input/output with other codes. The availability of pre- and post-processors should be given adequate consideration in selecting a code.

6. Familiarity with the selected code is also a consideration in light of time and resource constraints.

7. To enhance technical acceptability, the selected code should be generally known and accepted by the user community.

8. To reduce the presence of known bugs, the selected code should be a recent version, preferably the last one that has been fully tested, of a family of codes.

These code selection criteria are based on information from the LAW programs of the DOE (Case 1988) and U.S. Nuclear Regulatory Commission (Kozak 1989), as well as experience gained from submitted DOE radiological performance assessments (WSRC 1992; Kincaid 1993). A summary description of risk-assessment codes at Hanford (DOE/RL 1991) was also used.

1.2 CODE IDENTIFICATION METHODOLOGY

Although the above code selection criteria provide useful guidance for code selection, a methodology is needed to identify suitable codes for engineered-system release calculations. The methodology used in this report consists of 1) identifying model requirements, and 2) critically reviewing the capabilities of existing codes against the model requirements. In identifying model requirements, the best current information on the system geometry and materials under consideration was used to identify those physical and chemical processes that must be simulated in the selected engineered-system release model. Any computer model that met at least 50% of the requirements was included in the set of codes from which the final selection was made. Each computer code was then ranked in accordance with a point ranking system described in the Code Selection section. The intent was to make the code selection process as unbiased as possible, al-

though the authors' opinion as to the importance of a particular process certainly influenced the final ranking.

2.0 MODEL REQUIREMENTS

In this section, the model requirements are described, given the best current information on the design and materials that are under consideration for use in the engineered system.

2.1 SYSTEM DESCRIPTION

Figure 1 gives a schematic illustration of a multi-barrier, engineered-system concept for Hanford LAW. The engineered system is assumed to begin with the water chemistry conditioner (crushed glass) and end at the bottom soil/clay layer. No specific materials have been selected for any of the engineered components depicted in Figure 1, and some of these components may not be included in the final design of the disposal facility. However, Table 1 gives a list of general types of materials that have been considered. By evaluating the important physical and

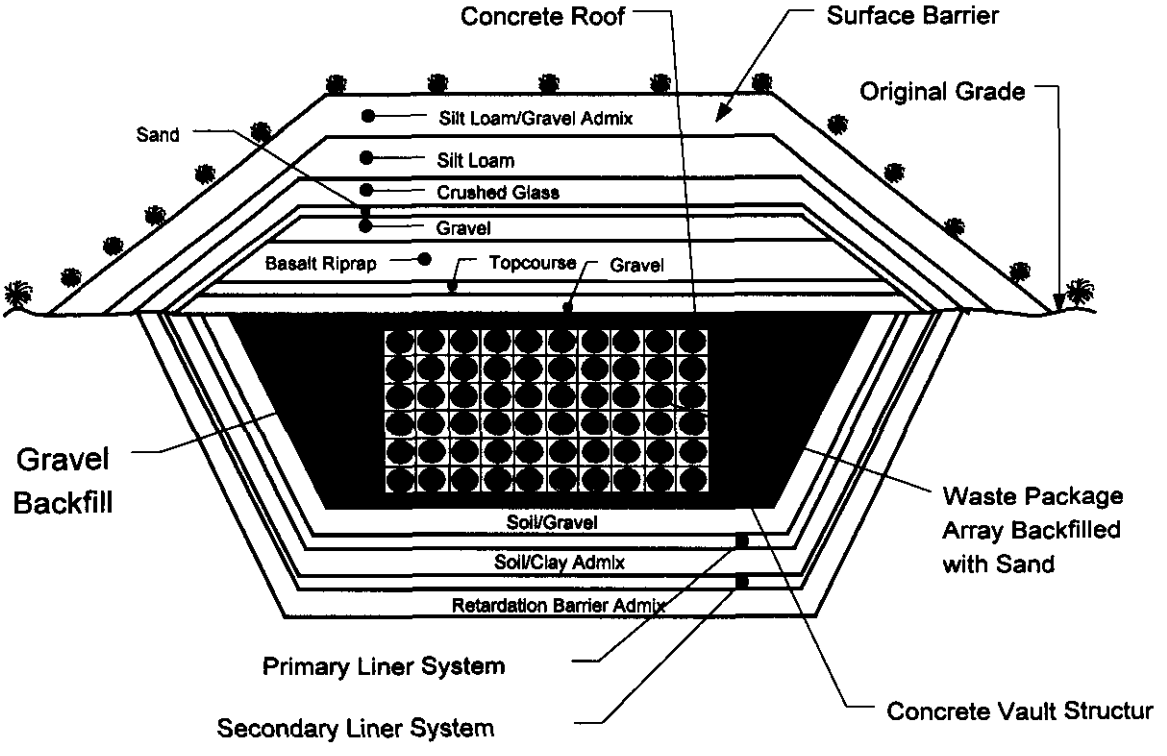

Figure 1. Engineered-System Concept for Hanford LAW

chemical properties of these materials, the important physical and chemical processes that must be modeled in the engineered system can be derived. The important physical processes are discussed in the next section followed by a discussion of the important chemical processes.

Table 1. List of Materials Under Consideration for Engineered-System Components

System Component	Materials
Water chemistry conditioner	Diatomaceous earth Amorphous silica Cristobalite Crushed glass
Vault	Portland concrete Reinforced portland concrete Sulfur polymer concrete
Backfill	Hanford soil Clay and clay-soil mixtures
Container	Carbon steel Stainless steel
Glass	Aluminosilicate Soda-lime silicate Borosilicate Phosphate
Retardation barrier	Iron metal-soil mixture Zeolites

2.2 PHYSICAL PROCESSES

Neglecting physical intrusion or a catastrophic event such as volcanism or meteor impact, radionuclide release from the engineered system can only occur by mass transport processes. Solid-state diffusion can be neglected because it is extremely slow at expected soil temperature (<25°C), and therefore, would contribute vanishingly small mass flux from the engineered system. The principal processes to be considered are therefore aqueous- and gas-phase mass transport.

2.2.1 Aqueous Phase Mass Transport

With the exception of the glass waste form and steel container, the materials being considered for the LAW engineered system are porous materials. Aqueous transport through porous materials has, traditionally, been treated with concepts derived from continuum mechanics. By averaging microscopic variations in the properties of the porous material over a representative elementary volume (REV), macroscopic properties for the REV are derived. Using the macroscopic properties of the REV and the fundamental principle of conservation of mass, the following equation can be derived:

$$\frac{\partial \theta_l c_l^i}{\partial t} = -\nabla \cdot \mathbf{q}_l^i + \theta_l \rho_l R_l^i + \dot{m}_l^i, \quad i = 1,2,...N_l \tag{1}$$

where c_l^i = aqueous concentration of component i, g/m^3

$\dot{m}_l^i$ = total mass source or sink rate of component i, g/m^3·s

N_l = number of aqueous components

$\mathbf{q}_l^i$ = total flux of component i, g/m^2·s

R_l^i = rate of production or consumption of i due to chemical reactions, g/g$_l$·s

θ_l = volumetric water content

ρ_l = fluid density, g/m^3.

If it is assumed that the phenomena of hydrodynamic dispersion in the REV can be represented by a Fickian type law, then the total flux due to advection, dispersion, and diffusion is given by

$$\mathbf{q}_l^i = \theta_l (c_l^i \mathbf{V} - \mathbf{D}_l(\theta_l) \cdot \nabla c_l^i). \tag{2}$$

where $\mathbf{D}_l$ = hydrodynamic dispersion tensor, m^2/s

$\mathbf{V}$ = fluid velocity vector, m/s.

Substituting Equation (2) into Equation (1), ones arrives at

$$\frac{\partial \theta_l c_l^i}{\partial t} = \nabla \cdot \theta_l \mathbf{D}_l(\theta_l) \cdot \nabla c_l^i - \nabla \cdot \theta_l c_l^i \mathbf{V} + \theta_l \rho_l R_l^i + \dot{m}_l^i, \quad i = 1,2,...N_l \tag{3}$$

which is commonly known as the advection-dispersion equation. The solution to Equation (3), in various forms, is the basis for almost every subsurface transport code that has been developed to date.

In principle, Equation (3) should be applicable for analyzing radionuclide release from the engineered system. However, Equation (3) may not be an adequate model for glass waste. Depending on the size of the waste glass logs and the degree of stress fracturing induced during cooling, the concept of an REV may break down. However, if the degree of fracturing is sufficiently dense, the glass may be treated as an equivalent nonfractured continuum (Berkowitz, Bear, and Braester 1988) or by a dual porosity model (Rowe and Booker 1990), and Equation (3) may be applicable. However, if the fracturing is discrete, then an alternative mathematical treatment of transport along the fractures must be developed. For the code selection, it will be assumed that the glass can be treated with an equivalent continuum model so that codes with the capability of solving a form of Equation (3) are all that is required.

2.2.2 Gas Phase Mass Transport

The radionuclides incorporated in a silicate-based glass product have a low vapor pressure under disposal system conditions; therefore, gas-phase transport can be neglected for these species. However, gas-phase transport will be an important consideration when modeling chemical processes in the engineered system and must be considered in the engineered-system code. For example, dissolved O_2 may be consumed/produced from oxidation/reduction reactions that occur with the steel container and rebar used in the concrete vaults. These oxidation/reduction reactions can have a very large effect on the solubility (and hence release) of radionuclides like ^{99}Tc.

Gas phase mass transport is treated in much the same way as the development of the aqueous phase transport Equation (3). Gas phase transport can occur through the gas phase and as a dissolved component in the aqueous phase. Assuming Darcy's law applies for the advective transport, and a Fickian type law for the dispersive transport, the gas phase conservation equation is

$$\frac{\partial \theta_g c_g^i}{\partial t} = \nabla \cdot \theta_g \mathbf{D}_g(\theta_g) \cdot \nabla c_g^i + \nabla \left[\frac{\tilde{k} k_g c_g^i}{\mu_g} (\nabla P_g + \rho_g \mathbf{g} \nabla z) \right] + \theta_g \rho_g^i R_g^i + \dot{m}_g^i, i = 1,2,...N_g \quad (4)$$

where c_g^i = concentration of gas phase component *i*, g/m^3

$\mathbf{D}_g$ = gas dispersion tensor, m^2/s

$\mathbf{g}$ = gravitational constant, m/s^2

$\tilde{k}$ = intrinsic permeability tensor, m^2

k_g = relative gas phase permeability

$\dot{m}_g^i$ = total mass source or sink rate of gas component *i*, g/m^3·s

N_g = number of gas components

P_g = total gas phase pressure, Pa

R_g^i = rate of production or consumption of *i* due to chemical reactions, g/g$_g$·s

z = elevation, m

μ_g = gas phase dynamic viscosity, Pa·s

θ_g = volumetric gas content

ρ_g = gas phase density, g/m^3.

The same caveats regarding the applicability of the REV concept discussed in Section 2.2.1 apply to the solution of Equation (4). Equation (3) for aqueous component transport and Equation (4) for gas component transport are coupled through the terms R_l^i and R_g^i, which account for interphase (gas-water) chemical reactions.

2.2.3 Fluid Flow

Water flow in the near-surface unsaturated zone is transient because of intermittent precipitation events. Transient water flow begins with the entry of water at the ground surface and subsequent infiltration downward into the disposal facility. The rate of infiltration into the facility is controlled by the rate and duration of water application at the surface, the hydraulic conductivity of engineered barriers, the vault, and surrounding soil, and the matric and gravity potential gradients. At some distance from the ground surface, transient effects will dampen out and the downward flowing water will reach a steady infiltration rate. The distance at which steady infiltration occurs is sometimes referred to as the penetration depth (Eagleson 1978; Salvucci 1993). Thus, the unsaturated zone essentially comprises two regions: an unsteady-flow region between the ground surface and penetration depth, and a steady-flow region between the penetration depth and the saturated zone water table. The steady flux in the lower unsaturated region is equal to the

annual rate of ground-water recharge, and therefore, comprises contributions not only from the most recent pulse, but from previous precipitation events as well. Given expected recharge rates for the Hanford Site, the disposal facility will be situated below the penetration depth in the region of steady flow.

Assuming, once again, that the concept of a REV applies and that Darcy's law is valid for modeling fluid flow through the engineered system, a water mass conservation equation can be derived

$$\frac{\partial \rho_l \theta_l}{\partial t} = \nabla \left[\frac{\tilde{k} k_l(\theta_l) \rho_l}{\mu_l} (\nabla P_l + \rho_l \mathbf{g} \nabla z) \right] + \theta_l \rho_l R_l + \dot{m}_l \qquad (5)$$

where k_l = relative water permeability
P_l = liquid phase pressure, Pa
R_l = rate of water consumption due to all chemical reactions, $g_w/g_l \cdot s$
$\dot{m}_l$ = total mass source or sink rate of fluid, $g/m^3 \cdot s$
μ_l = liquid phase dynamic viscosity, Pa·s.

The need to solve the fluid mass conservation Equation (5) in the engineered-system simulator is dependent on

1. assumptions regarding the effects of mass transport and chemical reactions on the properties of the engineered components, such as porosity and permeability
2. assumptions regarding the influence of chemical reactions on the water mass balance, i.e., moisture content.

If it is assumed that mass transport and chemical reactions have a negligible impact on the properties and moisture content of the engineered system, then there is no need to solve Equation (5) in the engineered-system simulator. The flow field can be calculated from any number of codes capable of simulating unsaturated flow. However, because chemical reactions are likely to play a significant role in altering the properties of the engineered-system components and in consuming/releasing water, the preferred engineered-system code would include the capability for solving the water mass conservation equation (5). Because the unsaturated hydraulic conductivity varies as a function of moisture content and particle size distribution in porous media, the ability to define different functions describing the moisture characteristic curves (e.g., van Genuchten,

1980) for each subsurface material is critical. An accurate evaluation of Equation (5) would also require a means to estimate the change in the water permeability function (k_l) as the distribution of solids change as a function of time. This could be done with an empirical function or weighted sum for the major mineral phases affecting k_l.

2.2.4 Heat Transport

The process of radioactive decay generates heat in a solid due to the energy loss associated with the interactions of the emitted charged particles or photons with the atoms in the solid and the energy loss associated with collisions from the recoiling nucleus. Because of the long half-life and small concentration of radionuclides in LAW, the increase in temperature of the engineered system over ambient conditions is expected to be small. This conjecture was checked with a simple heat transfer calculation.

The vault can be idealized as a composite, infinitely long slab as illustrated in Figure 2. By neglecting heat transfer through the side walls, a conservative estimate of the temperature rise can be obtained. The applicable steady-state heat conduction equations are obtained from Fourier's law and are

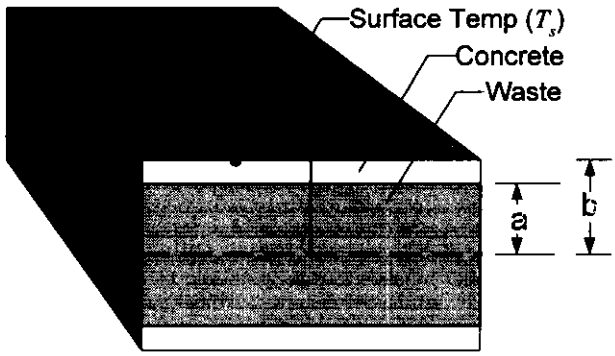

Figure 2. Schematic of Slab Geometry Used for Heat Transfer Calculation

$$\frac{d^2T_1}{dx^2} + \frac{Q}{\kappa_1} = 0, \quad 0 \le x \le a$$
$$\frac{d^2T_2}{dx^2} = 0, \quad a \le x \le b \tag{6}$$

where T_ℓ = temperature in waste ($\ell = 1$) or concrete ($\ell = 2$) regions, K
Q = volumetric heat generation rate of waste glass, W/m^3
κ_ℓ = thermal conductivity of glass ($\ell = 1$) or concrete ($\ell = 2$), W/m·K.

A solution to Equation (6) is sought subject to the following boundary conditions

$$\left.\frac{dT_1}{dx}\right|_{x=0} = 0 \tag{7}$$

$$T_1(a) = T_2(a) \tag{8}$$

$$\kappa_1 \frac{dT_1}{dx} = \kappa_2 \frac{dT_2}{dx} \tag{9}$$

$$T_2(b) = T_s \tag{10}$$

Equation (7) results from the symmetry of the problem at the vault centerline. Equations (8) and (9) specify continuity of temperature and heat flux, respectively, at the glass/concrete interface, and Equation (10) sets the temperature at the outer surface of the concrete. The solution to the equation system 6 through 10 is

$$\begin{aligned} T_1(x) &= T_s - \frac{qx^2}{2\kappa_1} + qa^2\left(\frac{1}{2\kappa_1} - \frac{1}{\kappa_2}\right) + \frac{qab}{\kappa_2}, \quad 0 \le x \le a \\ T_2(x) &= T_s - \frac{1}{\kappa_2}(qax + qab), \quad a \le x \le b \end{aligned} \tag{11}$$

The peak temperature occurs at x=0, so the maximum temperature rise expected in the vault (ΔT_{max}) is

$$\Delta T_{max} = T_1(0) - T_s = q\left[a^2\left(\frac{1}{2\kappa_1} - \frac{1}{\kappa_2}\right) + \frac{ab}{\kappa_2}\right] \tag{12}$$

Assuming an interior vault depth of 7.5 m and concrete wall thickness of 0.5 m, we have a = 3.25 m and b = 3.75m. For the glass and concrete, a thermal conductivity of 1.13 W/(m·°C) and 1.8 W/(m·°C), respectively, will be assumed. The volumetric heat generation rate, Q, can be determined from the available information (Mann et al. 1998) on the total expected radionuclide inventory. Assuming the inventory is uniformly distributed in 200,000 m^3 of glass, and conservatively assuming that the total decay energy is deposited in the solid, a decay heat generation rate of 0.045 W/m^3 was estimated. This heat generation rate is about 10 times less than was calculated in the previous version of this document. The change is due almost entirely to the factor of 4 reduction in the amount of ^{90}Sr and factor of 2 reduction in the amount of ^{137}Cs expected in the

ILAW, based on the updated inventory data in Mann et al. (1998). The maximum (center) temperature difference between the composite slab and its immediately surrounding soil is, therefore,

$$\Delta T_{max} = 0.045\left[3.25^2\left(\frac{1}{(2)(1.13)} - \frac{1}{1.8}\right) + \frac{(3.25)(3.75)}{1.8}\right] = 0.25\ °C. \quad (13)$$

This small temperature rise is within expected seasonal temperature fluctuations at the site and so is not a significant factor affecting the performance of the engineered system. Consequently, the engineered-system model need not consider temporal or spatial variations in temperature, which obviates the need for solving a heat transport equation.

2.2.5 Radioactive Decay

Although the process of radioactive decay is not an important process when considering heat transfer for a LAW site, the process is very important when modeling radionuclide release from the engineered system. Radioactive decay is a straightforward physical process that is usually included in subsurface transport codes. Much less common, however, is the capability for simulating radioactive decay chains and decay chain ingrowth. For reasons that will be discussed in Section 2.3.7, modeling radioactive decay and decay chain ingrowth in multicomponent chemical-transport codes requires careful consideration.

2.3 CHEMICAL PROCESSES

The selected engineered-system code must consider several important chemical processes coupled with the physical processes described in Section 2.2. Chemical processes control such important factors as radionuclide solubility and retardation, and corrosion rate of the LAW glass. The chemical processes to be modeled include

- aqueous complexation
- acid-base reactions
- oxidation/reduction
- dissolution/precipitation
- ion-exchange
- adsorption.

Each of these chemical processes is discussed in more detail below.

2.3.1 Aqueous Complexation

In complexation reactions, a central cation such as a radionuclide or metal ion reacts with an anion, commonly called a ligand, to form a new soluble species called a complex. In turn, these complexes can react with other ligands to form additional complexes. Complexation reactions are especially important because these reactions significantly modify the stability, and hence, mobility of actinide and transition metals. Inorganic ligands include common anions in natural waters, e.g., OH^-, Cl^-, SO_4^{2-}, CO_3^{2-}, PO_4^{3-}, etc. These ligands may also be contributed to the aqueous phase as a result of glass-water reactions. Inorganic ligands are typically present in solution in excess compared to radionuclides and metals. Important organic ligands include molecules associated with natural humic substances and synthetic organic complexing agents.

2.3.2 Acid-Base Reactions

Acid-base reactions involve the transfer of the proton (H^+) between two species. Chemical species which lose a proton are called acids and species which gain a proton are called bases. The pH of a solution is a measure of the activity of H^+ (more precisely, H_3O^+ ion) in solution; it is defined as the net negative logarithm of the H^+ activity ($pH = -\log a_{H^+}$). Acid-base reactions are involved in many aqueous complexation, precipitation, or sorption reactions. Solution pH controls aqueous speciation, solubility of compounds, sorption behavior of elements (e.g., K_d values), complex formation, and oxidation-reduction processes. For example, under oxidizing conditions in carbonate free aqueous media, the Pu^{+6} species is in the form of PuO_2^{2+} for $pH < 5$. At pH between 5 and 7, it is in the form of $PuO_2(OH)^-$, and at pH above 7 it is in the form of $PuO_2(OH)_3^-$. Corresponding measured values for the K_d of Pu range from less than 10 ml/g at low pH, to between 10 and 100 ml/g for the neutral pH range, to over 1000 ml/g at high pH. Solution pH also impacts the corrosion rate of many materials including silicate-based glass waste forms where higher pH is more corrosive to the glass.

2.3.3 Oxidation-Reduction Reactions

Oxidation-reduction (redox) reactions involve the transfer of electrons from one species to another resulting in changes in oxidation states. Redox reactions can be classified as aqueous complexation, precipitation, or adsorption reactions; these reactions can significantly alter the mobility of multiple-oxidation state radionuclides. For example, the effectiveness of adsorption mechanisms often depends on the oxidation state of the radionuclide. Important radionuclides such as ^{99}Tc, the transition metals, and the actinides uranium and plutonium have much lower solubilities in natural waters in their lower oxidation states.

The transfer of electrons in oxidation-reduction reactions is often treated in a mathematically analogous manner as the transfer of protons in acid-base reactions. For example, the activity of the hypothetical electron in solution is defined by the parameter *pe*, which equals the negative logarithm of the hypothetical electron activity. The *pe* can also be expressed in terms of the redox potential (Eh), which is related to *pe* by

$$pe = \left(\frac{F}{2.303RT}\right) Eh \qquad (14)$$

where F is the Faraday constant, R is the gas constant, and T is the absolute temperature. However, the overall redox state of real aqueous systems usually cannot be characterized by a single parameter such as Eh. The concept of a "system" *Eh* or a "system" *pe* is based on the assumption that all redox reactions in a system are in a state of thermodynamic equilibrium. This assumption is a poor one for most real systems (Jenne 1981; Hostetler 1984; Lindberg and Runnells 1984). Redox disequilibrium in natural aqueous systems is created by solar irradiation, radioactive decay, fluid mixing, slow reaction kinetics, and transfer of redox components from one phase to another. It should also be clear that *pe* is not a perfect analog to pH, because pH is defined with respect to H^+, a real aqueous species, whereas *pe* is defined with respect to a hypothetical species.

Oxidation-reduction in aqueous systems is commonly treated in terms of redox couples and their associated half-reactions. Common couples in aqueous solution include $O_{2(aq)} / H_2O_{(\ell)}$, $H_{2(aq)} / H_2O_{(\ell)}$, Fe^{2+}/Fe^{3+}, HS^-/SO_4^{2-}, SO_3^{2-} / SO_4^{2-}, $S_2O_3^{2-} / SO_4^{2-}$, NH_4^+ / NO_3^-, $N_{2(aq)} / NO_3^-$, and a host

of organic/ HCO_3^- couples. Each couple can be treated as having its own redox state. This can be expressed in a variety of ways, including a couple-specific *Eh* or *pe*.

Another way of expressing redox state that has become increasingly popular in geochemical models is the concept of a hypothetical oxygen fugacity in aqueous solution. Oxygen fugacity in an aqueous solution is hypothetical because fugacity is a property of gas species and gas species do not exist in aqueous solution. However, $O_{2(g)}$ makes a good hypothetical aqueous species, much like the hypothetical aqueous electron is used to calculate *pe*.

The concept of a hypothetical $O_{2(g)}$ aqueous species is important because it allows the modeler to express the redox state of a system in terms of a variable that does not necessarily imply redox equilibrium as does a *pe* or *Eh*. Consequently, the preferred method for treating redox reactions in the engineered-system model is with the hypothetical $O_{2(g)}$ aqueous species.

2.3.4. Dissolution-Precipitation Reactions

Dissolution-precipitation reactions are heterogeneous chemical reactions that directly remove or release radionuclides and other elements from solution. Therefore, these types of reactions play a very important role in the overall performance of the engineered system. Extensive amounts of precipitation or dissolution can also alter the pore or fracture structure of an engineered-system component and thereby indirectly alter the mass transport properties of the component.

Dissolution-precipitation of a solid phase in an aqueous solution is a dissociation-association process in which two or more soluble species are released into or removed from solution. It is subject to the common ion effect, which occurs when a solution already contains the same ions that would be released or removed when the solid dissolves or precipitates. The presence of common ions from other sources reduces the solubility of the solid relative to its solubility in pure water.

Glass corrosion is a special type of dissolution-precipitation reaction in that it is an irreversible process. Glass corrosion is the primary mechanism of releasing radionuclides from the LAW form into the adjacent environment and must be accurately described in the engineered-system

model. Fortunately, there is an extensive body of work on borosilicate glass waste forms from which a widely accepted mathematical model has been developed. Using this model, the flux of any element i released from the glass into the aqueous phase, J_i^a, is given by

$$J_i^a = \nu_i k_0 (1 - e^{\frac{A}{RT}}) \prod_j \gamma_j c_j^{-\eta_j}, \quad i = 1, 2, \ldots N \tag{15}$$

where ν_i = stoichiometric coefficient of element i in the glass
k_0 = forward rate constant, g/(m^2·s)
A = chemical affinity of the reaction, J/mol
N = number of elements
R = gas constant, J/mol/K
T = temperature, K
c_j = concentration of jth aqueous reactant species, g/m^3
γ_j = activity coefficient of jth reactant species
η_j = stoichiometric coefficient for the jth reactant species.

Equation (15) represents a constitutive relationship that relates temperature and the composition of water contacting the glass to the corrosion rate. Because these quantities are known or calculated at each node in a chemical-transport model [Equation (3)], incorporation of a glass corrosion model [Equation (15)] can be done naturally.

Mathematically, dissolution-precipitation reactions assumed to be at equilibrium could be treated via mass-action expressions or in terms of chemical potentials. A mass-action formulation results in a system of non-linear algebraic equations that must be solved, whereas a formulation in chemical potentials requires a solution to a global free energy minimization problem. Either formulation should yield equivalent results.

Because the temperature of the LAW disposal site is expected to be approximately 15°C, an assumption of chemical equilibrium for all reactions may not be appropriate, particularly for some dissolution-precipitation reactions. At 15°C, metastable phases may persist for indefinite periods of time and many of these phases may be amorphous. This is a consequence of the Ostwald Step Rule (Ostwald 1897), which states that the reaction products initially obtained are the least stable ones lying nearest to the original state in free energy and also the "simplexity princi-

ple" (Goldsmith 1953), which states that the most disordered phase should form from a random system of components. Consequently, the selected engineered-system code should have the capability for specifying kinetically constrained reaction sets.

2.3.5 Ion-Exchange

Ion-exchange reactions are a class of adsorption reactions that may be an important control on the mobility of radionuclides and other species, especially through clays and zeolites. Ion-exchange occurs when there is a free energy reduction from the substitution of an ion in the aqueous phase with an atom in the exchangeable solid. The ability of a solid to exchange ions is usually expressed by the cation exchange capacity (CEC), which is defined as the number of milliequivalents (meq) of monovalent cations per unit mass of dry solid. The equivalent of an ion is its molecular weight divided by the absolute value of its charge. Typical CEC values for soils containing organic materials range from 30 to 100 meq/100g, depending on the mineral type, pH, and composition of the contacting solution.

As was the case for the dissolution precipitation reactions, ion-exchange reactions may be treated mathematically via mass-action expressions or chemical potentials. Mass action formulations for ion-exchange reactions are similar to those for dissolution-precipitation reactions with the exception that the equilibrium constant of the latter is replaced by a selectivity coefficient. The chemical potential formulation requires a state equation that relates the change in electrostatic potential that occurs from the ion-exchange reaction.

2.3.6 Adsorption

Adsorption is the phenomenon of increase in the mass of a substance on the solid at a fluid-solid interface. The component's affinity for adsorption to the solid surface is due to 1) electrical attraction such as van der Waals attraction, or 2) chemisorption, which is a surface complexation reaction that binds the adsorbed species to the solid surface.

The main factors affecting the adsorption and desorption of species to or from the solid are the physical and chemical characteristics of the adsorbent and of the solid surface. Interactions between mineral surfaces and dissolved ions can depend strongly on solution pH and the min-

eral's zero point of charge (ZPC). If the pH of the contacting solution is above the ZPC, the mineral surface will have a net negative charge and an affinity for cations; the reverse occurs if the pH is less than the ZPC. This phenomenon is particularly important in systems containing clays and particles coated with common hydrous oxides such as those of aluminum, manganese, and iron. These materials are often dominant sorbents in geochemical systems. Clay minerals tend to have overall negative charges for all but very acidic conditions (i.e., pH<4). Metal oxides, however, may have reactive sites capable of removing anionic radionuclide species from solution for the near-neutral to slightly basic pH range.

Numerous adsorption models exist that may be used in an engineered-system code. Empirical models are the most popular type of adsorption model, usually expressed as an isotherm, that relates the quantity of an adsorbed species to its quantity in the aqueous phase at constant temperature. Equilibrium isotherms are based on the assumption that the quantities of the component on the solid and in the adjacent solution are in equilibrium. Any change in the concentration of one of the species produces an instantaneous change in the other. Common isotherms include the linear equilibrium isotherm or K_d model given by

$$F_s^i = K_d^i c_l^i, \quad i = 1,2,...N_l \tag{16}$$

where F_s^i = mass of component i per unit mass of solid

K_d^i = distribution coefficient of component i, m^3/g,

and the Langmuir isotherm

$$F_s^i = \frac{k_3 c_l^i}{1 + k_4 c_l^i}, \quad i = 1,2,...N_l \tag{17}$$

where k_3 and k_4 are constants. There are also a variety of non-equilibrium isotherms, although these have been almost never applied in transport codes.

A semi-empirical type of adsorption model that is used in several chemical-transport codes is a surface complexation model. As was the case for the chemical reactions discussed previously, the surface complexation model may be formulated in terms of mass-action expressions or by chemical potentials. Mass-action formulations require equilibrium constants for the surface

complexation reactions being considered and the chemical potential formulation requires information on the change in electrostatic potential that occurs from the adsorption reaction. This is usually done with the aid of a double or triple-layer site binding model. For the selected engineered-system code, both empirical and surface complexation adsorption model options should be available. The latter model is expected to be used in cases where particular adsorption reactions play a crucial role in the mobility and release of a radionuclide.

2.3.7 Radioactive Decay

As discussed in section 2.2.5, the process of radioactive decay is a simple physical process to include in a transport code. However, the process of decay-chain ingrowth is not so easily implemented. Decay-chain ingrowth refers to a series of parent and daughter decay reactions that can result in the accumulation of daughter radionuclide(s) because of the differences in half-life between the members of the chain. For example, consider the decay chain

$$^{243}_{95}\mathrm{Am} \xrightarrow{7.37 \times 10^{3}\ \mathrm{y}} {}^{239}_{93}\mathrm{Np} \xrightarrow{2.35\ \mathrm{d}} {}^{239}_{94}\mathrm{Pu} \xrightarrow{2.44 \times 10^{4}\ \mathrm{y}} {}^{235}_{92}\mathrm{U}. \qquad (18)$$

Because the half-life of ^{235}U is 7.1 x 10^8 y, the decay of this radionuclide is usually insignificant over the time scales of performance assessment calculations. However, the ^{243}Am parent is usually completely decayed over typical performance assessment time scales of 10^6 y. Consequently the decay of the parent results in the accumulation of ^{239}Pu and ^{235}U.

The difficulty in describing decay-chain ingrowth in coupled chemical transport codes is the fact that each radionuclide is partitioned into multiple chemical species. These species may be aqueous, precipitated, adsorbed, etc. To maintain proper mass balance, it is, therefore, necessary to explicitly write "chemical reactions" that describe the decay of each parent species. For example, the decay of the aqueous species $AmOHCO_3$ can be written as

$$^{243}_{95}\mathrm{AmOHCO_3}(aq) \rightarrow {}^{239}_{94}\mathrm{Pu}^{3+} + \mathrm{OH}^- + \mathrm{CO_3^{2-}}. \qquad (19)$$

The decay reaction (19) is written as an irreversible, kinetically constrained reaction with the rate constant given simply by the decay constant for the ^{243}Am parent. Equation (19) is only valid when the time step being taken is much larger than the 2.35d half-life of the $^{239}_{93}$Np intermediate.

Similar reactions can be written for all the radioactive species to be considered in a simulation. Obviously, for a kinetically constrained reaction like Equation (19) to be implemented, the selected engineered-system code must be capable of treating kinetically constrained reaction sets in addition to the usual equilibrium reaction sets.

3.0 COMPARISON OF EXISTING CODES

Having described in the previous section the important physical and chemical processes that are expected to significantly impact the performance of the engineered system, we now need to evaluate the capabilities of existing computer codes in meeting these requirements and develop a means to rank the computer codes. The mechanism chosen to do this is to 1) develop a list of needed capabilities and 2) assign a figure of merit score from 1 to 10 to each capability. The figure of merit score is broken into two parts:

a) importance to modeling the performance of the engineered system

b) degree of difficulty in adding the capability to an existing code.

The figure of merit score is intended as an unbiased scheme to rank computer codes with similar capabilities. For Part *a*, a score of 1 indicates that the process has little or no importance for modeling radionuclide release from the engineered system, whereas a score of 10 means that the process is critical to the model and must be included in the selected code. Part *b* of the figure of merit score is needed because it is expected that no existing code meets all of the capabilities identified in Sections 1.0 and 2.0. Consequently, the degree of difficulty in modifying or adding a particular capability to an existing code is an important consideration in the code selection process. A Part *b* score of 1 indicates that a person familiar with the process and the code could add the capability in less than a man-week, whereas a score of 10 indicates that at least a man-year of effort would be required to add the capability to the code.

To be selected for detailed ranking, the computer code must have the capability for simulating coupled chemical reactions and transport. This requirement excluded a large number of subsurface solute transport codes (such as PORFLOW) and batch equilibrium chemistry codes such as EQ3/6.

3.1 COMPUTER CODE RANKING

The needed (or desired) code capabilities were divided into four categories. These are

- Physical Processes
- Numerical Methods
- Chemical Processes
- Functionality

Each category was then broken down into specific capabilities that were assigned the two part figure of merit score discussed in the previous section. A detailed description of the important physical and chemical capabilities was provided in Section 2.0; these are reproduced in Table 2. The total possible composite score for the first two categories is 265 out of a possible 400 points, which is 66% of the score. This fact reflects an emphasis in selecting the code with the most complete physical and chemical models.

The capabilities shown in Table 2 under the Numerical Methods category reflect general issues associated with the numerical solution of the governing partial differential equations. An emphasis was placed on codes with capabilities for 2-D simulations. Wave front sharpening is an important consideration in the solution of advection-dominated transport problems and to minimize numerical dispersion. Preference was given to codes with an option to solve the reaction transport equation implicitly versus the more typical operator splitting scheme. Operator splitting schemes are conceptually easier to implement since the reaction and transport equations are solved separately. However, the method is often slow to converge and may have mass balance problems when taking large time steps with radioactive decay (Valocchi and Malmstead 1992). Finally, parallel processing features are considered important when attempting to run problems with a large number of chemical species.

The capabilities listed under the Functionality category were given only a composite figure of merit score since these capabilities do not directly impact the use of the code for performance assessment calculations. The functionality categories considered important were the availability of a graphical user interface, a separate version of the code compiled for parallel computing, familiarity in the waste management community with code (name recognition), public availability

of the code, and finally whether the code is under active software quality assurance configuration management.

Each part *a* and *b* figure of merit score was added together to arrive at a composite figure of merit score. Codes having a specific capability were assigned the composite figure of merit score for that capability. Codes not having the capability were assigned a composite figure of merit score of zero for that capability. Figure of merit scores for each code were then tabulated to arrive at a total figure of merit score for the computer code. Table 2 gives a detailed listing of the figure of merit score for each computer code considered. The references used to compile the information on the capabilities of each code are given in Section 5.1 following the formal reference list.

Table 2. List of Engineered-System Code Capabilities and Figure of Merit Scores. References for each code are given at the end of the References section.

Capability List	Merit(a)	Merit(b)	Composite	SUGAR	DYNAMIX	CHEMATE	CAT	THCC	UNSATCHEM-2D	OS3D	GIMRT	CHMTRNS	BLT-EC	UT-CHEM	AREST-CT	3DFATMIC	HYDROGEOCHEM2	CRF-A	MULTIFLO	FEHM	STORM
Physical Processes																					
Solute advection	10	5	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Solute diffusion	5	2	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Solute dispersion	8	5	13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gas advection	7	5	12						✓					✓					✓	✓	✓
Gas diffusion	7	2	9						✓					✓					✓	✓	✓
Gas dispersion	7	5	12						✓					✓					✓	✓	✓
Water mass conservation	9	10	19						✓					✓		✓			✓	✓	✓
Unsaturated hydraulic properties	9	5	14																✓	✓	✓
Energy conservation	1	3	4					✓	✓			✓						✓	✓	✓	✓
Permeability texture relationship	3	1	4											✓				✓	✓		✓
Dual porosity/permeability	3	1	4																✓	✓	✓
Fluid density equation of state	1	1	2					✓	✓			✓		✓	✓	✓		✓			✓
				35	35	35	35	41	93	35	35	41	35	93	37	58	35	45	113	109	118
Chemical Processes																					
aqueous complexation	10	8	18	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
acid-base reactions	10	8	18	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
oxidation/reduction	10	10	20	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
dissolution/precipitation	10	10	20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ion-exchange	4	7	11			✓		✓	✓			✓	✓	✓	✓		✓	✓	✓		✓
adsorption(empirical)	8	1	9	✓		✓		✓		✓	✓		✓			✓	✓	✓	✓	✓	✓
adsorption(surface complexation	4	7	11									✓	✓				✓	✓			
reaction kinetics	8	9	17				✓			✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
radioactive decay	10	1	11	✓		✓		✓				✓	✓		✓		✓	✓		✓	✓
decay-chain ingrowth	7	10	17										✓		✓					✓	✓
user-defined reactions	10	6	16	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
				112	92	123	109	123	67	118	118	142	151	67	137	118	151	151	129	146	157
Numerical Methods																					
1-D geometry	10	2	12	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2-D geometry	10	8	18		✓				✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
3-D geometry	3	10	13		✓					✓	✓			✓		✓			✓	✓	
wave front sharpening	8	5	13											✓		✓					
operator splitting	2	3	5	✓	✓	✓	✓		✓	✓			✓			✓	✓		✓	✓	
global implicit	6	8	14					✓			✓	✓		✓	✓			✓	✓		✓
parallelized algorithms	5	8	13				✓										✓				
				17	48	17	30	26	35	48	57	26	35	70	44	61	48	44	62	48	44
Functionality																					
graphical user interface			10				✓						✓					✓			
workstation version			2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
supercomputer version			3																		
MPP version			9				✓														
code name familiarity			5		✓	✓						✓			✓		✓			✓	
publicly available			8		✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓
software quality management			10												✓				✓	✓	✓
				2	15	15	21	10	10	10	10	15	12	10	25	10	15	12	12	25	30
OVERALL FIGURE OF MERIT			418	196	190	190	195	200	205	211	220	224	233	240	243	245	249	252	316	328	336

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results from the composite figure of merit scores for the computer codes are listed in Table 2. The results show that the STORM code is the most suitable model for the purposes of conducting performance assessment calculations for the Hanford LAW engineered system. However, two codes that have been released since Revision 0 of this document was prepared rank just behind STORM. The second highest ranked code is FEHM. This code has been developed by George A. Zyvoloski and colleagues at Los Alamos National Laboratory to assist in the understanding of flow fields and mass transport in the saturated and unsaturated zones below the proposed Yucca Mountain nuclear waste repository in Nevada. Although FEHM's figure of merit score is quite good (328 compared with 336 for STORM), currently, FEHM is limited to a total of 10 interacting species, which is simply inadequate to model radionuclide release from the expected LAW glass formulations that contain 8 or more major components, excluding the radionuclides of interest. Also, FEHM is based on the operator splitting method of coupling water flow and reactive transport, which limits the size of time steps that can be achieved. The third highest ranked code is MULTIFLO, which has been developed by Peter C. Lichtner at the Center for Nuclear Waste Regulatory Analyses for application to a repository-scale model of the redistribution of moisture, heat and various chemical constituents at Yucca Mountain. Currently MULTIFLO does not simulate radioactive decay or other kinetic aqueous reactions. Discussions with Dr. Lichtner have also indicated difficulties in taking large time steps with the operator-splitting numerical method used in MULTIFLO.

The STORM code meets all of the general code selection criteria specified in Section 1.1 and nearly all of the desirable features. Desirable feature #1, "The selected code should be certified (that is, simulation results compared with field and/or laboratory data) for a system similar to that being modeled," has not been performed. However, experiments are underway that will be used to confirm the STORM code. Confirmation efforts to date only include verification of the numerical algorithms in STORM. Desirable feature #2, "The degree of complexity of the selected code shall be consistent with the quantity and quality of data and the objectives of the computation," is only partially met. The complexity of the STORM code is consistent with the objectives

of the computation to calculate radionuclide release from the engineered system but specific thermodynamic and kinetic data required to run the code have not been measured for the proposed LAW engineered-system components. However, experimental programs are in progress so that these data will be available for use in STORM calculations.

STORM was developed by coupling STOMP, a nonisothermal multiphase flow simulator (White and Oostrom, 1996), with AREST-CT version 1.1, a reactive transport and porous medium alteration simulator (Chen et al. 1995; Chen et al. 1997). The general approach was to couple the two codes by making major modifications to AREST-CT subroutines while modifying STOMP routines as little as possible. The AREST-CT code had been developed for the DOE specifically for the analysis of radionuclide releases from waste packages being designed for high-level waste disposal at the proposed Yucca Mountain repository in the state of Nevada. The characteristics of this site, i.e., unsaturated zone, glass waste forms, etc., has led to the incorporation of process models that are directly applicable to assessing the performance of currently anticipated engineered-system designs for the LAW site at Hanford. Hence, the relatively high ranking of the STORM code is to be expected. The fact that this code is also supported for use on a separate DOE program is an additional benefit in lowering the overall cost of code development and maintenance to the DOE.

It is important to note that in 1995, when the AREST-CT code was selected in Revision 0 of this document, reactive transport codes were considered fairly exotic computational tools and were few in number. Since then, development of reactive transport codes with increasingly sophisticated capabilities is being done at several universities, national laboratories, and research institutes both in the U.S. and abroad. The more widespread recognition and application of these powerful codes in solving waste disposal problems lends support for the approach we recommended in 1995 and again in this document in using the STORM reactive transport code for ILAW disposal system performance assessment.

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Subsurface Transport Over Reactive Multiphases (STORM): A General, Coupled, Nonisothermal Multiphase Flow, Reactive Transport, and Porous Medium Alteration Simulator, Version 2

User's Guide

D. H. Bacon
M. D. White
B. P. McGrail

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Pacific Northwest National Laboratory
Richland, Washington 99352

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Summary

The U.S. Department of Energy must approve a performance assessment (PA) to support the design, construction, approval, and closure of disposal facilities for immobilized low-activity waste (ILAW) currently stored in underground tanks at Hanford, Washington. A critical component of the PA is to provide quantitative estimates of radionuclide release rates from the engineered portion of the disposal facilities. Computer simulations are essential for this purpose because impacts on groundwater resources must be projected to periods of 10,000 years and longer. The computer code selected for simulating the radionuclide release rates is the Subsurface Transport Over Reactive Multiphases (STORM) simulator.

The STORM simulator solves coupled conservation equations for component mass and energy that describe subsurface flow over aqueous and gas phases through variably saturated geologic media. The resulting flow fields are used to sequentially solve conservation equations for reactive aqueous phase transport through variably saturated geologic media. These conservation equations for component mass, energy, and solute mass are partial differential equations that mathematically describe flow and transport through porous media.

The STORM simulator solves the governing-conservation equations and constitutive functions using numerical techniques for nonlinear systems. The partial differential equations governing thermal and fluid flow processes are solved by the integral volume finite difference method. These governing equations are solved simultaneously using Newton-Raphson iteration. The partial differential equations governing reactive solute transport are solved using either an operator split technique where geochemical reactions and solute transport are solved separately, or a fully coupled technique where these equations are solved simultaneously.

The STORM simulator is written in the FORTRAN 77 language, following American National Standards Institute (ANSI) standards. The simulator utilizes a variable source code configuration that allows tailoring of the execution memory and speed to the specific problem by editing text parameter files and recompiling the code. Execution of the STORM simulator is controlled through a text input file. This input file uses a structured format of associated groups of input data. Input data files and results are also presented for model verification and example simulations. Appendix A to this report presents examples of the STORM Version 2 input data format for each of the groups.

Acronyms and Abbreviations

ANSI	American National Standards Institute
AREST-CT	TBS
DOE	Department of Energy
Ecology	Washington State Department of Ecology
Eh	electrode potential in volts
GMRES	Generalized Minimal Residual Method (accelerator)
IC	Incomplete Cholesky (preconditioner)
L	length
ILAW	immobilized low activity waste
LAW	low activity waste
M	mass
N/A	not applicable
NSPCG	nonsymmetric preconditioned conjugate gradient
ODE	ordinary differential equation
PA	performance assessment
PDE	partial differential equation
PNNL	Pacific Northwest National Laboratory
PUF	Pressurized Unsaturated Flow (experiments)
SI	Systeme Internationale
STDIO	standard input/output device
STOMP	Subsurface Transport Over Multiple Phases
STORM	Subsurface Transport Over Reactive Multiphases
STORM1	STORM mode with unsaturated flow
STORM2	STORM mode with two-phase flow
STORM3	STORM mode with two-phase flow and heat transfer
T	time
TVD	Total Variation Diminishing (transport scheme)
VOC	volatile organic carbon

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1.0 Introduction

The Hanford Site, in southeastern Washington State, has been used extensively to produce nuclear materials for the U.S. strategic defense arsenal by the Department of Energy (DOE) and its predecessors, the U.S. Atomic Energy Commission and the U.S. Energy Research and Development Administration. A large inventory of radioactive and mixed waste has accumulated in 177 buried single- and double shell tanks. Liquid waste recovered from the tanks will be pretreated to separate the low-activity fraction from the high-level and transuranic wastes (Ecology 1996). Vitrification is the leading option for immobilization of these wastes, expected to produce approximately 550,000 metric tons of Low Activity Waste (LAW) glass. This total tonnage, based on nominal Na_2O oxide loading of 20 percent by weight, is destined for disposal in a near-surface facility.

Before disposal of the immobilized waste can proceed, the DOE must approve a performance assessment, a document that describes the impacts, if any, of the disposal facility on public health and environmental resources. Results from a recent performance assessment are in a study published 2 years ago (Mann et al. 1998). A major conclusion from this study is that release rates of radionuclides from the glass waste form by reaction with water determines the impacts of the disposal action more than any other independent parameters. Consequently, a sound scientific basis for determining the long-term release rates of radionuclides from these glasses must be developed before this disposal action is accepted by regulatory agencies, stakeholders, and the public.

The rate of glass corrosion depends on temperature and the chemical composition of the water contacting it. Because glass dissolution itself changes the pH and solution composition, water percolating through a disposal system has neither a constant nor a uniform composition. Consequently, the glass corrosion rate in the disposal system also varies as a function of time and space. Over the last several years, DOE has supported the development of a numerical simulator at the Pacific Northwest National Laboratory (PNNL). This simulator can compute time and spatial variations in the chemical environment of unsaturated disposal systems in response to the corrosion of waste forms as well as other physical and chemical processes (McGrail and Bacon 1998). This report describes the latest accomplishments in the development of this computational tool, Subsurface Transport Over Reactive Multiphases (STORM), Version 2, a general, coupled non-isothermal multiphase flow and reactive transport simulator. It was developed by coupling STOMP, a non-isothermal multiphase flow simulator (White and Oostrom 1996), with AREST-CT Version 1.1, a reactive transport and porous medium alteration simulator (Chen et al. 1995; Chen et al. 1997). The general approach was coupling the two codes by making major modifications to AREST-CT subroutines, and modifying STOMP routines as little as possible.

The underlying mathematics in STORM is contained in a set of coupled, nonlinear, partial differential equations. They describe the rate of change of the solute concentrations of pore water in a variably saturated, non-isothermal porous medium, and the alteration of waste forms, packaging materials, backfill, and host rocks. The detailed mathematics is discussed elsewhere (Chen et al. 1996; White and Oostrom 1996). The following topics are included.

- kinetic dissolution of waste forms
- kinetic dissolution of host rocks
- kinetic precipitation and dissolution of secondary phases
- aqueous equilibrium speciation
- gas-aqueous equilibria
- redox reactions
- two-phase flow (water and air)
- dynamic hydraulic properties

Other physical and chemical features of the code are:

- 1-D (vertical Z-axis) or 2-D (X-Z Plane) solution domains
- general interface to take user specified chemistry and hydraulic properties
- non-isothermal multiphase flow and chemistry
- ionic strength correction according to modified B-dot equation
- spatially varying distribution of minerals in solid phase
- effective reaction surface varies with dissolution and precipitation of solids

The primary output of STORM, as a function of time and space, consists of the following:

- concentrations of aqueous species
- concentrations of gaseous species
- release flux of aqueous species and chemical components
- pH and Eh changes
- radii, surface areas, and volume fractions of solids
- dissolution/precipitation rates of solids
- production/consumption rates of aqueous species, including water
- temperature
- porosity and permeability changes
- aqueous phase saturations, velocities
- gas phase saturations, velocities

2.0 Governing Equations

2.1 Multiphase Flow and Heat Transfer

In broad terms, the STORM simulator solves coupled conservation equations for component mass and energy that describe subsurface flow over multiple phases through variably saturated geologic media. The resulting flow fields are used to sequentially solve conservation equations for reactive aqueous phase transport through variably saturated geologic media. These conservation equations for component mass, energy, and solute mass are partial differential equations. They mathematically describe flow and transport through porous media and are collectively entitled the governing equations. The STORM simulator has capabilities for modeling subsurface flow over two distinct phases: aqueous and gas. The aqueous phase primarily comprises liquid water with small quantities of dissolved air. The gas phase comprises variable amounts of air and water vapor.

It is possible to compile three modes of STORM: STORM1 (unsaturated flow), STORM2 (2-phase flow), and STORM3 (2-phase flow and heat transfer). STORM1 provides the fastest execution time if neither gas-phase flow or heat transfer is a major consideration.

2.1.1 Water Mass Conservation Equation

The water mass conservation equation, shown in Equation (2.1), equates the time rate of change of water mass within a control volume with the flux of water mass crossing the control volume surface. In the STORM simulator, water exists in the diffusive pore space as liquid water in the aqueous phase and as water vapor in the gas phase. Phase partitioning of water mass is computed assuming equilibrium conditions, implying the time scale for establishing thermodynamic equilibrium is significantly shorter than for component transport. Water transport occurs by advection through the aqueous and gas phases and also by diffusion-dispersion through the gas phase. Following the low solubility assumption for dissolved air in the aqueous phase, air diffusion-dispersion through the aqueous phase is neglected. Flow of fluid phases is computed from Darcy's law. Transport of phase components is computed from Fick's law.

$$\frac{\partial}{\partial t}\left[\sum_{\gamma=\ell,g}\left(\phi_D\,\omega_\gamma^w\,\rho_\gamma\,s_\gamma\right)\right]=-\sum_{\gamma=\ell,g}\left(\nabla\mathbf{F}_\gamma^w+\nabla\mathbf{J}_\gamma^w\right)+\dot{m}^w \tag{2.1}$$

where

$$\mathbf{F}_\gamma^w=-\frac{\omega_\gamma^w\,\rho_\gamma\,k_{r\gamma}\,\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma+\rho_\gamma\,g\,\mathbf{z}_g\right)\ for\ \gamma=\ell,g \tag{2.2}$$

$$\mathbf{J}_\gamma^w = -\tau_\gamma \phi_D \rho_\gamma s_\gamma \frac{M^w}{M_\gamma} D_\gamma^w \nabla \chi_\gamma^w \quad for\ \gamma = \ell, g \tag{2.3}$$

where ϕ_D = diffusive porosity

ω_γ^j = mole fraction of component j in phase γ

ρ_γ = phase density for phase γ, kg m^{-3}

s_γ = phase saturation for phase γ

$\mathbf{F}_\gamma^j$ = advective flux of component j in phase γ, kg m^{-2} s^{-1}

$\dot{m}^w$ = **mass source rate of component j, kg m^3 s^{-1}**

$\mathbf{J}_\gamma^j$ = **diffusive-dispersive flux of component j for phase γ, kg m^{-2} s^{-1}**

$\mathbf{k}$ = intrinsic permeability tensor, m^2

$k_{r\gamma}$ = fluid relative permeability of phase γ

P_γ = pressure of phase γ, Pa

$\mathbf{z}_g$ = unit gravitational direction vector

g = acceleration of gravity, m s^{-2}

μ_γ = kinematic viscosity of phase γ, Pa s

τ_γ = phase tortuosity for phase γ

M_γ = molecular weight of phase γ, kg mol^{-1}

D_γ^j = diffusion coefficient of component j for phase γ, m^2 s^{-1}

χ_γ^j = mole fraction of component j in phase γ

a = air component

w = water component

g = gas phase

ℓ = **aqueous phase**

t = **time, s**

2.1.2 Air Mass Conservation Equation

In a similar manner to the water mass conservation equation, the air mass conservation equation, shown in Equation (2.4), equates the time rate of change of the air mass within a control volume with the flux of air mass crossing the control volume surface. In the STORM simulator, air exists in the diffusive pore space as a component of the gas phase and is dissolved in the aqueous phase. Phase partitioning of air mass is computed assuming equilibrium conditions: this assumption implies the time scale for thermodynamic equilibrium in geologic media is significantly shorter than that for component transport. Air transport occurs by advection and diffusion dispersion through the aqueous and gas phases. Flow of fluid phases is computed from Darcy's law. Transport of phase components is computed from Fick's law.

$$\frac{\partial}{\partial t}\left[\sum_{\gamma=\ell,g}\left(\phi_D\,\omega_\gamma^a\,\rho_\gamma\,s_\gamma\right)\right]=-\sum_{\gamma=\ell,g}\left(\nabla\mathbf{F}_\gamma^a+\nabla\mathbf{J}_\gamma^a\right)+\dot{m}^a \tag{2.4}$$

where

$$\mathbf{F}_\gamma^a=-\frac{\omega_\gamma^a\,\rho_\gamma\,k_{r\gamma}\,\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma+\rho_\gamma\,g\,\mathbf{z}_g\right)\ for\ \gamma=\ell,g \tag{2.5}$$

$$\mathbf{J}_\gamma^a=-\tau_\gamma\,\phi_D\,\rho_\gamma\,s_\gamma\,\frac{M^a}{M_\gamma}\,D_\gamma^a\,\nabla\,\chi_\gamma^a\ for\ \gamma=\ell,g \tag{2.6}$$

2.1.3 Energy Conservation Equation

The energy conservation equation, shown in Equation (2.7), equates the time rate of change of energy within a control volume with the flux of energy crossing the control volume surface. In the STORM simulator, thermal energy is partitioned, according to thermal equilibrium conditions, among the fluid and solid phases. The thermal capacitance of unconnected pore space, represented by the difference between the total and diffusive porosity, is computed as it is filled with liquid water. Heat transfer occurs by advection of phase mass, diffusion of component mass, and thermal diffusion through the fluid and solid phases. Heat transfer by hydraulic dispersion of flowing fluid phases is neglected. Enhanced vapor transport is incorporated through enhancement factors for component diffusion through the gas phase. Energy associated with component mass sources is included as internal heat generation sources. Reference states for enthalpy and internal energy are component dependent. Latent heat transport is considered through vapor transport using the gas phase and equilibrium thermodynamics.

$$\begin{aligned}&\frac{\partial}{\partial t}\left[\sum_{\gamma=\ell,g}\left(\phi_D\,\rho_\gamma\,s_\gamma\,u_\gamma\right)+\left(1-\phi_T\right)\rho_s\,u_s+\left(\phi_T-\phi_D\right)\rho_\ell\,u_\ell\right]=\\&-\sum_{\gamma=\ell,g}\left(\nabla\left(\rho_\gamma\,h_\gamma\,\mathbf{q}_\gamma\right)+\sum_{j=w,a}\left(\nabla\,h^j\,\mathbf{J}_\gamma^j\right)\right)+\nabla\left(\mathbf{k}_e\,\nabla\,T\right)+\sum_{j=w,a}\left(h^j\,\dot{m}^j\right)+\dot{Q}\end{aligned} \tag{2.7}$$

where the Darcy velocity is given by

$$\mathbf{q}_\gamma=-\frac{k_{r\gamma}\,\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma+\rho_\gamma\,g\,\mathbf{z}_g\right)\ for\ \gamma=\ell,g \tag{2.8}$$

and the diffusive flux by

$$\mathbf{J}_\gamma^j = -\tau_\gamma \phi_D \rho_\gamma s_\gamma \frac{M^j}{M_\gamma} D_\gamma^j \nabla \chi_\gamma^j \quad \text{for } \gamma = \ell, g \text{ and } j = w, a \tag{2.9}$$

where ϕ_T = total porosity
h_j = enthalpy of component j, J kg^{-1}
h_γ = enthalpy of phase γ, J kg^{-1}
$\mathbf{k}_e$ = equivalent thermal conductivity tensor, W m^{-1} K^{-1}
T = temperature, K
$\dot{Q}$ = thermal energy source, W
μ_γ = kinematic viscosity of phase γ, Pa s
μ_γ = internal energy of phase γ, J kg^{-1}

2.2 Solute Transport

2.2.1 Solute Mass Conservation Equation

The solute mass conservation equation, shown in Equation (2.10), equates the time rate for change of solute mass within a control volume with the flux of solute mass crossing the control volume surface. The solute mass conservation equation is solved when an *Operator Split* solution scheme is used. In the STORM simulator, solute mass is partitioned among the fluid and solid phases assuming thermodynamic and geochemical equilibrium conditions. This assumption implies the time scales for thermodynamic and geochemical equilibrium are short compared against those for solute transport. For geologic media, this assumption is generally appropriate. Solute transport occurs by advection and diffusion-dispersion through the aqueous phase and gas phase. Radioactive chain decay of solutes is computed using first-order decay kinetics. Solute mass conservation equations are solved sequentially with progeny solutes preceding parent solutes. Progeny solute production rates are computed from parent decay rates and chain decay fractions with

$$\frac{\partial C}{\partial t} = -\sum_{\gamma=l,g} \left(\nabla \left[C_\gamma q_\gamma \right] \right) + \dot{m}^C - \dot{R}^C C + \sum_{\gamma=l,g} \left(\nabla \left[\left(\tau_\gamma s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{hy} \right) \nabla C_\gamma \right] \right) \tag{2.10}$$

where C = mass of solute per unit volume of porous media, m^{-3}
C_γ = mass of solute per unit volume of either liquid or gas, m^{-3}
D_γ^C = solute diffusion coefficient for phase γ, $m^2\ s^{-1}$
$\mathbf{D}_{h\gamma}$ = hydraulic dispersion tensor for phase γ, $m^2\ s^{-1}$
$\dot{m}_C$ = solute source rate, s^{-1}
R^C = solute decay rate constant, s^{-1}

2.2.2 Aqueous Species Mass Conservation Equation

The aqueous species mass conservation equation is written as follows

$$\frac{\partial \phi_D \rho_\ell s_\ell C_i^\ell}{\partial t} = -\nabla \cdot F_i^\ell + S_i^r \tag{2.11}$$

where C_i^ℓ is the concentration of species i in the aqueous phase (denoted by ℓ) in mol kg^{-1}, F_i^ℓ is the solute flux of species i in the aqueous phase, S_i^r is the source/sink term of species i due to chemical reactions in mol $m^{-3}\ s^{-1}$. The aqueous species mass conservation equation is solved when a *Fully Coupled* solution scheme is used.

If it is assumed that the phenomenon of hydrodynamic dispersion can be represented by a Fickian type law, then the total solute flux due to advection, dispersion, and diffusion is given by

$$\mathbf{F}_i^S = \phi_D \rho_\ell s_\ell \left(C_i \mathbf{V}_\ell - \mathbf{D}(s_\ell) \cdot \nabla C_i \right) \tag{2.12}$$

where $\mathbf{D}$ is the hydrodynamic dispersion tensor of species i in the aqueous phase, $m^2\ s^{-1}$.

The flow fields resulting from the air, water, and energy conservation equations are coupled with the solute mass conservation equations via transient changes in water saturation and average linear pore water velocity. This velocity is related to the Darcy velocity by

$$\mathbf{V}_\ell = \frac{\mathbf{q}_\ell}{\phi_D s_\ell} \ . \tag{2.13}$$

2.2.3 Coupled Aqueous and Gaseous Species Mass Conservation Equation

The mass conservation law for a particular species can be written as the sum of transport in the gas and aqueous phases:

$$\frac{\partial}{\partial t}\rho_l \phi_D \left(s_g C_i^g + s_l C_i^l\right) = -\nabla \bullet F_i^S + S_i^r \tag{2.14}$$

where F_i^S is the total flux of species i in both the gas and aqueous phases.

The total flux due to advection, dispersion, and diffusion in both the aqueous and gas phases is given by

$$F_i^S = \phi_D s_g \left(\mathbf{V}_g C_i^g - \mathbf{D}_i^g \cdot \nabla C_i^g\right) + \phi_D s_l \left(\mathbf{V}_l C_i^l - \mathbf{D}_i^l \cdot \nabla C_i^l\right) \tag{2.15}$$

where V_g is the pore-gas velocity and $\mathbf{D}_i^g$ is the hydrodynamic dispersion tensor for species i in the gas phase. The coupled aqueous and gaseous species mass conservation equation is solved when a *Fully Coupled* solution scheme is used.

Assuming equilibrium between the gaseous phase and aqueous phase, the concentration of the dissolved gas component in the aqueous phase can be expressed as a linear function of the concentration (or mole fraction or partial pressure) of that component in the gaseous phase through Henry's constant

$$C_i^l = K_H p_i^g = K_H^{'} C_i^g \tag{2.16}$$

where C_i^l = aqueous phase concentration of the dissolved gas component
p_g = partial pressure of the component in the gas phase
C_i^g = gas phase concentration of the component
K_H = Henry's law constants expressed as a function of partial pressure
$K_H^{'}$ = Henry's law constants expressed as a function of mole fraction

Substituting (2.15) and (2.16) into (2.14) gives the mass conservation law in terms of the aqueous phase concentration of each species.

$$\frac{\partial}{\partial t}\left[\phi_D \rho_\ell \left(s_g K_H'^{-1} + s_\ell\right) C_i^\ell\right] = S_i^r + \nabla \cdot \left[-\phi_D \rho_\ell \left(s_g \mathbf{V}_g K_H'^{-1} + s_\ell \mathbf{V}_\ell\right) C_i^\ell + \phi_D \rho_\ell \left(s_g \mathbf{D}_i^g K_H'^{-1} + s_\ell \mathbf{D}_i^\ell\right) \cdot \nabla C_i^\ell\right] \quad (2.17)$$

A series of transformations are applied to Equation (2.17) to eliminate terms associated with equilibrium chemical reactions. Each aqueous species is defined as a reactive species, a non-reactive species, or an equilibrium species. Because of the transformations applied, equilibrium species must be transported at the same rate as the linearly related reactive species. A different Henry's Law constant and dispersion coefficient is allowed only for each reactive aqueous species that is in equilibrium with a gas species.

2.3 Geochemical Reactions

A chemical reaction generally can be written as

$$\nu_{mj} B_m + \sum_{i=1}^{N_s} \nu_{ij} A_i = 0 \quad (2.18)$$

where B_m = solid m
A_i = aqueous species i
ν_{ij} = stoichiometric coefficient of aqueous species i in reaction j (negative for reactants, positive for products)
ν_{mj} = stoichiometric coefficient of solid m in reaction j (negative for dissolution, positive for precipitation, zero for pure aqueous reaction)

If the rate of the reaction in unit bulk volume is shown as W_j (in general a nonlinear function of the aqueous species concentrations), the rate of aqueous species i in that reaction is $\nu_{ij} W_j$. (This nonlinear function is defined in Section 1.3.2.) The source/sink term due to reactions in Equation (2.14) is then

$$S_i^r = \sum_{j=1}^{N_r} \nu_{ij} W_j \quad (2.19)$$

where N_r is the number of reactions.

2.3.1 Equilibrium and Kinetic Reactions

Geochemical models usually assume some reactions to be in equilibrium. This assumption is often justified for some reactions, especially those involving only aqueous species. However, solid dissolution/precipitation reactions can be quite slow and should be treated as kinetic. Furthermore, the equilibrium approach cannot capture some metastable solid phases, such as amorphous solids, that in many cases are intermediate products of reaction. For this reason, STORM has been designed to treat both equilibrium and kinetic reactions separately. To this end, the source/sink term is split, due to chemical reactions, into equilibrium and kinetic parts.

$$S_i^r = \sum_{j=1}^{N_e} \nu_{ij} W_j^e + \sum_{j=1}^{N_k} \nu_{ij} W_j^k \tag{2.20}$$

where W_j^e = the rate of equilibrium reaction j (mol m^{-3} s^{-1})

W_j^k = the rate of kinetic reaction j (mol m^{-3} s^{-1})

N_e = the number of equilibrium reactions

N_k = the number of kinetic reactions

$N_r = N_e + N_k$.

Equilibrium reactions are by no means zero-rate reactions. In fact, equilibrium reactions have high reaction rates and reach equilibrium quickly when transport, other reactions, or changes in physical-chemical conditions disturb it. Specifically, if the rate of a reaction is much greater than the characteristic time of the problem being solved, it should be classified as equilibrium; otherwise it should be classified as kinetic.

2.3.2 Rate Law of Kinetic Reactions

For any kinetic reaction, assuming its rate law is of the mass-action type, two equivalent ways can define the reaction rate: one is to use the forward rate and backward rate; the other is to use the forward rate and the equilibrium constant. In STORM, the latter approach is used. Thus,

$$W_j = A_{m(j)} k_j \left[\prod_{\nu_{ij}<0} (\gamma_i c_i)^{\frac{|\nu_{ij}|}{f_j}} - \prod_{\nu_{ij}>0} (\gamma_i c_i)^{\frac{\nu_{ij}}{f_j}} \Big/ \left(K_j^{eq}\right)^{1/f_j} \right] \tag{2.21}$$

where $A_{m(j)}$ = a factor that for aqueous reactions equals 1, and for surface-limited reactions it equals the effective reaction area in unit bulk volume
k_j = the rate constant of reaction j
K_j^{eq} = the equilibrium constant of reaction j
γ_i = the activity coefficient of species i
f_j = the factor of the reaction order
W_j = generally a nonlinear function of concentrations of aqueous species

Several formulas, such as the Davies equation (Davies 1962), the B-dot equation (Helgeson 1969), and Pitzer's model (Pitzer 1973), can be used to calculate activity coefficients. The B-dot equation, with modifications for neutral species (Wolery 1992), is computationally economic and stable for problems of moderately high salinity. Although Pitzer's model can handle high ionic strength, the lack of constants for all but a few aqueous species limits its applicability. Thus, the B-dot equation is used to calculate activity coefficients in STORM.

2.3.3 Solid Reactions

In the subsurface, chemical reactions change not only the concentration of solutes but also the properties of the porous media. Changes in the volume fraction and surface area of solids, porosity and permeability result in changes in the fluid flow field, solute transport, and chemical reactions. Interactions may take place through several paths and in some cases be very strong. Ignoring the interactions will not only decrease the accuracy of the simulations but in many cases, also will yield even qualitatively incorrect predictions. To fully account for the interactions between the fluid phases and the porous media, it is necessary to consider dynamic changes in the properties of porous media as a result of mass redistribution from chemical reactions. The first step is to introduce variables that describe porous media texture.

STORM uses two primary variables to describe a mineral: the volume fraction V_m and one or more sizes of variables (depending on the shape of the mineral grains). The volume fractions of minerals and the porosity of the porous medium obey the relation

$$\sum_{m=1}^{N_m} V_m + \phi_T = 1 \tag{2.22}$$

From the volume fraction and size variables, the number density n_m (number of grains of mineral m in unit bulk volume of porous media) is derived and the specific surface area A_m (surface area of mineral m in unit bulk volume of porous media) is determined when the shape of the grains is specified. For spherical grains, the size variable is the radius R_m, so that

$$n_m = \frac{3V_m}{4\pi R_m^3} \tag{2.23}$$

and

$$A_m = 4\pi R_m^2 n_m \tag{2.24}$$

By assuming that a dissolution/precipitation reaction is a surface-limited kinetic reaction, observing the rate law of Equation (2.21), the change rate of the volume fraction is

$$\frac{\partial V_m}{\partial t} = 4\pi R_m^2 n_m \frac{\partial R_m}{\partial t} \tag{2.25}$$

For general cases of more than one dissolution/precipitation reaction occurring for one mineral, the rate of change of the mineral radius is

$$\frac{\partial R_m}{\partial t} = \sum_{j=1}^{N_k} \frac{k_j}{\rho_m} \left[\prod_{\nu_{ij}<0} (\gamma_i c_i)^{\frac{|\nu_{ij}|}{f_j}} - \prod_{\nu_{ij}>0} (\gamma_i c_i)^{\frac{\nu_{ij}}{f_j}} \Big/ \left(K_j^{eq}\right)^{1/f_j} \right] \tag{2.26}$$

where ρ_m is the molar density of mineral m (mol m^{-3}), and the summation is over all kinetic reactions pertaining to mineral m.

Substituting Equation (2.24) into Equation (2.21) gives

$$W_j^k = 4\pi R_{m(j)}^2 n_{m(j)} k_j \left[\prod_{\nu_{ij}<0} (\gamma_i c_i)^{\frac{|\nu_{ij}|}{f_j}} - \prod_{\nu_{ij}>0} (\gamma_i c_i)^{\frac{\nu_{ij}}{f_j}} \Big/ \left(K_j^{eq}\right)^{1/f_j} \right] \tag{2.27}$$

that serves as a bridge between the aqueous phase and solid phases so that the whole system is mass-conservative.

2.4 Coupling Between Fluid Flow and Geochemical Reactions

2.4.1 Porosity Changes Coupled with Multiphase Flow

Porosity changes due to mineral dissolution and precipitation could have a significant effect on the flow regime surrounding the disposal facility. Therefore, porosity changes, calculated by the STORM texture solver, are coupled with the multiphase flow solver. Dissolution and precipitation reactions can change the volume fractions of solids as a function of time, thus changing the porosity as described in

Section 2.3.3. Furthermore, intrinsic permeability varies as a function of porosity. Two options for modeling this relationship are available in STORM. One option is the Fair and Hatch (1933) formula, developed from dimensional considerations and verified experimentally,

$$k = \frac{1}{\beta}\left[\frac{(1-\phi_T)^2}{\phi_T^3}\left(\frac{\alpha}{100}\sum_{(m)}\frac{P_m}{d_m}\right)^2\right]^{-1} \tag{2.28}$$

where k = intrinsic permeability in cm^2
β = packing factor, found experimentally to be about 5
α = sand shape factor, varying from 6.0 for spherical grains to 7.7 for angular ones
P_m = percentage of sand held between adjacent sieves
d_m = geometric mean diameter of adjacent sieves

The second option is the Kozeny-Carmen equation that was obtained from a theoretical derivation of Darcy's law and includes numerical coefficients that must be determined empirically,

$$k = C_0 \frac{\phi_T^3}{(1-\phi_T)^2 M_S^2}, \tag{2.29}$$

where M_S = specific surface area of the porous matrix (defined per unit volume of solid)
C_o = coefficient for which Carman (1937) suggested the value of 1/5

This modification was tested on a 3-node problem to ensure that water mass was being conserved as porosity varied during glass dissolution.

2.4.2 Water Consumption in Chemical Reactions Coupled with Multiphase Flow

Consumption of water varied during dissolution of waste glass, such as the following hydrolysis reaction for LD6-5412 glass:

$$\begin{aligned} &Glass + 0.5OH^- + 0.45H_2O = 0.0202K^+ + 0.4208Na^+ 0.046Ca^{2+} + \\ &0.154Al(OH)_{3(aq)} + 0.094BO_2^- + 0.2712HSiO_3^- + 0.3348H_2SiO_4^{2-} + \\ &2.2795x10^{-8}SeO_3^{2-} + 1.6172x10^{-6}TcO_4^{2-} + 3.8318x10^{-8}IO_3^- + \\ &2.7213x10^{-5}U(OH)_{4(aq)} + 1.9265x10^{-9}Pu(OH)_5^- + 2.7251x10^{-9}NpO_2(OH)_{(aq)} \end{aligned} \tag{2.30}$$

The consumption/production of water during precipitation of hydrated minerals may be large enough to affect unsaturated flow in the region of the waste repository. The STORM code couples unsaturated

flow with water production/consumption by chemical reactions through the mass source rate of water in Equation (2.1).

$$\dot{m}^w = \sum_{j=1}^{N_r} \nu_{wj} W_j / \Omega \tag{2.31}$$

where N_r is the total number of reactions, ν_{wj} is the stoichiometric coefficient of water in reaction j, W_j is the rate of reaction per unit bulk volume, given by Equation (2.21), and Ω is the number of moles of solvent water comprising a mass of 1 kg (Ω=55.51). The water source/sink term due to reactions is added to any other water source/sinks specified in the STORM input file.

2.4.3 Gas Consumption in Chemical Reactions Coupled with Multiphase Flow

Consumption of gaseous species, particularly oxygen, may occur at large enough rates to affect the flow of air in the vadose zone. The STORM code couples unsaturated flow with gas production/consumption by chemical reactions through the mass source rate of air in Equation (2.4).

$$\dot{m}^a = \sum_{j=1}^{N_r} \nu_{gj} W_j M_j \tag{2.32}$$

where N_r is the total number of reactions, ν_{gj} is the stoichiometric coefficient of the gaseous species in reaction j, W_j is the rate of reaction per unit bulk volume, and M_j is the molecular weight of the gaseous species. The gas source/sink term due to reactions is added to any other gas source/sinks specified in the STORM input file.

3.0 Numerical Solution Methods

3.1 Introduction

The STORM simulator solves the governing-conservation equations and constitutive functions using numerical techniques for nonlinear systems. This section documents the transformation of the governing-conservation equations from partial-differential form to algebraic form, algebraic expression of boundary conditions, linearization of the conservation equations and constitutive functions, and solution of linear systems.

The governing-conservation equations for water, air, and energy conservation are discretized to algebraic form following the integrated-finite-difference method of (Patankar 1980). This transformation requires the physical domain to be spatially discretized into an orthogonal computational domain comprised of non-overlapping volumes (nodes). Each volume can contain a maximum of two neighboring nodes for each dimensional direction. Intrinsic properties are assumed to be uniform over the volume domain and are defined for a node point at the geometric center of the volume. Flux quantities are defined at the geometric center of the surfaces between node volumes and along a direction parallel to the surface normal. Fluxes across node surfaces between neighboring inactive nodes or adjacent to the domain boundary are controlled through boundary conditions. Solution of the governing-conservation equations in time requires discretization of the time domain. The method of Patankar (1980) is implicit using backward Euler time differencing. The expressions that result from discretizing the governing equations are nonlinear algebraic equations.

The STORM simulator uses a Cartesian grid system. Coordinate directions for Cartesian systems follow the right-hand rule from the x to y to z directions. Positive and negative directions along the x, y, and z coordinates are referred to as East, West, North, South, Top, and Bottom, respectively. The gravitational vector can be aligned arbitrarily with respect to the Cartesian directions.

The system of algebraic equations that include the discretized governing-conservation equations and the constitutive functions are nonlinear. Non-linearities in the soil-moisture retention functions, relative permeability functions, and physical properties near phase transitions are the primary contributors. Conversion of the algebraic equations from nonlinear to linear form follows the iterative Newton-Raphson (Kreyszig 1979) technique for multiple variables. Typically, the technique yields quadratic convergence of the residuals, given sufficiently close estimates of the primary unknowns. Each iteration loop requires the solution of a system of linear equations in terms of the equation residuals. Because only orthogonal grid systems are considered, the system of linear equations has a block-banded structure.

The governing-conservation equations are discretized following the integrated finite difference of Patankar (1980) that is locally and globally conserving. Mass conservation equations for water and air components are nearly identical in form and, therefore, result in similar algebraic forms. The

conservation equation for energy differs from the mass conservation equations having diffusive-dispersive and advective components. Discretization of combined diffusive and advective transport requires donor-cell weighting of the transport components, yielding different algebraic forms than those for the mass conservation equations. The conservation equation for solute transport is similar in form to the energy conservation equation, but its discretization uses a different donor-cell weighting scheme, resulting in a separate algebraic form.

3.2 Water and Air Mass Conservation Equation

The water and air mass conservation equations, shown in Equations **(2.1)** and **(2.4)**, are discretized by assuming a piecewise profile to express the variation in primary variables between node points and integrating over the node volume. The accumulation terms (that is, left-hand-side terms) are integrated over the node volume according to Equation (3.1), where the specific terms for the water and air conservation equations appear as shown in Equations (3.2) and (3.3), respectively. Intrinsic properties for the node volume are represented by properties at the node centroid. Source terms are similarly integrated over the node volume according to Equation (3.4).

$$\frac{\partial}{\partial t}\left[\int_{\bar{V}} \overline{M}^{j} d\bar{V}\right] = \frac{\partial}{\partial t}\left[\overline{M}^{j}\bar{V}\right] \quad \text{for } j = w,a \tag{3.1}$$

$$\frac{\partial}{\partial t}\left[\overline{M}^{w}\bar{V}\right] = \frac{\partial}{\partial t}\left[\bar{V}\sum_{\gamma=l,g}\left(\phi_D \omega_\gamma^w \rho_\gamma s_\gamma\right)\right] \tag{3.2}$$

$$\frac{\partial}{\partial t}\left[\overline{M}^{a}\bar{V}\right] = \frac{\partial}{\partial t}\left[\bar{V}\sum_{\gamma=l,g}\left(\phi_D \omega_\gamma^a \rho_\gamma s_\gamma\right)\right] \tag{3.3}$$

$$\int_{\bar{V}} \dot{m}^{j} d\bar{V} = \dot{m}^{j}\bar{V} \quad \text{for } j = w,a \tag{3.4}$$

Flux terms are evaluated on the node surfaces and for the mass conservation equations comprise advective and diffusive components. Integration of the flux terms over the node volume proceeds by first converting the volumetric integral of flux over a control volume to a surface integral through Green's theorem (Kreyszig 1979) according to Equation (3.5). Discretizing the control volume surfaces into node surfaces and defining flux directions parallel to the surface normal allows the surface integrals to be converted to summations over all node surfaces, according to Equation (3.6). This transformation strictly requires an orthogonal grid system for the flux directions to be aligned with the surface normals.

Nonorthogonal systems will yield mass balance errors. Darcy fluxes are discretized, in the six coordinated directions, using upwind interfacial averaging for the component mass fraction, phase density, and relative permeability and harmonic averaging for the intrinsic permeability and phase viscosity according to Equation (3.6). These default interfacial averaging schemes can be altered by user input. Diffusive fluxes are discretized, in the six coordinate directions, using harmonic averaging for the combination of terms that comprise an effective diffusion coefficient. The user can also alter the default interfacial averaging scheme for each parameter. Geometric variables for a Cartesian coordinate system are shown in Figure 3.1 for the X-Z coordinate plane and in Figure 3.2 for the Y-Z coordinate plane.

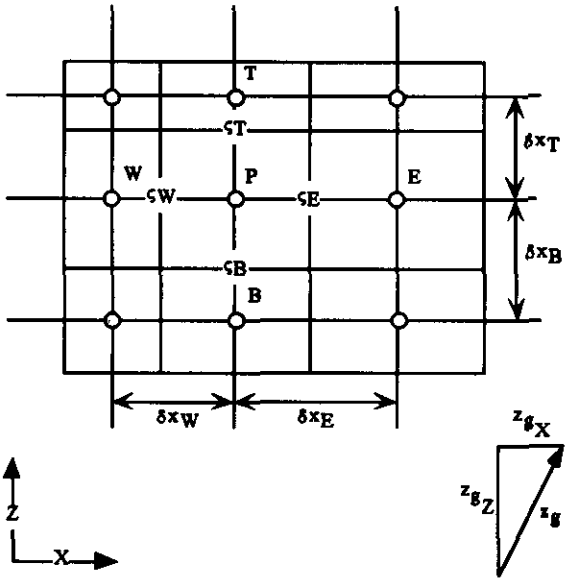

Figure 3.1. X-Z Coordinate Plane for Cartesian Systems

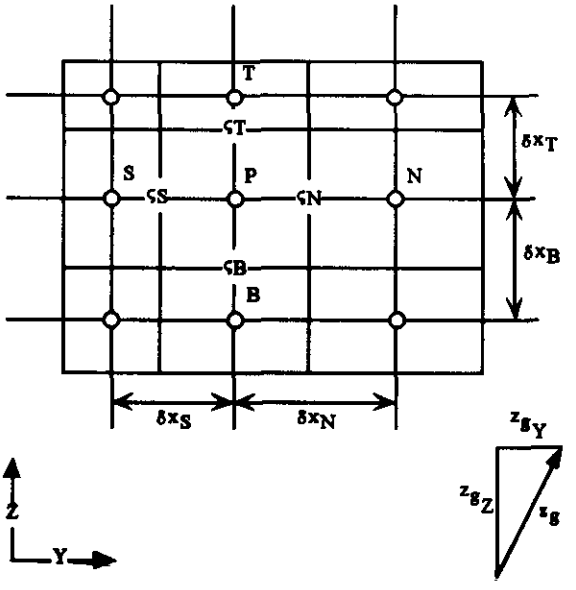

Figure 3.2. Y-Z Coordinate Plane for Cartesian Systems

$$\int_{\bar{V}}\left[\sum_{\gamma=l,g}\left(\nabla\mathbf{F}_\gamma^j+\nabla\mathbf{J}_\gamma^j\right)d\bar{V}\right]=\int_{\Gamma}\left[\sum_{\gamma=l,g}\left(\mathbf{F}_\gamma^j+\mathbf{J}_\gamma^j\right)\cdot\mathbf{n}d\Gamma\right]\ \text{for}\ j=w,a \tag{3.5}$$

where $\int_{\bar{V}}[\ ]d\bar{V}$ = volume integral

$\int_{\Gamma}[\ ]d\Gamma$ = surface integral

$\sum_{\gamma=l,g}$ = summation over aqueous and gas phases

$\sum_{j=w,a}$ = summation over water and air components

where

$$\mathbf{F}_\gamma^j=\frac{\omega_\gamma^j\rho_\gamma k_{r\gamma}\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma+\rho_\gamma g\mathbf{z}_g\right)\ \text{for}\ \gamma=l,g\ \text{and}\ j=w,a$$

$$\mathbf{J}_\gamma^j=-\tau_\gamma\phi_D\rho_\gamma s_\gamma\frac{M^j}{M_\gamma}D_\gamma^j\nabla\chi_\gamma^j\ \text{for}\ \gamma=l,g\ \text{and}\ j=w,a$$

$$\int_{\Gamma}\left[\sum_{\gamma=l,g}\left(\mathbf{F}_\gamma^j+\mathbf{J}_\gamma^j\right)\cdot\mathbf{n}d\Gamma\right]=\sum_{\varsigma=\mathrm{W,E,S,N,T,B}}\left[\sum_{\gamma=\mathrm{l,g}}\left(\mathrm{F}_{\gamma\varsigma}^{\mathrm{j}}+J_{\gamma\varsigma}^{\mathrm{j}}\right)\right]\mathrm{A}_\varsigma\ \ \text{for}\ j=w,a \tag{3.6}$$

where A_ς is the area of surface ς, and where,

$$F_{\gamma\varsigma}^j=-\frac{\left\langle\omega_\gamma^j\rho_\gamma k_{r\gamma}\right\rangle_\varsigma^{uw}\left\langle\mathbf{k}\right\rangle_\varsigma^h}{\left\langle\mu_\gamma\right\rangle_\varsigma^h}\left[\frac{P_{\gamma\varsigma+}-P_{\gamma\varsigma-}}{\delta x_\varsigma}+\left\langle\rho_\gamma g\right\rangle_\varsigma^a z_{g\varsigma}\right]\ \text{for}\ \gamma=l,g;j=w,a;\ \text{and}\ \varsigma=E,W,S,N,B,T$$

$$J_{\gamma\varsigma}^j=-\left\langle\tau_\gamma\phi_D\rho_\gamma s_\gamma\frac{M^j}{M_\gamma}D_\gamma^j\right\rangle_\varsigma^h\frac{\chi_{\gamma\varsigma+}^j-\chi_{\gamma\varsigma-}^j}{\delta x_\varsigma}\ \ \text{for}\ \gamma=l,g;j=w,a;\ \text{and}\ \varsigma=E,W,S,N,B,T$$

and where $\langle\ \rangle_{\varsigma}^{h}$ represents harmonic interfacial averaging at surface ς, $\langle\ \rangle_{\varsigma}^{uw}$ represents upwind or donor cell interfacial averaging at surface ς, $\langle\ \rangle_{\varsigma}^{a}$ represents harmonic interfacial averaging at surface ς, and $\sum_{\varsigma=W,E,S,N,T,B}$ is the summation over all node surfaces (West, East, South, North, Top, Bottom).

The mass conservation equations are discretized in time using a fully implicit scheme according to Equation (3.7), where the time levels are indicated with superscripts. The primary unknowns for the mass conservation equations are intrinsic properties at node volume centroids (node grid point) for time level $t+\delta t$.



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(3.7)

Converting Equation (3.7) to residual form, where $\bar{R}^{j}$ is the residual for the mass conservation equation of component j, yields the expression shown in Equation (3.8).

$$\left\{\bar{R}^{j}\right\}^{t+\delta t} = \bar{V}\left[\frac{\left\{\bar{M}^{j}\right\}^{t+\delta t} - \left\{\bar{M}^{j}\right\}^{t}}{\delta t}\right] - \bar{V}\left\{\dot{m}^{j}\right\}^{t+\frac{\delta t}{2}} + \sum_{\varsigma=W,E,S,N,T,B}\left[\sum_{\gamma=l,g}\left(\left\{F_{\gamma\varsigma}^{j}\right\}^{t+\delta t} + \left\{J_{\gamma\varsigma}^{j}\right\}^{t+\delta t}\right)\right]A_{\varsigma} \quad \text{for } j = w,a \tag{3.8}$$

3.3 Energy Conservation Equation

The energy conservation equation, shown in Equation **(2.7)**, is discretized by assuming a piecewise profile to express the variation in primary variables between node points and integrating over the node volume. The thermal capacitance terms (that is, left-hand-side terms) and energy source terms are integrated over the node volume according to Equations (3.9) and (3.10), respectively.

$$\frac{\partial}{\partial t}\left[\int_{\bar{V}} \bar{E}\,d\bar{V}\right] = \frac{\partial}{\partial t}\left[\bar{E}\bar{V}\right] \tag{3.9}$$

where

$$\bar{E} = \sum_{\gamma=l,g} \left(\phi_D \, \rho_\gamma \, s_\gamma \, u_\gamma\right) + \left(1-\phi_T\right) \rho_s \, u_s + \left(\phi_T - \phi_D\right) \rho_l \, u_l$$

$$\int_{\bar{V}} \left[\sum_{j=w,a} \left(h^j \dot{m}^j\right) + \dot{Q} \right] d\bar{V} = \left[\sum_{j=w,a} \left(h^j \dot{m}^j\right) + \dot{Q} \right] \bar{V} \tag{3.10}$$

Thermal energy is transferred through advection and diffusion. Spatial discretization of the advective and diffusive thermal flux proceeds by first converting the volumetric integral of flux over a control volume to a surface integral using Green's theorem (Kreyszig 1979), according to Equation (3.11). Surface integrals are approximated by discretizing the control volume surfaces into node surfaces and summing the contributions to heat flux over the node surfaces, according to Equation (3.12).

$$\begin{aligned} &\int_{\bar{V}} \left[-\sum_{\gamma=l,g} \left(\nabla \rho_\gamma h_\gamma \mathbf{q}_\gamma + \sum_{j=w,a} \left(\nabla h^j \mathbf{J}_\gamma^j\right) + \nabla\left(\mathbf{k}_e \nabla T\right) \right) \right] d\bar{V} \\ &= \int_{\Gamma} \left[-\sum_{\gamma=l,g} \left(\rho_\gamma h_\gamma \mathbf{q}_\gamma + \sum_{j=w,a} \left(h^j \mathbf{J}_\gamma^j\right) + \left(\mathbf{k}_e \nabla T\right) \right) \right] \mathbf{n} d\Gamma \end{aligned} \tag{3.11}$$

where

$$\mathbf{q}_\gamma = -\frac{k_{r\gamma}\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma + \rho_\gamma g \mathbf{z}_g\right) \quad \text{for } \gamma = l,g$$

$$\mathbf{J}_\gamma^j = -\tau_\gamma \phi_D \rho_\gamma s_\gamma \frac{M^j}{M_\gamma} D_\gamma^j \nabla \chi_\gamma^j \quad \text{for } \gamma = l,g \text{ and } j = w,a$$

$$\begin{aligned} &\int_{\Gamma} \left[-\sum_{\gamma=l,g} \left(\rho_\gamma h_\gamma \mathbf{q}_\gamma + \sum_{j=w,a} \left(h^j \mathbf{J}_\gamma^j\right) + \left(\mathbf{k}_e \nabla T\right) \right) \right] \mathbf{n} d\Gamma \\ &= \sum_{\varsigma=W,E,S,N,B,T} \left[-\sum_{\gamma=l,g} \left(\left(\rho_\gamma h_\gamma \mathbf{q}_\gamma\right)_\varsigma + \sum_{j=w,a} \left(h^j \mathbf{J}_\gamma^j\right)_\varsigma + \left(\mathbf{k}_e \nabla T\right)_\varsigma \right) \right] A_\varsigma \end{aligned} \tag{3.12}$$

where

$$q^j_{\gamma\varsigma} = -\frac{\left\langle k_{r\gamma}\right\rangle^{uw}_{\varsigma}\left\langle \mathbf{k}\right\rangle^{h}_{\varsigma}}{\left\langle \mu_\gamma \right\rangle^{h}_{\varsigma}}\left[\frac{P_{\gamma\varsigma+}-P_{\gamma\varsigma-}}{\delta x_\varsigma}+\left\langle \rho_\gamma g\right\rangle^{a}_{\varsigma} z_{g\varsigma}\right] \text{ for } \gamma = l,g; j = w,a; \text{ and } \varsigma = E,W,S,N,B,T$$

$$J^j_{\gamma\varsigma} = -\left\langle \tau_\gamma \phi_D \rho_\gamma s_\gamma \frac{M^j}{M_\gamma} D^j_\gamma \right\rangle^{h}_{\varsigma}\frac{\chi^j_{\gamma\varsigma+}-\chi^j_{\gamma\varsigma-}}{\delta x_\varsigma} \text{ for } \gamma = l,g; j = w,a; \text{ and } \varsigma = E,W,S,N,B,T$$

The diffusive term of Equation (3.12) is computed using a user-defined interfacial average for the effective thermal conductivity, where the default form is harmonic averaging, according to Equation (3.13). The advective components of Equation (3.12) are computed using upwind (donor cell) averaging, according to Equations (3.14) and (3.15).

$$\left(\mathbf{k}_e \nabla T\right)_\varsigma = \left\langle \mathbf{k}_e\right\rangle^{h}_{\varsigma}\frac{T_{\varsigma+}-T_{\varsigma-}}{\delta x_\varsigma} \text{ for } \varsigma = E,W,S,N,B,T \tag{3.13}$$

$$\left(\rho_\gamma h_\gamma \mathbf{q}_\gamma\right)_\varsigma = \left(\rho_\gamma h_\gamma\right)_{\varsigma-}\max\left[q_{\gamma\varsigma-},0\right]-\left(\rho_\gamma h_\gamma\right)_{\varsigma+}\max\left[-q_{\gamma\varsigma+},0\right] \quad \text{for } \gamma = l,g \text{ and } \varsigma = E,W,S,N,B,T \tag{3.14}$$

$$\left(h^j \mathbf{J}^j_\gamma\right)_\varsigma = \left(h^j\right)_{\varsigma-}\max\left[J^j_{\gamma-},0\right]-\left(h^j\right)_{\varsigma+}\max\left[-J^j_{\gamma+},0\right] \quad \text{for } \gamma = l,g \text{ and } \varsigma = E,W,S,N,B,T \tag{3.15}$$

As with the mass conservation equations, the energy conservation equations are discretized in time using a fully implicit scheme, according to Equation (3.16), where the time levels are indicated with superscripts. The primary unknowns for the energy equation are the temperatures at the node centroids (node grid points) for time level t + δt. In residual form, Equation (3.16) appears as shown in Equation (3.17).

$$\bar{V}\left[\frac{\{\bar{E}\}^{t+\delta t}-\{\bar{E}\}^{t}}{\delta t}\right] = \bar{V}\left\{\sum_{j=w,a}\left(h^j \dot{m}^j\right)+\dot{Q}\right\}^{t+\frac{\delta t}{2}} = \sum_{\varsigma=W,E,S,N,B,T}\left[\left\{\left(\mathbf{k}_e\nabla T\right)_\varsigma\right\}^{t+\delta t}\right]A_\varsigma - \sum_{\varsigma=W,E,S,N,B,T}\left[\sum_{\gamma=l,g}\left(\left\{\left(\rho_\gamma h_\gamma \mathbf{q}_\gamma\right)_\varsigma\right\}^{t+\delta t}-\sum_{j=w,a}\left\{\left(h^j \mathbf{J}^j_\gamma\right)_\varsigma\right\}^{t+\delta t}\right)\right]A_\varsigma \tag{3.16}$$

$$\{R_e\}^{t+\delta t} = \bar{V}\left[\frac{\{E\}^{t+\delta t} - \{E\}^{t}}{\delta t}\right] - \bar{V}\left\{\sum_{j=w,a}\left(h^j \dot{m}^j\right) + \dot{Q}\right\}^{t+\frac{\delta t}{2}}$$
$$- \sum_{\varsigma=W,E,S,N,B,T}\left[\left\{\left(\mathbf{k}_e \nabla T\right)_\varsigma\right\}^{t+\delta t}\right] A_\varsigma \qquad (3.17)$$
$$+ \sum_{\varsigma=W,E,S,N,B,T}\left[\sum_{\gamma=l,g}\left(\left\{\left(\rho_\gamma h_\gamma \mathbf{q}_\gamma\right)_\varsigma\right\}^{t+\delta t} - \sum_{j=w,a}\left\{\left(h^j \mathbf{J}_\gamma^j\right)_\varsigma\right\}^{t+\delta t}\right)\right] A_\varsigma$$

3.4 Solute Conservation Equation

The solute mass conservation equation, shown in Equation **(2.10)** is discretized by assuming a piecewise profile for the solute concentration between node points and integrating over the node volume. The advection and diffusion-dispersion transport terms of the solute mass conservation equation are combined following the power-law scheme of Patankar (1980). Integration of the accumulation, source, and decay terms for solute mass over the node volume proceeds according to Equation (3.18).

$$\int_{\bar{V}}\left(\frac{\partial C}{\partial t} - \dot{m}^C - \dot{R}^C C\right) d\bar{V} = \frac{\partial C}{\partial t}\bar{V} - \dot{m}^C \bar{V} - \dot{R}^C C \bar{V} \qquad (3.18)$$

Solute transport fluxes are computed between node points and comprise advective and diffusive-dispersive components. Integration of the flux terms proceeds by converting volumetric integrals to surface integrals following Green's theorem (Kreyszig 1979), according to Equation (3.19). Surface integrals are approximated by discretizing the control volume surfaces into node surfaces and summing the contributions to solute transport over the node surfaces, according to Equation (3.20). The diffusive-dispersive term of Equation (3.20) is computed using a user-defined interfacial average where the default scheme is harmonic averaging, according to Equation (3.21).

$$\int_{\bar{V}}\left[-\sum_{\gamma=l,g}\left(\nabla\left[C_\gamma q_\gamma\right]\right) + \sum_{\gamma=l,g}\left(\nabla\left[\left(\tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right)\nabla C_\gamma\right]\right)\right] d\bar{V}$$
$$= \int_{\Gamma}\left[-\sum_{\gamma=l,g}\left(C_\gamma q_\gamma\right) + \sum_{\gamma=l,g}\left(\left(\tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right)\nabla C_\gamma\right)\right] \cdot \mathbf{n} d\Gamma \qquad (3.19)$$

where

$$\mathbf{q}_\gamma = -\frac{k_{r\gamma}\,\mathbf{k}}{\mu_\gamma}\left(\nabla P_\gamma + \rho_\gamma\, g\, \mathbf{z}_g\right) \text{ for } \gamma = l, g$$

$$\begin{aligned}&\int_\Gamma \left[-\sum_{\gamma=l,g}\left(C_\gamma q_\gamma\right) + \sum_{\gamma=l,g}\left(\left(\tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right)\nabla C_\gamma\right)\right]\cdot \mathbf{n}\, d\Gamma \\ &= \sum_{\varsigma=W,E,S,N,B,T}\left[-\sum_{\gamma=l,g}\left(C_\gamma q_\gamma\right)_\varsigma + \sum_{\gamma=l,g}\left(\left(\tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right)\nabla C_\gamma\right)_\varsigma\right] A_\varsigma\end{aligned} \tag{3.20}$$

where

$$q_{\gamma\varsigma}^j = -\frac{\left\langle k_{r\gamma}\right\rangle_\varsigma^{uw}\left\langle \mathbf{k}\right\rangle_\varsigma^h}{\left\langle \mu_\gamma\right\rangle_\varsigma^h}\left[\frac{P_{\gamma\varsigma+} - P_{\gamma\varsigma-}}{\delta x_\varsigma} + \left\langle \rho_\gamma g\right\rangle_\varsigma^a z_{g\varsigma}\right] \text{ for } \gamma = l,g;\ j = w,a;\ \text{and } \varsigma = E,W,S,N,B,T$$

$$\left(\left(\tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right)\nabla C_\gamma\right)_\varsigma = \left\langle \tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right\rangle_\varsigma^h \frac{C_{\gamma\varsigma+} - C_{\gamma\varsigma-}}{\delta x_\varsigma} \tag{3.21}$$

$$\text{for } \gamma = l,g \text{ and } \varsigma = E,W,S,N,B,T$$

Solution of the solute transport equation depends on the local Peclet number that represents the ratio of advective transport to diffusive-dispersive transport, according to Equation (3.22)

$$Pe_{\gamma_\varsigma} = \frac{q_{\gamma\varsigma}\delta x_\varsigma}{\left\langle \tau_\gamma\, s_\gamma \phi_D D_\gamma^C + s_\gamma \phi_D \mathbf{D}_{h\gamma}\right\rangle_\varsigma^h} \tag{3.22}$$

The power law scheme is based on the solute concentration profile for steady conditions with no sources or decay. For a Peclet number of zero, diffusion-dispersion transport dominates and a linear profile of solute concentration occurs between two spatial points. For a Peclet number of one, advection and diffusion-dispersion equally contribute to solute transport. The solute concentration profile will be skewed towards an upstream solute concentration. For large Peclet numbers, advection transport dominates and the upstream solute concentration defines the solute concentration profile between two spatial points. The power-law scheme closely approximates the exact solution for steady conditions without excessive computational expense. Solute flux from combined advective and diffusive-dispersive transport can be expressed using the power-law scheme according to Equation (3.23).

$$G^C_{\gamma_\varsigma} = -C_{\gamma_{\varsigma^+}}\left[\max\left(-q_{\gamma_\varsigma},0\right)+\left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1-\left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5,0\right)\right]$$

$$+C_{\gamma_{\varsigma^-}}\left[\max\left(q_{\gamma_\varsigma},0\right)+\left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1-\left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5,0\right)\right] \qquad (3.23)$$

for $\gamma = l,g$ and $\varsigma = W,E,S,N,B,T$

where

$$\left(D^C_{\gamma_e}\right)_\varsigma = \frac{\left\langle \tau_\gamma\, s_\gamma \phi_D D^C_\gamma + s_\gamma \phi_D \mathbf{D}_{h\gamma} \right\rangle^h_\varsigma}{\delta x_\varsigma}$$

The discretized solute concentration equation can be written in two compact forms. The first form uses the expressions of solute flux according to Equation (3.24). The second form uses a linear system format with coefficients for the solute concentrations according to Equation (3.25).

$$\sum_{\gamma=l,g}\left(G^C_{\gamma_W} - G^C_{\gamma_E} + G^C_{\gamma_S} - G^C_{\gamma_N} + G^C_{\gamma_B} - G^C_{\gamma_T}\right) = \frac{\partial C}{\partial t}\bar{V} - \dot{m}^C\bar{V} - \dot{R}^C C\bar{V} \qquad (3.24)$$

$$a_P C_P - \sum_{\varsigma=W,E,S,N,B,T} a_\varsigma C_\varsigma = \frac{\partial C}{\partial t}\bar{V} - \dot{m}^C\bar{V} - \dot{R}^C C\bar{V} \qquad (3.25)$$

where

$$a_\varsigma = \sum_{\gamma=l,g} a_{\gamma_\varsigma}$$

$$a_{\gamma_P} = \sum_{\varsigma=W,E,S,N,B,T} a_{\gamma_\varsigma} + \sum_{\varsigma=E,N,T} q_{\gamma_\varsigma} - \sum_{\varsigma=W,S,B} q_{\gamma_\varsigma}$$

$$a_{\gamma_\varsigma} = \max\left(q_{\gamma_\varsigma}, 0\right) + \left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1 - \left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5, 0\right) \text{ for } \gamma = l,g \text{ and } \varsigma = W,S,B$$

$$a_{\gamma_\varsigma} = \max\left(-q_{\gamma_\varsigma}, 0\right) + \left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1 - \left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5, 0\right) \text{ for } \gamma = l,g \text{ and } \varsigma = E,N,T\,.$$

The solute mass conservation equation is discretized in time using a fully implicit scheme, according to Equation (3.26), in linear system format, where time levels are indicated with superscripts.

$$\sum_{\varsigma=P,w,E,S,N,B,T} a_\varsigma \left\{C_\varsigma\right\}^{t+\delta t} = \frac{\left\{C_P\right\}^t}{\delta t}\bar{V} - \dot{m}^C\bar{V} \tag{3.26}$$

where

$$a_\varsigma = \sum_{\gamma=l,g} a_{\gamma_\varsigma}$$

$$a_{\gamma_P} = \sum_{\varsigma=W,E,S,N,B,T} a_{\gamma_\varsigma} + \sum_{\varsigma=E,N,T} V_{\gamma_\varsigma} - \sum_{\varsigma=W,S,B} V_{\gamma_\varsigma} + \frac{\bar{V}}{\delta t} + \dot{R}^C\bar{V}$$

$$a_{\gamma_\varsigma} = \max\left(q_{\gamma_\varsigma}, 0\right) + \left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1 - \left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5, 0\right) \text{ for } \gamma = l,g \text{ and } \varsigma = W,S,B$$

$$a_{\gamma_\varsigma} = \max\left(-q_{\gamma_\varsigma}, 0\right) + \left(D^C_{\gamma_e}\right)_\varsigma \max\left(\left(1 - \left(\frac{0.1\left|q_{\gamma_\varsigma}\right|}{\left(D^C_{\gamma_e}\right)_\varsigma}\right)\right)^5, 0\right) \text{ for } \gamma = l,g \text{ and } \varsigma = E,N,T\,.$$

3.4.1 Newton-Raphson Linearization

The discretized governing equations for component mass conservation and energy conservation, Equations (3.8) and (3.17), form a nonlinear set of algebraic equations. Nonlinear equation sets arise from the dependence of secondary variables on the primary unknowns. Cross dependencies of secondary

variables in one governing equation with the primary variable unknown in other governing equations requires this system of nonlinear equations be solved simultaneously. A primary assumption associated with the solute mass conservation equation is that solute concentrations are infinitely dilute. This assumption implies that fluid properties are independent of solute concentrations, which allows the solute conservation equations to be solved separately from the coupled flow and energy transport solutions. The discretized governing equations for solute mass conservation, Equation (3.26), form a linear set of algebraic equations that are solved directly following the solution of the coupled flow and energy transport system. The nonlinear situations in the coupled flow and energy transport system of equations are resolved through the application of the iterative Newton-Raphson technique.

The Newton-Raphson linearization technique is an iterative method for solving nonlinear algebraic equations of the form shown in Equation (3.27), where $f(x)$ is differentiable in x. The linearization concept approximates $f(x)$ with suitable tangents. Each iteration yields a new estimate of x as the intersection of the tangent to the function $f(x)$ at the previous estimate of x and the abscissa axis, according to Equation (3.28) in mathematical form. In this formulation, $f(x)$ is considered the equation residual. For convergent systems, the residual decreases quadratically with iteration. In multiple variable systems, as with the coupled flow and energy transport system, the scalar function, $f(x)$, is replaced with a vector function $\mathbf{R}(\mathbf{x})$, according to Equation (3.29). The vector function, $\mathbf{R}(\mathbf{x})$, represents the system of nonlinear algebraic equations produced from discretizing the conservation equations for component mass and energy, Equations (3.8) and (3.17). The vector of unknowns, $\mathbf{x}$, represents the set of primary variables for the system that are determined by the operational mode and phase conditions. Equation (3.29) can be rewritten in terms of increments to the primary variables, according to Equation (3.30). The partial derivatives shown in Equation (3.30) form the Jacobian matrix.

$$f(x)=0 \tag{3.27}$$

$$x^{n+1}=x^{n}-\frac{f(x)}{f'(x)} \tag{3.28}$$

$$x^{n+1}=x^{n}-\frac{\mathbf{R}(\mathbf{x})}{\mathbf{R}'(\mathbf{x})} \tag{3.29}$$

$$\frac{\partial \mathbf{R}(\mathbf{x})}{\partial \mathbf{x}}\Delta\mathbf{x}=-\mathbf{R}(\mathbf{x}) \tag{3.30}$$

To simplify these discussions, a one-dimensional system involving the solution of the water mass, air mass, and energy conservation equations is considered. The system of linear equations that result from

applying the Newton-Raphson linearization technique to this system of nonlinear algebraic equations is shown in Equation (3.31) for a computational domain with n nodes. In Equation (3.31), each Jacobian matrix element represents a block matrix of order three, according to Equation (3.32). Each unknown vector element represents a vector of increments to the primary variables of order three, according to Equation (3.33). Each solution vector element represents a vector of equation residuals of order three, according to Equation (3.34).

$$\begin{vmatrix} \frac{\partial \mathbf{R}_1}{\partial \mathbf{x}_1} & \frac{\partial \mathbf{R}_1}{\partial \mathbf{x}_2} & 0 & 0 & \cdot & 0 & 0 & 0 \\ \frac{\partial \mathbf{R}_1}{\partial \mathbf{x}_1} & \frac{\partial \mathbf{R}_2}{\partial \mathbf{x}_2} & \frac{\partial \mathbf{R}_2}{\partial \mathbf{x}_3} & 0 & \cdot & 0 & 0 & 0 \\ 0 & \frac{\partial \mathbf{R}_3}{\partial \mathbf{x}_2} & \frac{\partial \mathbf{R}_3}{\partial \mathbf{x}_3} & \frac{\partial \mathbf{R}_3}{\partial \mathbf{x}_4} & \cdot & 0 & 0 & 0 \\ 0 & 0 & \frac{\partial \mathbf{R}_4}{\partial \mathbf{x}_3} & \frac{\partial \mathbf{R}_4}{\partial \mathbf{x}_4} & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & \cdot & \frac{\partial \mathbf{R}_{n-2}}{\partial \mathbf{x}_{n-2}} & \frac{\partial \mathbf{R}_{n-2}}{\partial \mathbf{x}_{n-1}} & 0 \\ 0 & 0 & 0 & 0 & \cdot & \frac{\partial \mathbf{R}_{n-1}}{\partial \mathbf{x}_{n-2}} & \frac{\partial \mathbf{R}_{n-1}}{\partial \mathbf{x}_{n-1}} & \frac{\partial \mathbf{R}_{n-1}}{\partial \mathbf{x}_n} \\ 0 & 0 & 0 & 0 & \cdot & 0 & \frac{\partial \mathbf{R}_n}{\partial \mathbf{x}_{n-1}} & \frac{\partial \mathbf{R}_n}{\partial \mathbf{x}_n} \end{vmatrix} \begin{vmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \\ \mathbf{x}_4 \\ \cdot \\ \mathbf{x}_{n-2} \\ \mathbf{x}_{n-1} \\ \mathbf{x}_n \end{vmatrix} = \begin{vmatrix} -\mathbf{R}_1 \\ -\mathbf{R}_2 \\ -\mathbf{R}_3 \\ -\mathbf{R}_4 \\ \cdot \\ -\mathbf{R}_{n-2} \\ -\mathbf{R}_{n-1} \\ -\mathbf{R}_n \end{vmatrix} \tag{3.31}$$

$$\frac{\partial \mathbf{R}_k}{\partial \mathbf{x}_l} = \begin{vmatrix} \frac{\partial R_k^w}{\partial PV_l^w} & \frac{\partial R_k^w}{\partial PV_l^a} & \frac{\partial R_k^w}{\partial PV_l^e} \\ \frac{\partial R_k^a}{\partial PV_l^w} & \frac{\partial R_k^a}{\partial PV_l^a} & \frac{\partial R_k^a}{\partial PV_l^e} \\ \frac{\partial R_k^e}{\partial PV_l^w} & \frac{\partial R_k^e}{\partial PV_l^a} & \frac{\partial R_k^e}{\partial PV_l^e} \end{vmatrix} \tag{3.32}$$

$$-\mathbf{x}_l = \begin{vmatrix} \Delta PV_l^w \\ \Delta PV_l^a \\ \Delta PV_l^e \end{vmatrix} \tag{3.33}$$

$$-\mathbf{R}_k = \begin{vmatrix} -R_k^w \\ -R_k^a \\ -R_k^e \end{vmatrix} \tag{3.34}$$

For a 2-dimensional system involving the solution of the water mass, air mass, and energy conservation equations, the Jacobian matrix contains two extra bands of block matrixes: one below and one above the diagonal band. These extra bands are located one half-band width from the main diagonal band, where the half-band width equaled the lesser of the number of nodes per row or column for a 2-dimensional grid. A 3-dimensional grid contains four extra bands of block matrixes, two below and two above the diagonal band. The furthest bands are located one half-band width from the main diagonal band, where the half-band width equaled the least number of nodes in a plane. For example, a 3-dimensional Cartesian grid with 20 nodes in the X coordinate direction, 30 nodes in the Y coordinate direction, and 40 nodes in the Z coordinate direction, has a half-band width of 600.

The Newton-Raphson scheme has two major computational components. The first component involves computing the Jacobian matrix and solution vector elements; the second component involves solving the resulting linear system of equations. During each iteration, both components are required. The Jacobian matrix elements are essentially partial derivatives of the equation residuals with respect to the primary variables. These partial derivatives are computed numerically as exemplified in Equation (3.35)

$$\frac{\partial R_k^j}{\partial PV_l^i} \cong \frac{R_k^j \left|^{PV_l^i + \Delta PV_l^i} - R_k^j \right|^{PV_l^i}}{\Delta PV_l^i}. \tag{3.35}$$

For robustness and directness in coding, numerical evaluation of these partial derivatives was chosen over analytical evaluation. The numerical evaluation scheme requires that the equation residuals be evaluated with the most current values of the primary variables and with each primary variable slightly incremented. Increments to the primary variables are critical parameters for implementing the Newton-Raphson linearization scheme using numerical derivatives. Excessively large increments can lead to non-convergent solutions because the tangents to the residual equations are computed incorrectly. In contrast, excessively small increments can result in changes in the equation residuals that are below the precision limit.

Each Newton-Raphson iteration procedure begins with the start of a new time step or after a convergence failure and reduction in time step. Each iteration begins by executing logic algorithms that determine the primary variable set from phase conditions and fix the primary variable increments. The next step is to calculate all secondary variables with the current primary variables and with each primary variable incremented. Following this, all flux variables are evaluated with the current primary variable and associated secondary variables and then repeated with the incremented primary and associated secondary variables. With the secondary variables and fluxes evaluated, the residuals to the governing

equations are computed using current and incremented values of the primary, secondary, and flux variables. The current and incremented equations residuals are then used to compute the partial derivatives that comprise the Jacobian matrix and the solution vector.

The resulting system of linear equations is then solved with either a direct or iterative linear system solver, with the unknowns as increments to the primary variables. Converged solutions are recognized by comparing the maximum normalized increment to the primary variables against a convergence criterion (that is, a user-specified limit). A Newton-Raphson iteration ends by updating the primary variables with the latest computed primary increments. If the largest normalized primary variable increment exceeds the convergence limit, another iteration is executed. If the solution is convergent, the solute transport equations are solved or a new time step is initiated. In the case of a non-convergent solution, the time step is reduced, the primary variables are reset to the most recent converged values, and the time step is reinitiated.

3.4.2 Linear System Solvers

The system of linear equations that results from the discretization of the governing partial differential equations over a particular computational domain always has a banded structure, where the number of off diagonal bands equals the dimensions of the computational domain. Elements within the Jacobian coefficient are actually submatrixes, where the submatrix order equals the number of solved coupled governing equations. For example, the solution of only the water conservation equation produces single element submatrixes, whereas the simultaneous solution of the three mass conservation equations with the energy equation yields four-by-four submatrixes. These structured Jacobian coefficient matrixes arise from the element sequencing scheme incorporated into the STORM simulator and the limitations on the computational domain structures. The matrix sequencing or numbering algorithms are designed to minimize the largest half-band width for a given computational domain and solution option combination. The sequencing algorithms are designed for orthogonal grid systems that are six-surfaced in three dimensions or four-sided in two dimensions.

Two linear equation solvers are available within the STORM simulator, a direct-banded matrix algorithm and an iterative conjugate gradient algorithm. The banded matrix algorithm is generally more appropriate for small to moderately sized Jacobian matrixes (order less than 35,000); whereas, the conjugate gradient algorithm appears more appropriate for larger order Jacobian matrixes. In general, the banded matrix algorithm requires more memory than the conjugate gradient algorithm that uses an efficient sparse matrix storage scheme. The banded matrix algorithm is computationally more efficient on small to moderately sized problems; however, for larger problems the conjugate gradient algorithm is the better performer. Both linear equation solution algorithms were obtained from publicly available software packages.

The banded matrix solution algorithm was extracted from the LINPACK subroutines (Dongarra et al. 1979) for general nonsymmetric band matrixes. The algorithm operates on band matrixes by decomposing the matrix into an upper triangular and lower triangular matrix. The matrix product of the lower triangular matrix times the upper triangular matrix equals the original band matrix (that is, $\mathbf{A} = \mathbf{L} \cdot \mathbf{U}$, where $\mathbf{A}$ is the band matrix, $\mathbf{L}$ is the lower triangular matrix and $\mathbf{U}$ is the upper triangular

matrix). The system of linear equations, $\mathbf{A}\cdot\mathbf{x} = \mathbf{b}$, is solved with the preceding decomposition or factorization by solving successively $\mathbf{L}(\mathbf{U}\cdot\mathbf{x}) = \mathbf{b}$. This factorization procedure produces nonzero elements outside the bands of the original band matrix. If m_l equals the half-band width of the Jacobian coefficient matrix (the STORM simulator produces band matrixes with equal lower and upper bandwidths), the two triangular factors have bandwidths of m_l and $2m_l$. Storage must be provided for the extra m_l diagonals. This requirement is illustrated for a 1-dimensional problem of five nodes and two solved mass conservation equations. The Jacobian coefficient matrix for this problem appears as shown in Equation (3.36). The band storage requires $3m_l + 1 = 10$ rows of storage arranged as shown in Equation (3.37). The * indicates elements that are never referenced but for which storage space must be provided. The + indicates elements that may be occupied during the factorization process. The original Jacobian coefficient matrix is referred to as **A** and its storage counterpart as **a**. The columns of **A** are stored in the columns of **a**, and the diagonals of **A** are stored in the rows of **a**, so the principal diagonal is stored in row $2m_l + 1$ of **a**.

$$\mathbf{A} = \begin{vmatrix} x_{1,1} & x_{1,2} & x_{1,3} & x_{1,4} & 0 & 0 & 0 & 0 & 0 & 0 \\ x_{2,1} & x_{2,2} & x_{2,3} & x_{2,4} & 0 & 0 & 0 & 0 & 0 & 0 \\ x_{3,1} & x_{3,2} & x_{3,3} & x_{3,4} & x_{3,5} & x_{3,6} & 0 & 0 & 0 & 0 \\ x_{4,1} & x_{4,2} & x_{4,3} & x_{4,4} & x_{4,5} & x_{4,6} & 0 & 0 & 0 & 0 \\ 0 & 0 & x_{5,3} & x_{5,4} & x_{5,5} & x_{5,6} & x_{5,7} & x_{5,8} & 0 & 0 \\ 0 & 0 & x_{6,3} & x_{6,4} & x_{6,5} & x_{6,6} & x_{6,7} & x_{6,8} & 0 & 0 \\ 0 & 0 & 0 & 0 & x_{7,5} & x_{7,6} & x_{7,7} & x_{7,8} & x_{7,9} & x_{7,10} \\ 0 & 0 & 0 & 0 & x_{8,5} & x_{8,6} & x_{8,7} & x_{8,8} & x_{8,9} & x_{8,10} \\ 0 & 0 & 0 & 0 & 0 & 0 & x_{9,7} & x_{9,8} & x_{9,9} & x_{9,10} \\ 0 & 0 & 0 & 0 & 0 & 0 & x_{10,7} & x_{10,8} & x_{10,9} & x_{10,10} \end{vmatrix} \tag{3.36}$$

$$\mathbf{a} = \begin{vmatrix} * & * & * & * & * & * & + & + & + & + \\ * & * & * & * & * & + & + & + & + & + \\ * & * & * & * & + & + & + & + & + & + \\ * & * & \bullet & x_{1,4} & 0 & x_{3,6} & 0 & x_{5,8} & 0 & x_{7,10} \\ * & * & x_{1,3} & x_{2,4} & x_{3,5} & x_{4,6} & x_{5,7} & x_{6,8} & x_{7,9} & x_{8,10} \\ * & x_{1,2} & x_{2,3} & x_{3,4} & x_{4,5} & x_{5,6} & x_{6,7} & x_{7,8} & x_{8,9} & x_{9,10} \\ x_{1,1} & x_{2,2} & x_{3,3} & x_{4,4} & x_{5,5} & x_{6,6} & x_{7,7} & x_{8,8} & x_{9,9} & x_{10,10} \\ x_{2,1} & x_{3,2} & x_{4,3} & x_{5,4} & x_{6,5} & x_{7,6} & x_{8,7} & x_{9,8} & x_{10,9} & * \\ x_{3,1} & x_{4,2} & x_{5,3} & x_{6,4} & x_{7,5} & x_{8,6} & x_{9,7} & x_{10,8} & * & * \\ x_{4,1} & 0 & x_{6,3} & 0 & x_{8,5} & 0 & x_{10,7} & * & * & * \end{vmatrix} \tag{3.37}$$

The conjugate gradient solution algorithm was extracted from a package of subroutines intended for solving large sparse linear systems by iterative methods (Oppe et al. 1988). This package of subroutines

is referred to as Nonsymmetric Preconditioned Conjugate Gradient (NSPCG) and has various acceleration techniques and preconditioners available for solving large sparse linear systems. The algorithms available from the NSPCG package are the Incomplete Cholesky (IC) preconditioner and the Generalized Minimal Residual Method (GMRES) accelerator. Preconditioners compute a splitting matrix Q so the preconditioned system of linear equations, $\mathbf{Q^{-1}Ax = Q^{-1}b}$, is better conditioned than the original system, $\mathbf{A \cdot x = b}$. The splitting matrix for the IC preconditioner is an incomplete LU decomposition of the Jacobian matrix A. The form of the splitting matrix is $\mathbf{Q = (D - S)D^{-1}(D - T)}$, where D is a diagonal matrix containing the factorization pivots, S is a lower triangular matrix, and T is an upper triangular matrix. It is necessary to store both S and T because the Jacobian coefficient matrix A is nonsymmetrical.

The NSPCG package allows several modes of storage for the Jacobian coefficient matrix. The storage mode selected for the STORM simulator represents the Jacobian coefficient matrix with two rectangular arrays, one real and one integer. Both arrays are dimensioned n by m, where n equals the number of unknowns and m equals seven times the number of solved coupled governing equations. Each row in the real coefficient matrix **C** contains the nonzero values of the corresponding row in the Jacobian coefficient matrix A; the corresponding row in the integer coefficient matrix J contains the column indexes. The Jacobian matrix, shown in Equation (3.36), is expressed as the real and integer matrixes shown in Equations (3.38) and (3.39), respectively. Although this storage format requires two coefficient matrixes, the storage requirements for large sparse systems (such as those for large multidimensional problems) are greatly reduced over those for the banded matrix solution scheme.

$$\mathbf{C} = \begin{vmatrix} x_{1,1} & x_{1,2} & x_{1,3} & x_{1,4} & 0 & 0 \\ x_{2,1} & x_{2,2} & x_{2,3} & x_{2,4} & 0 & 0 \\ x_{3,1} & x_{3,2} & x_{3,3} & x_{3,4} & x_{3,5} & x_{3,6} \\ x_{4,1} & x_{4,2} & x_{4,3} & x_{4,4} & x_{4,5} & x_{4,6} \\ x_{5,1} & x_{5,2} & x_{5,3} & x_{5,4} & x_{5,5} & x_{5,6} \\ x_{6,1} & x_{6,2} & x_{6,3} & x_{6,4} & x_{6,5} & x_{6,6} \\ x_{7,1} & x_{7,2} & x_{7,3} & x_{7,4} & x_{7,5} & x_{7,6} \\ x_{8,1} & x_{8,2} & x_{8,3} & x_{8,4} & x_{8,5} & x_{8,6} \\ x_{9,1} & x_{9,2} & x_{9,3} & x_{9,4} & 0 & 0 \\ x_{10,1} & x_{10,2} & x_{10,3} & x_{10,4} & 0 & 0 \end{vmatrix} \tag{3.38}$$

$$\mathbf{J} = \begin{vmatrix} 1 & 2 & 3 & 4 & 0 & 0 \\ 1 & 2 & 3 & 4 & 0 & 0 \\ 1 & 2 & 3 & 4 & 5 & 6 \\ 1 & 2 & 3 & 4 & 5 & 6 \\ 3 & 4 & 5 & 6 & 7 & 8 \\ 3 & 4 & 5 & 6 & 7 & 8 \\ 5 & 6 & 7 & 8 & 9 & 10 \\ 5 & 6 & 7 & 8 & 9 & 10 \\ 7 & 8 & 9 & 10 & 0 & 0 \\ 7 & 8 & 9 & 10 & 0 & 0 \end{vmatrix} \tag{3.39}$$

3.5 Geochemical Reactions

Combining Equation **(2.17)** and Equation **(2.20)** yields the solute mass conservation equation including geochemical reactions

$$\begin{gathered} \frac{\partial}{\partial t}\left[\phi_D \rho_l \left(s_g K_H'^{-1} + s_l\right) C_i^l\right] = \\ \nabla \bullet \left[-\phi_D \rho_l \left(s_g \mathbf{V}_g K_H'^{-1} + s_l \mathbf{V}_l\right) C_i^l + \phi_D \rho_l \left(s_g \mathbf{D}_i^g K_H'^{-1} + s_l \mathbf{D}_i^l\right) \cdot \nabla C_i^l\right] \\ + \sum_{j=1}^{N_e} \nu_{ij} W_j^e + \sum_{j=1}^{N_k} \nu_{ij} W_j^k \end{gathered} \tag{3.40}$$

In matrix form, Equation (3.40) can be written as

$$\frac{\partial}{\partial t}\left[\phi_D \rho_t \left(s_g K_H'^{-1} + s_t\right) \dot{\mathbf{C}}\right] = \dot{\mathbf{L}}(\dot{\mathbf{C}}) + \mathbf{N}\dot{\mathbf{W}} \tag{3.41}$$

where

$$\dot{\mathbf{L}}(\dot{\mathbf{C}}) = \left[L_1(C_1), \ldots, L_{N_s}(C_{N_s})\right]^T$$

$$L_t(C_i) = \nabla \bullet \left[-\phi_D \rho_t \left(s_g \mathbf{V}_g K_H'^{-1} + s_t \mathbf{V}_t\right) C_i^t + \phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H'^{-1} + s_t \mathbf{D}_i^t\right) \cdot \nabla C_i^t\right]$$

$$\dot{\mathbf{W}} = \left(W_1^e, \ldots W_{N_e}^e, W_1^k, \ldots W_{N_k}^k\right)^T$$

$$\mathbf{N} = \begin{bmatrix} \nu_{11} & \cdot\cdot & \cdot\cdot & \nu_{1,N_r} \\ \cdot & \cdot\cdot & \cdot\cdot & \cdot \\ \cdot & \cdot\cdot & \cdot\cdot & \cdot \\ \cdot & \cdot\cdot & \cdot\cdot & \cdot \\ \nu_{N_s,1} & \cdot\cdot & \cdot\cdot & \nu_{N_s,N_r} \end{bmatrix}$$

where N_s is the number of species, N_e is the number of equilibrium reactions, and N_k is the number of kinetic reactions.

3.5.1 Linear Transformation of the Reaction-Transport Equation

Ortoleva et al. (1987) pointed out that a subsurface system usually contains reactions of different time scales, and, therefore, "straightforward numerical solution of the solute equations is impractical." To remedy the stiffness of Equation (3.41), a modification is needed to the equation that separates reactions with different time scales. As discussed in Section **2.3.1**, geochemical models usually assume some reactions with a short time scale are equilibrium reactions, while assuming others are kinetic reactions. In most cases, separating reactions with different time scales is separating equilibrium reactions from kinetic reactions.

One approach to performing such separations is based on a canonical representation of reactions (Kirkner and Reeves 1988; Lichtner 1985; Reed 1982; Sevougian et al. 1993; Steefel and Lasaga 1994; Yeh and Tripathi 1991). That approach arbitrarily assigns one subset of species as the primary species (or base species) and the others as the secondary species. Reactions are written in canonical form, that is, each reaction involves only one secondary species, but requires several primary species (Lichtner 1985). Consequently, the rate of production/destruction of primary species, due to reversible reactions, is expressed as the weighted summary of secondary species with the number of moles of primary species in the secondary species as the weight. Adding the mass conservation equation of secondary species with that of the primary species leads to a mass conservation equation that does not contain a source/sink term of reversible reactions. It not only separates equilibrium reactions from kinetic ones, but it also reduces the number of nonlinear partial differential equations (PDE) from N_s to $N_s - N_e$.

From the perspective of linear algebra, the canonical representation approach is equivalent to a linear transformation on aqueous species. The original variables-species concentrations are transformed to total concentrations of chemical components, a linear combination of relevant species. This generalization has led toward a more general approach to separating equilibrium from kinetic reactions.

3.5.2 Q-R Decomposition

Look at the reaction matrix $\mathbf{N}$. Assume its columns are linearly independent (that is, the reactions are linearly independent) with the dimension of $N_s \times N_r$. The reactions are arranged so the first N_e

columns represent equilibrium reactions and the rest are kinetic reactions. The independent assumption guarantees $N_r \le N_s$. Matrix algebra states that $\mathbf{N}$ can be decomposed to

$$\mathbf{N}_{N_s \times N_r} = \mathbf{Q}_{N_s \times N_r} \cdot \begin{bmatrix} \mathbf{R}_{N_s \times N_r} \\ 0_{N_r \times (N_s - N_r)} \end{bmatrix} \tag{3.42}$$

(Golub and Van Loan 1983) where $\mathbf{Q}$ is an orthogonal matrix:

$$\mathbf{Q}^T = \mathbf{Q}^{-1} \tag{3.43}$$

and $\mathbf{R}$ is an upper-triangular matrix:

$$\mathbf{R}_{N_R \times N_R} = \begin{bmatrix} r_{11} & \cdot & \cdots & \cdot & \cdot \\ 0 & r_{22} & \cdots & \cdot & \cdot \\ 0 & \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdot & \cdots & \cdot & \cdot \\ 0 & 0 & \cdots & 0 & r_{N_R, N_R} \end{bmatrix} \tag{3.44}$$

Multiplying Equation (3.41) by $\mathbf{Q}^T$ gives

$$\frac{\partial}{\partial t}\left[\phi_D \rho_t \left(s_g K_H'^{-1} + s_t\right)\mathbf{Q}^T \dot{\mathbf{C}}\right] = \mathbf{Q}^T \dot{\mathbf{L}}(\dot{\mathbf{C}}) + \mathbf{R}\dot{\mathbf{W}} \tag{3.45}$$

Denote

$$\mathbf{Q}^T \dot{\mathbf{C}} = \dot{\vec{x}} = \left(\chi_1, \cdots, \chi_{N_e}, \chi_{N_e+1}, \cdots, \chi_{N_e+N_k}, \chi_{N_e+N_k+1}, \cdots, \chi_{N_s}\right)^T \tag{3.46}$$

and recognize that each χ_i is a linear combination of (C_i). Following the notes from the canonical representation approach (Lichtner 1985), χ_i is called the general component. However, χ_i does not bear the straightforward physical meaning as the chemical components do.

Also denote

$$\mathbf{R}\vec{\mathbf{W}} = \vec{\beta} = \left(\beta_1,\ldots,\beta_{N_e},\beta_{N_e+1},\ldots,\beta_{N_e+N_k}\right)^T \tag{3.47}$$

and

$$\vec{\mathbf{L}}(\vec{\chi}) = \mathbf{Q}^T\vec{\mathbf{L}}(\vec{\mathbf{C}}). \tag{3.48}$$

Note the last N_k components of $\vec{\beta}$ contain only the source terms of kinetic reactions.

Now Equation (3.45) can be written in three groups with different source terms. Group I, $\left(\chi_1,\ldots,\chi_{N_e}\right)^T$, contains source terms of equilibrium and kinetic reactions:

$$\frac{\partial}{\partial t}\left[\phi_D\rho_1\left(s_g K_H'^{-1}+s_1\right)\chi_l\right] = L(\chi_l)+\beta_l,\ \ l=1,\mathrm{K}\ ,N_e \tag{3.49}$$

Group II, kinetic reactive general components, $\left(\chi_{N_e+1},\ldots,\chi_{N_e+N_k}\right)^T$, contains the source terms only of the kinetic reactions:

$$\frac{\partial}{\partial t}\left[\phi_D\rho_1\left(s_g K_H'^{-1}+s_1\right)\chi_l\right] = L(\chi_l)+\beta_l,\ \ l=N_e+1,\mathrm{K}\ ,N_r \tag{3.50}$$

where $N_r = N_e + N_k$ is the total number of reactions. Group III, non-reactive general components, $\left(\chi_{N_e+N_k+1},\ldots,\chi_{N_s}\right)^T$, does not contain the source terms of either type of reactions:

$$\frac{\partial}{\partial t}\left[\phi_D\rho_1\left(s_g K_H'^{-1}+s_1\right)\chi_l\right] = L(\chi_l),\ \ l=N_{r+1},\mathrm{K}\ ,N_s \tag{3.51}$$

Because Equation (3.49) contains source terms of equilibrium reactions, it is still difficult to directly solve Equations (3.49) through (3.51) together. However, because of the equilibrium assumption made for the N_e reactions Equation (3.49) is disregarded and replaced with the N_e equilibrium conditions

$$\prod_{i=1}^{N_s}(\gamma_i C_i)^{\nu_{ij}} = K_j^{eq},\ \ j=1,\ldots,N_e \tag{3.52}$$

Equations (3.50) through (3.52) are the working equations. They contain N_s unknowns and N_s equations; thus, this system of equations is closed.

Note the working equations contain only N_k nonlinear PDE plus N_e algebra equations and $N_s - N_r$ linear PDE. Compared with the canonical representation approach that yields $N_s - N_e$ nonlinear PDE, this approach yields $N_s - N_e - N_k$ fewer nonlinear PDE. At the extreme case where $N_s = N_e + N_k$, those two approaches yield the same number of nonlinear PDE. Reducing the number of nonlinear PDE can save computing time. The real saving depends on the ratio of N_s and N_r. Observations indicate a speed-up factor of 1.5-3.

Unlike the canonical representation approach, the Q-R decomposition approach does not bear the concepts of primary species and secondary species. Thus, it does not impose the constraint of the canonical form on reactions. Eliminating this constraint frees the user from the trivial, but time-consuming, work of writing every reaction in canonical forms. The user has more time to consider whether or not the chemical model is physically relevant.

3.5.3 Finite Difference Discretization

Equations (3.50) and (3.51) are discretized using the control-volume finite difference method on a rectangular 2-D domain (Strikwerda 1989). For notational convenience in the discretization procedure, the subscript i is no longer used to denote different equations. Rather, as by convention, the subscript is used to denote grid point, and superscript denotes different time slices. Equation (3.50) can be discretized to

$$\frac{\left\{\phi_D \rho_t \left(s_g K_H^{t-1} + s_t\right)\chi\right\}_{i,j}^{t+\delta t} - \left\{\phi_D \rho_t \left(s_g K_H^{t-1} + s_t\right)\chi\right\}_{i,j}^{t}}{\Delta t}$$

$$= \lambda \left[\frac{\left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j}^{t+\delta t} - \left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i-1,j}^{t+\delta t}}{x_{i,j} - x_{i-1,j}} \right]$$

$$+ \lambda \left[\frac{\left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j}^{t+\delta t} - \left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j-1}^{t+\delta t}}{y_{i,j} - y_{i,j-1}} \right]$$

$$+ (1-\lambda) \left[\frac{\left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j}^{t} - \left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i-1,j}^{t}}{x_{i,j} - x_{i-1,j}} \right]$$

$$+ (1-\lambda) \left[\frac{\left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j}^{t} - \left\{\phi_D \rho_t \left(s_g \mathbf{V}_g K_H^{t-1} + s_t \mathbf{V}_t\right)\chi\right\}_{i,j-1}^{t}}{y_{i,j} - y_{i,j-1}} \right]$$

$$+ \lambda \left[\frac{\dfrac{\{\chi\}_{i+1,j}^{t+\delta t} - \{\chi\}_{i,j}^{t+\delta t}}{x_{i+1,j} - x_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i+\frac{1}{2},j} - \dfrac{\{\chi\}_{i-1,j}^{t+\delta t} - \{\chi\}_{i,j}^{t+\delta t}}{x_{i-1,j} - x_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i-\frac{1}{2},j}}{\left(x_{i+1,j} - x_{i-1,j}\right)/2} \right]$$

$$+ (1-\lambda) \left[\frac{\dfrac{\{\chi\}_{i+1,j}^{t} - \{\chi\}_{i,j}^{t}}{x_{i+1,j} - x_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i+\frac{1}{2},j} - \dfrac{\{\chi\}_{i-1,j}^{t} - \{\chi\}_{i,j}^{t}}{x_{i-1,j} - x_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i-\frac{1}{2},j}}{\left(x_{i+1,j} - x_{i-1,j}\right)/2} \right]$$

$$+ \lambda \left[\frac{\dfrac{\{\chi\}_{i,j+1}^{t+\delta t} - \{\chi\}_{i,j}^{t+\delta t}}{y_{i,j+1} - y_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i,j+\frac{1}{2}} - \dfrac{\{\chi\}_{i,j-1}^{t+\delta t} - \{\chi\}_{i,j}^{t+\delta t}}{y_{i,j-1} - y_{i,j}} \left\{\phi_D \rho_t \left(s_g \mathbf{D}_i^g K_H^{t-1} + s_t \mathbf{D}_i^t\right)\right\}_{i,j-\frac{1}{2}}}{\left(y_{i,j+1} - y_{i,j-1}\right)/2} \right]$$

$$+(1-\lambda)\left[\frac{\frac{\{\chi\}^{t}_{i,j+1}-\{\chi\}^{t}_{i,j}}{y_{i,j+1}-y_{i,j}}\left\{\phi_D\rho_i\left(s_g\mathbf{D}^g_i K^{j-1}_H+s_i\mathbf{D}^i_i\right)\right\}_{i,j+\frac{1}{2}}-\frac{\{\chi\}^{t}_{i,j-1}-\{\chi\}^{t}_{i,j}}{y_{i,j-1}-y_{i,j}}\left\{\phi_D\rho_i\left(s_g\mathbf{D}^g_i K^{j-1}_H+s_i\mathbf{D}^i_i\right)\right\}_{i,j-\frac{1}{2}}}{\left(y_{i,j+1}-y_{i,j-1}\right)/2}\right]$$

$$+\beta_l \qquad (3.53)$$

where λ is a time-weighting parameter: when λ =1, it is a fully implicit scheme, λ = 0.5 is the Crank-Nicolson scheme; λ = 0, is an explicit scheme. An upwinding scheme is used; thus,

$$i' = \begin{cases} i+1, \text{ when } \mathbf{V}_{ix} > 0 \\ i \quad , \text{ when } \mathbf{V}_{ix} < 0 \end{cases}, \text{ and } j' = \begin{cases} j+1, \text{ when } \mathbf{V}_{iy} > 0 \\ j \quad , \text{ when } \mathbf{V}_{iy} < 0 \end{cases}$$

Equation (3.51) can be discretized in the same manner. The only difference is that Equation (3.51) does not contain the β term.

The main argument against upwinding is the associated numerical diffusion that smears reaction fronts. However, upwinding has the advantage of being less prone to numerical oscillation. As noted by (Yeh et al. 1993), "one scheme resolving the problems of numerical oscillation tends to yield excessive numerical spreading, whereas the other scheme resolving the problems of numerical spreading tends to create severe numerical oscillation."

3.5.4 Fully Coupled Algorithm

Equation (3.53) is a nonlinear equation that can be solved by Newton-Raphson iteration that first converts Equation (3.53) to a linear equation (Press et al. 1986)

$$\mathbf{A}\vec{\delta}^{k} = \mathbf{b} \qquad (3.54)$$

where $\mathbf{A}$ is the global Jacobian matrix, $\vec{\delta}^{k}$ is a correction on the previous solution $\vec{\chi}^{k}$, and $\mathbf{b}$ is the constant term. After solving Equation (3.54), corrections are made on $\vec{\chi}^{k}$:

$$\vec{\chi}^{k+1} = \vec{\chi}^{k} - \vec{\delta}^{k} \qquad (3.55)$$

The new solution $\vec{\chi}^{k+1}$ gives new values of $\mathbf{A}$ and $\mathbf{b}$ that in turn yield $\vec{\chi}^{k+2}$... and the iteration is continued until the solution meets convergence criteria.

The preceding algorithm solves the transport and reaction parts in one step. Such an algorithm is referred to as Fully Coupled, although other researchers have given it different names, such as one-step (Mangold and Tsang 1991), DAE (Yeh and Tripathi 1989), and global implicit (Steefel and Lasaga 1994).

As stated by Yeh and Tripathi (1989), the difficulty of implementing a *Fully Coupled* algorithm is in the huge size of the global Jacobian matrix **A**. In their 2-dimensional example with 60 x 50 grids and 30 species, the global Jacobian matrix **A** has 90,000 x 90,000 = 8,100,000,000 entries. Assuming each entry uses 32 bits (double precision), the matrix requires 2025 MB of memory. It is impractical to store such a large matrix in most computers, and even matrix compression techniques cannot help much. However, the difficulty of storing **A** does not necessarily mean it is impractical to solve the equation. Many numerical algorithms used to solve Equation (3.54), for example, iteration schemes (Golub and Van Loan 1983), do not need to generate and store the global Jacobian matrix **A** in one piece.

Generally, in iteration algorithms, **A** is divided into many submatrixes, so that during the iteration procedure, only one of these submatrixes is needed. A natural way is to divide **A** into submatrixes with each submatrix containing the information of one node. The size of the submatrixes is $N_s \times N_s$. During the iteration, it is necessary only to solve a much smaller linear equation:

$$\mathbf{A}_{i,i}\vec{\delta}_i = \mathbf{b}_i - \sum_{i \neq j} \mathbf{A}_{i,j}\vec{\delta}_j \tag{3.56}$$

where $\mathbf{A}_{i,i}$ is the i th submatrix in diagonal, while $\mathbf{A}_{i,j}$ is an off-diagonal submatrix.

This way of dividing **A** allows the solution of the problem on the entire domain, node by node. Two classical ways are known to iterate the node-by-node scheme: one is the Jacobi iteration; the other is the Gauss-Seidel iteration (Press et al. 1986). The difference between the Jacobi and the Gauss-Seidel iterations is the latter utilizes the latest updated results of iteration, but the former does not. That difference gives the Gauss-Seidel iteration a factor of two in speed over the Jacobi iteration (Press et al. 1986). Therefore, Gauss-Seidel iteration is always preferred, and the Jacobi iteration is of little value in practice.

Equation (3.56) involves a fully coupled solute transport and geochemical reactions, solved on a node-by-node basis using Gauss-Seidel iteration. This algorithm is hereafter referred to as the *Fully Coupled* algorithm. The size of the Jacobian matrix involved in the *Fully Coupled* algorithm is only $N_s \times N_s$. Even a system with 100 species can be handled easily by most computers. Moreover, the size of the matrix is independent of the number of nodes and, thus, independent of the dimensions of problems. The algorithm is applicable to 1-, 2-, or 3-dimensional domains. Although the *Fully Coupled* algorithm bears the inherent disadvantage of slow convergence from Gauss-Seidel, it does not require large memory that otherwise prevents the problem from solution. Experience shows that combined with a flexible time-step control scheme, the algorithm can solve various practical problems.

3.5.5 Operator Split Algorithm

As an alternative to the *Fully Coupled* algorithm, an *Operator Split* algorithm to solve the reaction-transport equations is available in STORM. As its name suggests, the *Operator Split* algorithm splits the reaction-transport PDE into two parts. One is the transport part that is a linear PDE; the other is the chemical reaction part that is a nonlinear ordinary differential equation (ODE). The algorithm then solves them separately and sequentially (Mangold and Tsang 1991). It has been proved the *Operator Split* algorithm has an inherent mass conservation error (Valocchi and Malmstead 1992). Although a remediation scheme has been proposed by these authors to address that problem, the scheme works only when the boundary condition is homogenous (Barry et al. 1996). Otherwise, it can introduce an even larger error. Another remedial method is to iterate the two steps until they converge (Yeh and Tripathi 1991). This latter approach is implemented in STORM.

In the *Operator Split* algorithm, by splitting the transport part from the reaction part, the solute transport mass conservation equation is decoupled and, thus, can be solved separately. In STORM, when using the *Operator Split* algorithm, the solute transport mass conservation equation is solved as described in Section 3.4. The advantage is that each discretized PDE is a linear equation where the dimension of the coefficient matrix, $\mathbf{b}$, is equal to the number of nodes squared. Therefore, $\mathbf{b}$ is $(N_z)^2$ times smaller than the global matrix $\mathbf{A}$. For the preceding example, it is 9,000,000. Combined with matrix compression techniques, the matrix can be stored in workstations with moderate memory. Because $\mathbf{b}$ can be generated and stored at once, more sophisticated techniques of solving linear equations (such as conjugate gradient or preconditioning conjugate gradient methods) can be used to accelerate convergence.

The second step of *Operator Split* algorithm is to solve the nonlinear ODE at each node to obtain reaction rates for each species. This step is similar to the *Fully Coupled* algorithm. However, unlike the *Fully Coupled* algorithm where the latest updated results of neighboring nodes are used, the *Operator Split* algorithm cannot use them because the latest updated results of neighboring nodes cannot propagate to the current node until the next iteration between the first step and the second step. The solution of the geochemical reaction rates, while using the *Operator Split* algorithm, then effectively uses Jacobi iteration. Therefore, as described in Section 3.5.4, its convergence speed is only half that of the *Fully Coupled* algorithm.

Although the *Operator Split* algorithm is slower than the *Fully Coupled* algorithm, it is well known that contaminant transport simulators based on single-point upstream-weighting for solution of the conservation equations (Section 3.5.3) suffer from a grid size dependent artificial diffusion that smears otherwise sharp fronts. To enable STORM to better manage advection-dominated problems, such as simulating the Pressurized Unsaturated Flow (PUF) experiments, a Total Variation Diminishing (TVD) transport scheme has been implemented in conjunction with the *Operator Split* algorithm.

A flux-limited third-order scheme is applied to the advective-diffusion equations in STORM, following a method that is shown to exhibit close agreement with analytical solutions (Gupta et al. 1991). The difference scheme for the conservation equation is illustrated for 1-dimensional, strictly advective flow with constant grid size. This arrangement results in a strictly hyperbolic conservation equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = 0 \tag{3.57}$$

where c is the concentration of the aqueous species, t is time, x is distance, and u is the velocity (taken to be a positive constant). Integrating over mesh cell i and time step interval $[n,n+1]$ yields

$$\frac{c_i^{n+1} - c_i^n}{\Delta t} = \frac{u\bar{c}_{i+1/2} - u\bar{c}_{i-1/2}}{\Delta x} = 0 \tag{3.58}$$

where $u\bar{c}_{i+1/2}$ represents the time averaged flux through the right edge of the ith mesh cell. The principal problem in the formulation of difference schemes lies in the evaluation of these time-averaged fluxes. The finite-difference approximation may be generalized as

$$\bar{c}_{i+1/2} = c_i^n + \tfrac{1}{2}(1-\lambda)F_i\Delta x \tag{3.59}$$

where λ is the Courant number and F_i is the concentration gradient of the upwind cell. For $F_i = 0$, Equation (3.59) reduces to single-point upstream weighting, the technique used in the *Fully Coupled* algorithm that is only first-order accurate and consequently highly diffusive. A third-order scheme provides higher accuracy (Gupta et al. 1991)

$$F_i = \frac{2-\lambda}{3}\frac{c_{i+1}^n - c_i^n}{\Delta x} + \frac{1+\lambda}{3}\frac{c_i^n - c_{i-1}^n}{\Delta x} \tag{3.60}$$

Although higher-order schemes give better resolution for discontinuities, they exhibit spurious oscillations around these points. The underlying principle of constructing a TVD scheme is to combine lower and higher order fluxes and impose limiting functions on the higher-order flux to prevent formation of local extrema (Harten 1983). The higher order flux is viewed as consisting of the first-order flux, plus a corrective term. Rewrite Equation (3.59) in the following terms

$$\bar{c}_{i+1/2} = c_i^n + \phi(r)\frac{c_{i+1}^n - c_i^n}{2}(1-\lambda) \tag{3.61}$$

where $\phi(r)$ is the flux-limiting function and r is a measure of the smoothness of the data. One possible choice for r is the ratio of consecutive gradients (Sweby 1984). For $u > 0$,

$$r = \frac{c_i^n - c_{i-1}^n}{c_{i+1}^n - c_i^n} \ . \tag{3.62}$$

The third-order scheme can now be obtained by defining $\phi(r)$ appropriately

$$\phi(r) = \frac{2-\lambda}{3} + \frac{1+\lambda}{3} r \tag{3.63}$$

In order to prevent non-physical oscillations, the limiting function $\phi(r)$ must be chosen so that limited anti-diffusive flux is maximized in amplitude subject to the constraint of the resulting scheme being TVD that requires the following equation (Sweby 1984)

$$0 \le \frac{\phi(r)}{r}, \ \phi(r) \le 2 \ . \tag{3.64}$$

Equation (3.64) results in the following TVD limiting function for the third-order scheme

$$\phi(r) = \mathrm{MAX}\left[0, \mathrm{MIN}\left(2, 2r, \phi(r)\right)\right] \tag{3.65}$$

For multidimensional flow problems, the difference scheme given by Equation (3.61) can be applied similarly in the y and z directions.

3.6 Boundary Conditions

The discretization methods described previously for the mass, energy, and solute mass conservation equations strictly applied to interior nodes (that is, nodes surrounded by neighboring nodes). For nodes adjacent to a domain boundary or an inactive node, the discretized forms of the governing equations are modified according to the user specified boundary conditions. Zero flux boundary conditions are applied whenever no boundary condition is specified for a boundary surface. Boundary conditions that can be specified for a boundary surface are varied, depending on the operational mode, and other associated boundary conditions.

A total of eight boundary conditions are appropriate for flow boundaries and are applicable to the conservation equations for water and air: Dirichlet, Neumann, zero flux, initial condition, saturated, unit gradient, hydraulic gradient, and free gradient. The Dirichlet boundary condition specifies the value of intrinsic properties on the boundary surfaces (for example, aqueous pressure and gas pressure). The Neumann boundary condition specifies a surface flux on the boundary surface (for example, aqueous Darcy velocity and gas Darcy velocity). The zero flux boundary condition specifies an impermeable boundary for flow or transport and serves as the default condition for undeclared boundary surfaces (for example, zero fluid flow). The initial condition boundary condition uses the initial conditions in the nodes adjacent to a boundary surface to fix the intrinsic properties on the boundary surface. The saturated boundary condition is appropriate for fluid flow boundaries for 2-phase systems and establishes zero

capillary pressure conditions on the boundary surface. The unit gradient boundary condition is appropriate for fluid flow boundaries and establishes a fluid pressure on the boundary surface equal to the fluid pressure at the adjacent node, modified by the hydraulic gradient for the fluid. The free gradient boundary condition is appropriate for fluid flow boundaries for 2-phase systems and establishes a fluid pressure on the boundary surface by extrapolating the local pressure gradient within the computational domain to the boundary surface. The hydraulic gradient boundary condition is appropriate for fluid flow boundaries and establishes a series of boundary pressures according to the local hydraulic gradient for the fluid.

The five boundary conditions appropriate for transport boundaries and applicable to the conservation equations for energy and solute mass follow: Dirichlet, zero flux, initial condition, outflow, and inflow. The Dirichlet boundary condition specifies the value of intrinsic properties on the boundary surfaces (for example, temperature or solute concentration). The zero flux boundary condition specifies an impermeable boundary for flow or transport and serves as the default condition for undeclared boundary surfaces (e.g., zero heat flux, or zero solute flux). The initial condition boundary condition uses the initial conditions in the nodes adjacent to a boundary surface to fix the intrinsic properties on the boundary surface. The outflow boundary condition considers transport out of the computational domain by advection only, so no diffusive transport occurs. This boundary condition will not transport energy or solute mass into the domain. The inflow boundary condition considers transport into the computational domain only by advection and no diffusive transport occurs. This boundary condition will not transport energy or solute mass out of the domain.

In general, boundary conditions for simulations that involve the solution of multiple governing equations can be combined in a variety of ways, with one major restriction. Specification of a Neumann boundary condition for the energy equation on a boundary surface (other than the zero flux condition) requires that flow equation boundary conditions for that boundary surface be specified as zero flux. Nonzero fluid flow and heat transport can be achieved for boundary nodes through a combination of flow boundary conditions, a zero flux energy boundary, and energy sources for the boundary nodes. Regardless of the boundary condition or combination of boundary conditions a sufficient number of independent intensive variables must be declared to specify the thermodynamic and hydrologic state on the boundary surface. Definitions for geometric parameters for nodes with boundary surfaces on the west side are shown in Figure 3.3 for the X-Z Cartesian coordinate plane and in Figure 3.4 for the X-Y Cartesian coordinate plane.

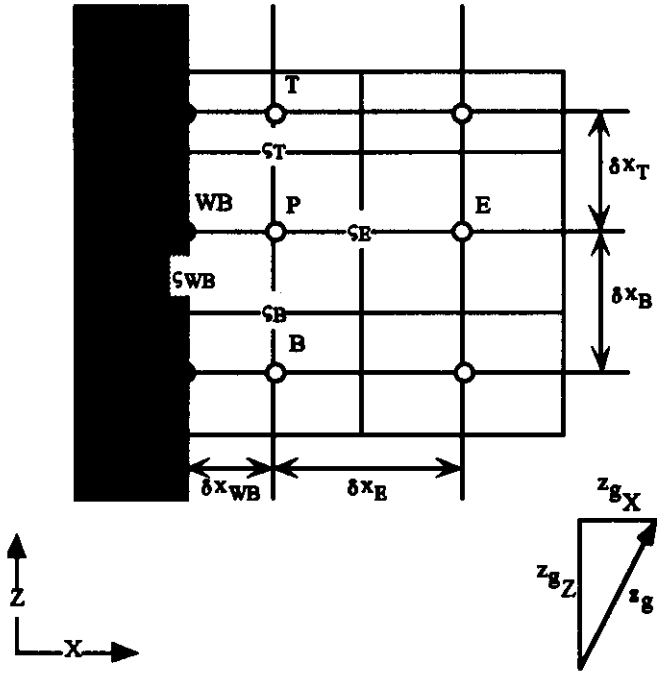

Figure 3.3. X-Z Cartesian Coordinate Plane for West Boundary

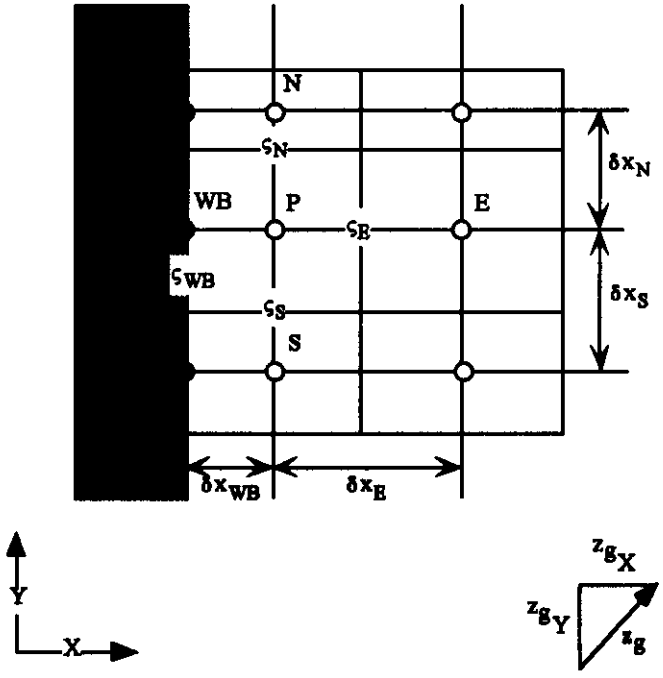

Figure 3.4. X-Y Cartesian Coordinate Plane for West Boundary

3.6.1 Dirichlet Boundary Condition

The Dirichlet boundary condition is equivalent to specifying the value for the primary unknown on the boundary surface. Assigned values of primary variables are used to compute secondary variables for the boundary surface. Average properties for transport between a boundary surface and the adjacent node are computed with user-specified averaging schemes between the values of the properties on the boundary surface and adjacent node. For example, the discretized forms for Darcy mass flux and diffusive mass flux rates of water, Equation (3.6), are modified for a Dirichlet aqueous phase boundary condition on a west boundary surface, according to Equations (3.66) and (3.67), respectively. For the solute mass conservation equation, a Dirichlet boundary condition on the west surface produces a modification to the discretized conservation equation, Equation (3.26), according to Equation (3.68).

$$F_l^{w}{}_{WB} = -\frac{\left\langle \omega_l^{w} \rho_l k_{rl} \right\rangle_{WB}^{uw} \langle \mathbf{k} \rangle_{WB}^{h}}{\langle \mu_l \rangle_{WB}^{h}} \left(\frac{(P_{lP} - P_{lWB})}{\delta x_{WB}} + \langle \rho_l g \rangle_{WB}^{a} z_{gWB} \right) \tag{3.66}$$

$$J_l^{w}{}_{WB} = -\left\langle \tau_l n_D \rho_l s_l \frac{M^{w}}{M_l} \mathbf{D}_l^{w} \right\rangle_{WB}^{h} \frac{\left(\chi_l^{w}{}_{P} - \chi_l^{w}{}_{WB}\right)}{\delta x_{WB}} \tag{3.67}$$

$$a_P C_P - \sum_{\zeta = E,S,N,B,T} a_\zeta C_\zeta = \frac{\partial C}{\partial t}\overline{V} - m^C \overline{V} - R^C C \overline{V} + a_{WB} C_{WB} \tag{3.68}$$

3.6.2 Neumann Boundary Condition

The Neumann boundary condition is equivalent to specifying the flux on a boundary surface. Fluxes that may be specified are aqueous volumetric, gas volumetric, energy, and solute mass. For example, the discretized form for Darcy mass flux of water, Equation (3.6), is modified for a Neumann boundary condition on a west boundary surface, according to Equation (3.69). Sufficient information is needed to fix the thermodynamic and hydrologic state on the boundary surface. Calculation of phase pressures from phase volumetric flow rates requires an iterative solution because averaged values of properties (for example, relative permeability) are nonlinear functions of the phase pressure on the boundary. To avoid an iterative solution of the phase pressure on the boundary phase, pressures are computed assuming a unit relative permeability, according to Equation (3.70) for a west boundary surface.

$$F_l^{w}{}_{WB} = \left\langle \omega_l^{w} \rho_l \right\rangle_{WB}^{uw} V_{lWB} \tag{3.69}$$

$$P_{lWB} = \delta x_{WB} \left(\frac{V_l^w{}_{WB} \langle \mu_l \rangle_{WB}^h}{\langle \mathbf{k} \rangle_{WB}^h} + \langle \rho_l g \rangle_{WB}^a z_{gWB} \right) + P_{lP} \tag{3.70}$$

3.6.3 Zero Flux Boundary Condition

The zero flux boundary condition is the default boundary condition and is equivalent to specifying zero flow or transport across the boundary surface. Complex boundary conditions that involve multiple specifications on a single boundary surface, require that sufficient information be specified to fix the thermodynamic and hydrologic state on the boundary surface. For example, a recognized boundary condition combination for a water-air system (that is, the Two-Phase Volatile operational mode) is a Dirichlet aqueous boundary and zero flux gas boundary. Isothermal water-air systems require two independent intensive variables to fix the thermodynamic and hydrologic state of the system. For this boundary system, the Dirichlet aqueous boundary assigns a value to the aqueous pressure. The gas pressure can be specified by user input or be computed using zero flux boundary conditions and solving Equation (3.6) for the gas pressure, according to Equation (3.71) for a west boundary surface.

$$P_{gWB} = \delta x_{WB} \langle \rho_g g \rangle_{WB}^a z_{gWB} + P_{gP} \tag{3.71}$$

3.6.4 Initial Condition Boundary Condition

The initial condition boundary condition is identical in application to the Dirichlet boundary condition, with the following exception: the primary variable is fixed to the initial value at the adjacent node. No user input is required for this type of boundary condition because boundary values are obtained through the initial condition specifications. Initial boundary pressures are computed once at the start of a simulation.

3.6.5 Saturated Boundary Condition

The saturated boundary condition is recognized for water-air systems and performs as do dynamic Dirichlet boundary conditions, where zero capillary pressure is maintained on the boundary surface. The saturated boundary condition fixes the aqueous pressure equal to the gas pressure on a boundary surface, regardless of the boundary condition for the gas pressure. For a single-phase system, the gas pressure is fixed through the initial conditions and the aqueous pressure is maintained on a saturated boundary equal to this gas pressure. For a 2-phase system, the gas pressure on a boundary surface is user-specified according to the gas-phase boundary conditions. The saturated boundary condition for the aqueous phase fixes the aqueous pressure at the boundary surface equal to the gas pressure. Saturated boundary pressures are computed with each Newton-Raphson iteration.

3.6.6 Unit Gradient Boundary Condition

The unit gradient boundary condition is recognized for aqueous-phase and gas-phase boundary conditions and maintains a unit gradient in the phase hydraulic head. A unit gradient in the phase hydraulic head is equivalent to setting the normalized Darcy velocity equal to minus one, according to Equation (3.72) for a west boundary surface. Phase pressure on the boundary surface is computed by solving Equation (3.72) for the boundary pressure, according to Equation (3.73), for a west boundary surface. Unit gradient boundary pressures are computed with each Newton-Raphson iteration.

$$\frac{V_{\gamma WB}\left\langle \mu_{\gamma}\right\rangle_{WB}^{h}}{\left\langle k_{r\gamma}\right\rangle_{WB}^{uw}\left\langle \mathbf{k}\right\rangle_{WB}^{h}} = -1 = -\left(\frac{\left(P_{\gamma P} - P_{\gamma WB}\right)}{\delta x_{WB}} + \left\langle \rho_{\gamma} g\right\rangle_{WB}^{a} z_{gWB} \right) \text{ for } \gamma = l, g \tag{3.72}$$

$$P_{\gamma WB} = P_{\gamma P} + \delta x_{WB}\left(\left\langle \rho_{\gamma} g\right\rangle_{WB}^{a} z_{gWB} \right) \text{ for } \gamma = l, g \tag{3.73}$$

3.6.7 Free Gradient Boundary Condition

The free gradient boundary condition is recognized for aqueous-phase and gas-phase boundary conditions. This boundary condition is essentially a dynamic Dirichlet-type boundary, where the pressure on the boundary surface is set to maintain the pressure gradient in the interior nodes adjacent to the boundary surface. This boundary type requires, as a minimum, two active nodes adjacent to the boundary surface. The gradient in phase pressure is linearly extrapolated from the interior nodes to the boundary surface to determine the boundary pressure. Free gradient boundary pressures are computed with each Newton-Raphson iteration.

3.6.8 Outflow Boundary Condition

The outflow boundary condition is recognized for transport boundaries (for example, energy transport, solute transport). This boundary condition allows transported quantities to be moved across a boundary surface by advection only. Inward transport by diffusion or transport across the boundary surface is prohibited. Energy flux across an outflow boundary surface on a west boundary is computed according to Equation (3.74). Solute flux across an outflow boundary surface on a west boundary is computed according to Equation (3.75).

$$Q_{\gamma WB} = -\left(\rho_{\gamma} h_{\gamma}\right)_{P} \max\left[-V_{\gamma WB}, 0\right] \text{ for } \gamma = l, g \tag{3.74}$$

$$G^{C}_{\gamma\, WB} = -C_{\gamma P} \max\left[-V_{\gamma WB}, 0\right] \text{ for } \gamma = l, g \tag{3.75}$$

3.6.9 Inflow Boundary Condition

The inflow boundary condition is recognized for transport boundaries (for example, energy transport and solute transport). This boundary condition allows transported quantities to be inwardly transported across a boundary surface by advection only. Transport by diffusion or transport outward across the boundary surface is prohibited. Energy flux across an inflow boundary surface on a west boundary is computed according to Equation (3.76). Solute flux across an inflow boundary surface on a west boundary is computed according to Equation (3.77).

$$Q_{\gamma WB} = \left(\rho_\gamma h_\gamma\right)_p \max\left[V_{\gamma WB}, 0\right] \text{ for } \gamma = l, g \tag{3.76}$$

$$G^C_{\gamma\ WB} = C_{\gamma P} \max\left[V_{\gamma WB}, 0\right] \text{ for } \gamma = l, g \tag{3.77}$$

4.0 Input File

4.1 Introduction

The STORM simulator is controlled through a text file that must be named *input* for proper execution. This input file has a structured format composed of cards that contain associated groups of input data. Depending on the operational mode, input cards might be required, either optional or unused. Required cards must be present in an input file. Optional cards are not strictly required to execute the simulator, but may be required to execute a particular simulation. Unused cards are treated as additional text that is not recognized by the simulator, but does not hinder a proper execution. Cards may appear in any order within the input file. However, the data structure within a card is critical and must follow the formatting directives shown in Appendix A. Data structures within cards vary with the operational mode, which requires the user to follow a series of logic type statements to construct a readable input file. The STORM simulator contains logic to capture and report input errors. These capabilities are primarily limited to indicating syntax or formatting type errors and generally do not reveal such errors as those associated with ill-posed problems, atypical parameters, or inappropriate grid structures, for example. Because of its text format, STORM input files are generated with text editors, word processors, spread sheet programs, or graphical interfaces and are portable between computing environments. The input is case insensitive and allows considerable flexibility in specifying the simulation directives; however, close attention to the formatting instructions in this section will be necessary to prepare an executable input file.

4.2 Input File Structure

A STORM input file is composed of cards, some of which are required and others that are optional or unused. The number of required cards depends on the operational mode. If an attempt is made to execute the STORM simulator on an input file with an incomplete set of required cards, an error message will be generated and the code execution will stop. Optional cards are used to specify the STORM capabilities that may be required to execute a particular problem or generate desired output data. These cards are considered optional, because the capabilities accessed through these cards are not necessarily required to execute the code. Execution of the STORM simulator on input files with an incomplete set of optional cards yields messages that note the missing optional cards and allow the execution to continue. A summary of the required and optional cards that compose a STORM input file for each operational mode is shown in Table 4.1.

Each card is delimited on the first line with a card header that must contain a tilde symbol (for example, ~ Simulation Title Card) as the character in the first column of the line. Cards may be arranged in any order within an input file; however, the input format within a card is generally structured. If a card type is repeated within an input file, the STORM simulator reads only the first card. Blank lines or additional comment lines can be included in the input file outside of the card structures.

Table 4.1. Required and Optional Input Cards

Operational Mode	Card Name	Card Status
All	Initial Conditions	Optional
	Boundary Conditions	Optional
	Source	Optional
	Output Control	Optional
	Surface Flux	Optional
Water	Simulation Title	Required
	Solution Control	Required
	Grid	Required
	Rock/Soil Zonation	Required
	Mechanical Properties	Required
	Hydraulic Properties	Required
	Saturation Function	Required
	Aqueous Relative Permeability Function	Required
Water-Air	Simulation Title	Required
	Solution Control	Required
	Grid	Required
	Rock/Soil Zonation	Required
	Mechanical Properties	Required
	Hydraulic Properties	Required
	Saturation Function	Required
	Aqueous Relative Permeability Function	Required
	Gas Relative Permeability Function	Required
Water-Air-Energy	Simulation Title	Required
	Solution Control	Required
	Grid	Required
	Rock/Soil Zonation	Required
	Mechanical Properties	Required
	Hydraulic Properties	Required
	Thermal Properties	Required
	Saturation Function	Required
	Aqueous Relative Permeability Function	Required

4.3 Formatting and Notation

Each input card has formatting specifications that must be followed to create an input file readable by the STORM simulator. The format structure of certain cards varies with the operational mode or other input options, and the user must strictly follow the formatting instructions for the particular operational mode of interest. As expected, the complexity of the input increases with the operational mode. Guides

for formatting input cards and card lines are presented in Appendix A. The formatting guides shown in this appendix were written in a compact format using special notations. Definitions of the formatting notations used in Appendix A are given in Table 4.2.

Input files are organized into three hierarchical structures, cards, lines, and data. Cards are delimited by a tilde (~) in the first column of the card title. Lines are delimited by hard returns and commas delimit data. The STORM simulator recognizes three different types of data, integers, real data, and character strings. Integers are used primarily to indicate indexes or integral numbers. Integer data must be entered without decimal points or exponential notation. Real data are used to indicate dimensional parameters and can contain decimal points or exponential notation. Character string data are primarily used to indicate names, options, and units, and are limited to 64 characters, unless otherwise noted. Card lines comprise a series of input data items delimited by commas. A comma at the end of the card line is required to close the last data item. The format structure for each line in a card is shown in Appendix A using a format guide (for example, **Format:** *Integer*^{a}, *Real*^{b}, *Char*^{c},). Data types in the format statements are indicated as *Integer*, *Real* and *Char* (that is, integer, real, and character string) with lowercase letter superscripts. The lettered superscripts are used to correlate the data item with its position in the input line. The total length of a single input line cannot exceed 132 characters. Additional text may appear after the closing comma of an input line. Many input variables contain default values (indicated with underlining in Appendix A). Using a *null* entry accesses a default value. The *null* entry requires the closing comma for the input data item to immediately follow the previous closing comma or that only blank spaces fill the space between the closing commas. To start a line with a *null* entry, the closing comma can occur in column 1 or after a number of blank spaces. Example input cards are shown in Appendix A after the formatting instructions for each card. A considerable portion of the input file formatting and creation work is eliminated by developing input files from previously generated files or through an input generator.

4.4 Units

The STORM simulator offers considerable flexibility in specifying units. The user can declare units for both input or output data. Unspecified units are assumed to be in standard Systeme Internationale (SI) units for the data item. The STORM simulator operates internally almost exclusively in SI units, with pressures expressed in gauge, relative to 1 atmosphere. Unless specifically stated, all input and output pressures are expressed in absolute values. Unit variables are read by the STORM simulator as character strings, translated into primary unit form, and compared against the standard unit form for each data item. During the translation to primary unit form, a conversion factor to SI units is generated. A unit character string comprises a combination of the recognized units delimited by spaces or a single divisor symbol (that is, /). Only one divisor may appear in a unit character string. Spaces should not be used to separate the units immediately prior to or following the divisor symbol. The unit strings prior to the divisor symbol are considered part of the numerator and, conversely, the unit strings following the divisor symbol are considered part of the denominator. Units recognized by the STORM simulator are listed in Table 4.3.

Table 4.2. Input Format Notation Guide

Notation	Description
{ Option }	Enclosing braces indicate character string options. Options are chosen by entering word(s) within the braces, exactly as shown. Only one option should be chosen for each data entry.
[Optional]	Enclosing brackets indicate optional characters or words. These characters can be entered to include the input file to improve its readability.
{{ Fractured }}	Indicates the word fractured is within the rock/soil type name, thus indicating a dual porosity model.
< Data Types >	Indicates repeated formatting.
Char[a]	Character string data type, referenced by superscript a
Integer[a]	Integer data type (no character data or decimal points) reference by superscript a.
Real[a]	Real data type (decimal points and exponential notation are acceptable), reference by superscript a.
#	A pound symbol in the first column indicates a comment line that is ignored during execution. Comment lines may be placed inside or outside card structures. All lines outside of the card structures are ignored during execution.
~ Card Name	A tilde symbol in the first column indicates the start of a new card.
,	Data entries are comma delimited. Commas shown in the line format structures must be entered as shown, including a closing comma at the end of each line. Characters following the last comma of a data line are ignored during execution.
Units[a] (m)	Indicates the SI unit for the input data item referenced by superscript a.
Format:	Indicates line formatting instructions and the beginning of a new input line. Each format statement requires a new input line.
Endcard:	Indicates end of a card.
For: Integer Instructions **Endfor**: Integer	Indicates instruction looping.
If: Name: Card = { Opt_1 } Instructions1 **Elseif**: Name: Card = { Opt_2 } Instructions2 **Elseif**: Instructions3 **Endif**:	Indicates decision logic.

Table 4.2. Input Format Notation Guide (contd)

Notation	Description
IfDef: Opt_1 Instructions1 **ElseifDef**: Opt_2 Instructions2 **ElseDef**: Instructions3 **EndifDef**:	Indicates C preprocessor options and logic.
Note:	Indicates formatting information.

Table 4.3. Recognized Units

Notation	Description	SI Equivalent	Conversion to SI	Base Units
1	one	N/A	N/A	N/A
aqu	aqueous phase	N/A	N/A	N/A
aqueous	aqueous phase	N/A	N/A	N/A
atm	atmosphere	Pa	101325.0	$M / L T^2$
bar	bar	Pa	$1.\times10^{5}$	$M / L T^2$
btu	Btu	J	1054.4	$M L^2 / T^2$
c	Celsius	C	1.	K
cal	calorie	J	4.184	$M L^2 / T^2$
ci	Curie	N/A	N/A	N/A
cm	centimeter	m	$1.\times10^{-2}$	M
cp	centipoise	Pa s	$1.\times10^{-3}$	M / L T
d	day	s	1/86400.	T
darcy	Darcy	m^2	9.8697×10^{-13}	L^2
day	day	s	1/86400.	T
debyes	Debyes	N/A	N/A	$(M / L T^2)^{1/2}$
deg	degrees	rad	0.017453	N/A
degree	degrees	rad	0.017453	N/A
dyn	dynes	N	$1.\times10^{-5}$	$M L / T^2$
dynes	dynes	N	$1.\times10^{-5}$	$M L / T^2$
f	Fahrenheit	C	(f-32)×(5/9)	K
ft	foot	m	0.3408	L
furlong	furlong	m	2.01168×10^{2}	L
g	gm	kg	$1.\times10^{-3}$	M
gal	gallon	m^3	3.7854×10^{-3}	M^3
gas	gas phase	N/A	N/A	N/A
gm	gm	kg	$1.\times10^{-3}$	M

Table 4.3. *Recognized Units (contd)*

Notation	Description	SI Equivalent	Conversion to SI	Base Units
gram	kg	kg	$1.\times10^{-3}$	M
hc	hydraulic cond.	N/A	1.03910×10^{-7}	N/A
hour	hour	s	1/3600.	T
hp	horsepower	W	745.7	$M L^2 / T^3$
hr	hour	s	1/3600.	T
in	inch	m	2.54×10^{-2}	L
j	Joule	J	1.	$M L^2 / T^2$
k	Kelvin	C	1.	K
kg	kilogram	kg	1.	M
kgmol	kilogram-mole	kgmol	1.	Mo
l	liter	m^3	$1.\times10^{-3}$	L^3
lb	pound	kg	0.45359	M
lbm	pound	kg	0.45359	M
lbmol	pound-mol	kgmol	0.45359	Mo
liq	liquid	N/A	N/A	N/A
liter	liter	m^3	$1.\times10^{-3}$	L^3
m	meter	m	1.	L
mg	milligram	kg	$1.\times10^{-6}$	M
min	minute	s	1/60.	T
ml	milliliter	m^3	$1.\times10^{-6}$	L^3
mm	millimeter	m	$1.\times10^{-3}$	L
mol	mole	kgmol	$1.\times10^{-3}$	Mo
mole	mole	kgmol	$1.\times10^{-3}$	Mo
p	Poise	Pa s	$1.\times10^{-1}$	M / L T
pa	Pascal	Pa	1.	$M / L T^2$
pci	pico Curies	N/A	N/A	N/A
psi	lbs/in^2	Pa	6894.8	$M / L T^2$
r	Rakine	K		K
rad	radians	rad	1.	N/A
rod	rod	m	5.0292	L
s	second	s	1.	T
sec	second	s	1.	T
slug	slug	kg	14.594	M
sol	solid	N/A	N/A	N/A
solid	solid	N/A	N/A	N/A
w	Watt	W	1.	$M L^2 / T^3$
water	water	N/A	N/A	N/A

Table 4.3. Recognized Units (contd)

Notation	Description	SI Equivalent	Conversion to SI	Base Units
week	week	s	1/604800.	T
wh	water head	Pa	9.79353×10^3	M / L T^2
wk	week	s	1/604800.	T
yd	yard	m	0.9144	L
year	year	s	1/31557600.	T
yr	year	s	1/31557600.	T

The units listed under the subtitle *Miscellaneous Units* are primarily descriptive units that may be included in a unit character string to increase its readability. The *hc* unit, however, is uniquely reserved for specifying rock/soil hydraulic conductivity that is normally expressed in velocity units. Without the *hc* unit, the input for rock/soil permeability is interpreted as an intrinsic permeability value. The STORM simulator does not apply hydraulic conductivity values directly, but instead first converts hydraulic conductivity values into intrinsic permeability values using the density and viscosity of water at 20°C. Therefore, when rock/soil permeability values are read as hydraulic conductivity, the associated unit character string should include the *hc* unit (for example, hc cm/hr).

As an example, the standard units for thermal conductivity are W/K m; however, a user may prefer to specify thermal conductivity in the standard English units of Btu in/hr ft^2 F. In this case, the user enters the character string Btu in/hr ft^2 F for the unit data item. Note the carat (^) symbol is used to indicate an exponential. During simulator execution, the string of English units for thermal conductivity is translated into the primary unit form, m/s^3 kg K, and compared against the standard unit form. If the primary unit form does not agree with the standard unit form, an error message is generated by the STORM simulator and the program execution stops. Otherwise, if the comparison is successful, the input data for thermal conductivity, that precedes its unit string, is converted to SI units.

4.5 Card Descriptions

Formatting instructions for the input cards are provided in Appendix A. This section provides a brief synopsis of each input card with emphasis on its purpose and application. Italicized words refer to specific files, cards, options, and data entries shown in the card formats in Appendix A.

4.5.1 Simulation Title Card

This card primarily provides a means to document a simulation. Information recorded in this card is rewritten on the *output* file that then serves as a permanent record of the simulation. The user is encouraged to use descriptive titles and to briefly record the specifics and purpose of the simulation in the *Simulation Notes* section of the card. This record becomes especially valuable, when the user is making repeated simulations with small modifications to the input parameters. The changes required in either the *Simulation Title* or *Simulation Notes* will be invaluable when reviewing archived output files.

4.5.2 Solution Control Card

This card controls many general operational aspects of a simulation. Simulations are executed in one of three *Execution Modes*: *Normal*, *Restart*, or *Initial Conditions*. In the *Normal* mode, the simulation executes from initial conditions specified with the *Initial Conditions* Card, and no *restart* file is required. The *Restart* mode requires a *restart* file generated from a previous execution. Unless specified with an *Overwrite* indicator, initial conditions specified on the *Initial Conditions* Card are ignored. Restart files are generated during each plot file write sequence, and have name extensions that correspond to the generating time step (for example, the file *restart*.28 is generated after time step 28). Restart files contain principal field variables and time information. The *Initial Conditions* mode only executes through the initial checks on the input; no time steps are executed. The *No Flow* option (*Water/Transport* mode only) is used for transporting solutes through a steady-state flow field. For these simulations, the flow field is computed once during the initial time step and then remains unaltered. The *Dynamic Domain* option (*Water* mode only) conserves computations by temporarily removing nodes from the computational domain where changes in the flow field are insignificant. The active computational domain is updated every time step.

The *Operation Mode* option determines the governing equations that are solved by the simulator. Because execution performance is indirectly proportional to the number of solved governing equations, the user selects an *Operation Mode* most appropriate for the problem of interest. For example, if the physical system to be modeled does not contain thermal or gas pressure gradients, the most appropriate operational mode is the Water operational mode, where only the water mass conservation equation is solved. Executing the described physical system under the *Water-Air* operational mode yields nearly identical results; however, the execution time is significantly increased. Considerable attention is given to the selection of an appropriate operational mode for the physical system of interest. In terms of efficient and representative simulations, it is equally important not to eliminate critical physical phenomena through an erroneous assumption, as it is not to solve superfluous governing equations. Each operational mode allows the solution of solute transport equations, indicated by including the keyword Transport in the operational mode (for example, *Water-Air* and *Solute Transport*). Solute transport is solved using the Patankar method, unless the keyword TVD appears, indicating the TVD method.

Execution periods refer to a period of simulation time. The STORM simulator allows the user to specify single or multiple execution periods. For each execution period, the user can control the initial time step, maximum time step, time step acceleration factor, maximum number of Newton-Raphson iterations and convergence criterion. Recommended value for the *Time Step Acceleration Factor* is 1.25, the *Maximum Number of Newton-Raphson Iterations* is 8, and the *Convergence Criterion* is 1.e-06. Simulations involving complex phase transitions often require more Newton-Raphson iterations to reach convergence because of the design of the phase transition algorithms. For these types of simulations a value of 16 is recommended for the *Maximum Number of Newton-Raphson Iterations*. Except under special circumstances, it is not advisable to change the value for the *Convergence Criterion* from its recommended value. This value has proven through numerous applications to achieve a preferred balance between accuracy and execution speed.

Field variables, including physical, thermodynamic, and hydrologic properties, are defined in the finite-difference formulation at the node centers. Conversely, flux variables are defined at node

interfaces. Computation of flux variables requires knowledge of field variables at node interfaces. Such values are evaluated by averaging the field values for the two nodes adjoining an interfacial surface. Interfacial averaging schemes may be declared individually for each field variable through the *Interfacial Averaging Variables* input. The default interfacial averaging schemes for the STORM simulator are shown in Table 4.4.

Table 4.4. Default Interfacial Averaging Options

Field Variable	Interfacial Averaging
Aqueous density	Upwind
Aqueous relative permeability	Upwind
Aqueous viscosity	Harmonic
Dissolved air diffusion	Harmonic
Gas density	Upwind
Gas relative permeability	Upwind
Gas viscosity	Harmonic
Hydraulic dispersion	Harmonic
Intrinsic permeability	Harmonic
Solute diffusion	Harmonic
Thermal conductivity	Harmonic
Water vapor diffusion	Harmonic

For simulations of physical systems involving heat transfer, note that convergence problems may arise if the density properties are not averaged with upwind weighting. Likewise, infiltration problems typically demonstrate strong dependencies on the relative permeability of the infiltrating fluid.

4.5.3 Grid Card

The finite-difference formulation of the STORM simulator is based on orthogonal grid systems. Currently, two orthogonal grid systems are recognized, the Cartesian and cylindrical coordinate systems. The Cartesian coordinate system is a "right-handed" system with the longitudinal axis (z–direction) aligned with the negative gravitational vector. Cartesian coordinate systems can be defined that are tilted with respect to the gravitational vector. The cylindrical coordinate system has the longitudinal axis (z-direction) aligned with the negative gravitational vector and the radial (r–direction), and azimuthal (Q-direction) axes constrained to a horizontal plane. For the Cartesian coordinate system, the terms West, South, and Bottom refer to the negative x-, y-, and z-directions, respectively, and the terms East, North, and Top refer to the positive x-, y-, and z-directions, respectively. For the cylindrical coordinate system, the terms West, South, and Bottom refer to the negative r-, Q-, and z-directions, respectively, and the terms East, North, and Top refer to the positive r-, Q-, and z-directions, respectively. Negative dimensional values are not recognized and axes are defined as positive toward increasing node numbers. The grid dimensions that are specified on the Grid Card refer to node surfaces; therefore, for grids with non-uniform spacing, one plus the number of nodes entries are required for each grid direction. Node volumes are defined by their bounding surfaces. Cylindrical coordinates systems are restricted to

azimuthal axes that are less than 360 degrees. Refer to the STOMP Theory Manual (White and Oostrom 1996) for graphical descriptions of the Cartesian and cylindrical coordinate systems.

4.5.4 Rock/Soil Zonation Card

This card allows the user to partition the computational domain into rock/soil types. All active nodes within the computational domain must have an associated rock/soil type. Rock/soil types are defined with a unique name that must contain no more than 64 characters. Because most physical systems of interest contain formations or zones of rocks or soils, the computational domain also contains zones of nodes with similar hydrogeologic properties. With this card, the user defines the distribution of rock/soil zones. In subsequent input cards, hydrogeologic properties are defined with respect to the defined rock/soil types. This approach avoids having to specify hydrogeologic properties uniquely for every node. Generally, this approach is preferred. For simulations using statistically generated rock or soil formations, which require unique hydrogeologic properties for each node, no advantage is gained with this approach. The rock/soil types are extended to the boundary surfaces for nodes adjacent to boundary surfaces. Therefore, field variables for boundary surfaces are computed using the rock/soil type property descriptions from the node adjacent. Hydrogeologic properties for rock/soil types are specified through the *Mechanical Properties* Card, *Hydraulic Properties* Card, *Thermal Properties* Card, *Saturation Function* Card, *Aqueous Relative Permeability Function* Card, *Gas Relative Permeability Function* Card, and *Solute/Porous Media Interaction* Card. A rock/soil type may be repeatedly applied to a node with the last definition being applied. For example, to simplify the zonation of a problem with a dominant rock/soil type and isolated pockets or bands of another rock/soil type, the user initially declares the dominant rock/soil type as covering the entire problem domain. With subsequent lines, the user can overwrite the original rock/soil type for selected nodes with another rock/soil type. This layering approach is recommended and often avoids undeclared rock/soil types.

4.5.5 Mechanical Properties Card

This card allows the user to assign values to the particle density, porosity, specific storativity, compressibility, and tortuosity function for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. *Particle Density* represents the rock grain density. This value can be defaulted to 2650 kg/m^3 by using a *null* entry for both the particle density and its associated unit. *Total Porosity* refers to total connected and unconnected pore volumes. *Diffusive Porosity* refers only to the connected pore volume. As with Particle Density, the Specific Storativity can be defaulted by using a *null* entry for both the *Specific Storativity* and its associated *Units*. Default specific storativity is computed from the *Diffusive Porosity* and with a default value of $1.x10^{-7}$1/Pa for the compressibility. Tortuosity functions are required for simulations that involve solute transport or diffusion of components through phases (for example, water vapor diffusing through the gas phase). Tortuosities can be computed as either constants that require input values, or as functions of the phase saturation and diffusive porosity through the Millington and Quirk function. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a description of the Millington and Quirk tortuosity function.

4.5.6 Hydraulic Properties Card

This card allows the user to assign values to the intrinsic permeability for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. *Intrinsic Permeability* can be declared directly or through entering the *Hydraulic Conductivity* at reference conditions, where reference conditions refer to atmospheric pressure and 20°C. By default, the STORM simulator reads the permeability values on this card as intrinsic permeabilities, unless the character string *hc* is included in the associated units. Default units of *m^2* are applied to *null* entries for the units associated with permeability values. With the STORM simulator, a primary assumption is that principal components of the intrinsic permeability tensor are aligned with the principal coordinate directions. For cylindrical coordinate systems the radial, azimuthal, and vertical permeabilities correspond with the x-, y-, and z-direction values, respectively. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a description of the conversion of hydraulic conductivity to intrinsic permeability at reference conditions.

4.5.7 Thermal Properties Card

This card allows the user to assign values to the thermal conductivity and specific heat for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. This card is required only for simulations involving the solution of the energy conservation equation. Declaration of the thermal conductivity, depends on the operational mode and function option. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a description of thermal conductivity functions. The *Constant* option fixes the thermal conductivity to a constant value, independent of temperature or saturation. The *Parallel* option requires the thermal conductivity of the soil grains and models thermal conductivity with an equivalent parallel path model dependent on porosity, phase saturations, and temperature. The *Linear and Somerton* options scale the thermal conductivity between the unsaturated and saturated values depending on phase saturation. A primary assumption with the STORM simulator is that principal components of the thermal conductivity tensor are aligned with the principal coordinate directions. For cylindrical coordinate systems, the radial, azimuthal, and vertical permeabilities correspond with the x-, y-, and z-direction values, respectively.

4.5.8 Saturation Function Card

This card allows the user to declare and define a saturation-capillary pressure function for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. Saturation function types and the required input items are primarily dependent on the operational mode. Although functional forms for the saturation-capillary pressure functions are preferred, tabular input is acceptable. By default, tabular data is interpolated using linear interpolation. Values beyond the table limits will be assigned either the table minimum or maximum values, as appropriate. For the van Genuchten function, the *m Parameter* can be defaulted (with a *null* entry) or assigned a value. Default values will depend on which porosity distribution model (Mualem or Burdine) is chosen from the relative permeability function cards for the liquid phases. Hysteretic functions are those for which the drainage and imbibition scanning paths differ and that include capabilities for entrapment of fluids of lower wettabilities. Non-hysteretic functions require fewer input items than their hysteretic counterparts and use a single scanning path for drainage and imbibition events. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a complete description of saturation-capillary pressure functions.

4.5.9 Aqueous Relative Permeability Function Card

This card allows the user to declare and define a relative permeability-saturation function for the aqueous phase for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. Aqueous relative permeability function types and the required input items are dependent on the operational mode. The Mualem and Burdine relative permeability functions are also dependent on the saturation function type and are strictly applicable to the van Genuchten and Brooks and Corey functions. For these functions, either the van Genuchten *m Parameter* or the Brooks and Corey λ *Parameter* can be defaulted to the values entered or defaulted with the saturation function. Although functional forms for the relative permeability-saturation functions are preferred, tabular input is acceptable. By default, tabular data is interpolated using linear interpolation. Values beyond the table limits are assigned appropriately either the table minimum or maximum values. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a complete description of aqueous relative permeability-saturation functions.

4.5.10 Gas Relative Permeability Function Card

This card is used to declare and define a relative permeability-saturation function for the gas phase for each defined rock/soil type. Every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. This card is required only for simulations involving flow or transport through the gas phase. Gas relative permeability function types and the required input items are dependent on the operational mode. The Mualem and Burdine relative permeability functions are also dependent on the saturation function type and are strictly applicable to the van Genuchten and Brooks and Corey functions. For these functions, either the van Genuchten *m Parameter* or the Brooks and Corey λ *Parameter* can be defaulted to the values entered or defaulted with the saturation function. Functional forms for the relative permeability-saturation functions are preferred; however, tabular input is acceptable. By default, tabular data are interpolated using linear interpolation; cubic spline interpolation is optional. Values beyond the table limits are assigned either the table minimum or maximum values, as appropriate. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a complete description of gas relative permeability-saturation functions.

4.5.11 Solute/Fluid Interaction Card

This card allows the user to define solutes, solute-fluid interactions, and solute radioactive decay paths. It is required only for simulations involving solute transport. The STORM simulator is capable of simulating any number of solutes with the assumption that solute concentrations remain dilute. (Solute concentrations do not vary the physical properties of the transporting fluid phases.) Solutes can decay radioactively to produce other solutes. For the loose coupling between parent solutes and progeny solutes to function properly, parent solutes must be defined on this card prior the definition of their progeny. The STORM simulator actually solves the transport equation for each solute sequentially and in reverse order from the definition list on this card. Solutes are defined by a unique solute name that must contain no more than 64 characters. *Chain Decay Fraction* relates a parent decay member with a progeny and refers to the fraction of the decaying parent that produces a particular progeny. *Chain Decay Fraction* inputs are fractional values from 0.0 through 1.0, inclusively. Solute-fluid interaction parameters, such as

molecular diffusion coefficients and interphase partition coefficients, depend on the operational mode. Molecular diffusion coefficients refer to the diffusion of the solute through the transporting fluid phase outside of the porous media. Corrections for transport through porous media are handled within the STORM simulator. The interphase partition coefficients define the equilibrium distribution of solute between the active liquid phases. Partition coefficients that define the equilibrium adsorption of solute onto the solid phase are determined on the *Solute/Porous Media Interaction* Card. It is important for the user to carefully note the definitions and requested units for each interphase partition coefficient. The *Aqueous-Gas Partition Coefficient* is the ratio of the solute mass in the aqueous phase per unit mass of aqueous phase to the solute mass in the gas phase per unit volume of gas phase. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a more detailed description of the interphase partition coefficients, solute diffusion coefficients, radioactive decay rate equations, and radioactive chain decay fractions.

4.5.12 Solute/Porous Media Interaction Card

This card allows the user to define solid-aqueous phase partition coefficients and porous media dependent hydraulic dispersivities. It is required only for simulations involving transport of solutes. This card differs from the *Solute/Fluid Interaction* Card because the input parameters declared are dependent on the solute and rock/soil type. For every solute defined on the *Solute/Fluid Interaction* Card, every rock/soil type defined on the *Rock/Soil Zonation* Card must be referenced. The *Solid-Aqueous Partition Coefficient* defines the interphase equilibrium of a solute adsorbed on the solid and dissolved in the aqueous phase. This definition refers to the concentration of solute adsorbed on the solid phase per unit mass of solid phase with the concentration of solute dissolved in the aqueous phase per unit mass aqueous phase. The longitudinal and transverse hydraulic dispersivities are properties only of the rock/soil type. *Longitudinal Dispersivity* is defined with respect to dispersion along the flow path and is assumed independent of the flow direction with respect to the porous media structure. Likewise, *Transverse Dispersivity* is defined with respect to dispersion transverse to the flow path, independent of the flow direction. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a more complete description of the solid-aqueous interphase partitioning and hydraulic dispersion of transported solutes.

4.5.13 Initial Conditions Card

This card allows the user to assign starting values to primary and secondary field variables by initializing primary variables. However, the current version of the STORM simulator does not allow the user to initialize flux or surface variables. Such initializations are useful for solving transport problems with steady flow fields. Transport problem simulations with the STORM simulator require the solution of the flow fields. The variables that may be initialized are dependent on the operational mode. For all operational modes, default values for the initial conditions are specified within STORM as shown in Table 4.5.

For the *Water*, *Water-Air*, and *Water-Air-Energy* operational modes, STORM allows the user to specify the initial aqueous saturation by assigning initial conditions for any two of the following three variables: gas pressure, aqueous pressure, and aqueous saturation. The unassigned variable is computed from the other two through the declared saturation-capillary pressure functions. Initial conditions are

Table 4.5. Initial Condition Default Values

Initial Field Variable	Symbol	Default Value
Temperature (C)	T	20.
Pressure of phase j (Pa)	P_j	101325.
Saturation of phase j	s_j	0.
Mole fraction of component i in phase j	χ_j	0.
Solute concentration in phase j	Sj	0.

declared repeatedly for a node with the application of last definition. Initial conditions for solutes are expressed in terms of solute per unit volume where the volume can refer to the total node volume (*Volumetric*), the aqueous-phase volume (*Aqueous Volumetric*), or the gas-phase volume (*Gas Volumetric*). Solute units are undefined and expressed as the user chooses (for example, Ci, pCi, gm, kg, mol, or kgmol). Although units for expressing solute quantity vary among solutes, units must be consistent for a single solute among all input data entries.

The gradient utilities of the initial condition card are invaluable and are used to advantage whenever possible. Gradients to the initial conditions allow the user to specify that initial value of a field variable varies along one or more directions in the physical domain. The initial condition variable assigned to an initial condition domain applies to the node with the lowest x-, y-, and z-direction indexes. If nonzero gradient values are specified, the initial condition values vary according to the gradients specified for each physical direction. Default values for the initial condition gradients are zero, indicating no variation. Gradient values are applicable only over the initial condition domain of the state. An exemplary application of the initial condition gradient utility occurs for problems that start with hydrostatic conditions. For these problems, the pressure at the lowest z-direction node positions is entered with a *Z-Dir. Gradient* that equaled minus the fluid density times the acceleration of gravity. For water at 20°C, a z–direction gradient of -9793.5192 1/m yields constant head conditions, that is the equivalent to hydrostatic conditions. This approach is used to locate the position of a water table under no-recharge equilibrium conditions, given the rock/soil saturation function properties and a single pressure using an *Initial Condition* execution mode simulation.

4.5.14 Boundary Conditions Card

This optional card allows the user to control the simulation by defining time varying boundary conditions. Boundary conditions may be applied to any boundary surface or surface dividing active and inactive nodes. By default, all undeclared boundary surfaces have zero flux boundary conditions for flow and transport. Boundary conditions can be applied only to surfaces of active nodes. To apply a boundary condition to a boundary surface, the surface is referenced by the adjacent active node location and a direction with respect that node. To apply a boundary condition to a surface dividing an active and inactive node, the surface is referenced by the active node and the direction to the inactive node with respect to the active node. Boundary conditions vary within periods. The user is not allowed to assign multiple boundary conditions to a boundary surface during the same time period, but multiple boundary conditions do so over different time periods. The STORM simulator controls time steps to agree with time transitions in boundary conditions.

Application of boundary conditions requires an appropriate conceptualization of the physical problem and translation of that conceptualization into boundary condition form. The variety of boundary condition types available in the STORM simulator allow the user the flexibility to solve most subsurface flow and transport problems. In addition, the boundary condition card reader within the STORM simulator performs limited error checking on the boundary condition inputs. However, an error-free boundary condition card does not guarantee the user has not created either an ill-posed problem or an execution that successfully converges. For example, a mistake frequently made by STORM users is to specify infiltration rates at the top of a column with positive fluxes. Although this input is perfectly acceptable to the STORM boundary condition input reader, the specified condition actually withdraws flux from the top of the column because the z-axis and z-direction flux are positive in the upward direction.

The *Boundary Surface Direction* is specified with respect to the active node adjacent to a boundary surface. For the Cartesian coordinate system, the terms West, South, and Bottom refer to the negative x-, y-, and z-directions, respectively, and the terms East, North, and Top refer to the positive x-, y-, and z-directions, respectively. For the cylindrical coordinate system the terms West, South, and Bottom refer to the negative r-, Q-, and z-directions, respectively, and the terms East, North, and Top refer to the positive r-, Q-, and z-directions, respectively.

Boundary condition inputs depend on the operational mode, with the required inputs becoming more complex with increasing number of solved equations. Generally, the number of boundary types that must be declared for each boundary equals the number of solved governing flow and transport equations. The *Dirichlet* boundary type is used to specify a field value (for example, pressure, temperature, or solute concentration) at the boundary surface. The *Neumann* boundary type allows the user to specify a flux (for example, liquid phase flux, heat flux, or solute flux) at the boundary surface. The *Zero Flux* boundary type is used to impose no flow or transport conditions across the boundary. The *Saturated* boundary type is available only for 2-phase conditions and imposes total-liquid saturation conditions (for example, water table) at the boundary surface. The *Unit Gradient* boundary type imposes hydrostatic conditions across the boundary surface for the specified phase. The *Free Gradient* boundary type is available only for the *Water* operational mode and models a free drainage surface with respect to the aqueous phase. The *Hydraulic Gradient* boundary type is applied only to a column or plane of vertical surfaces. With this boundary type, the user specifies a fluid phase pressure at the lowest surfaces of a column or row. The simulator then computes fluid phase pressure for the remaining boundary surfaces assuming hydrostatic conditions for the fluid phase. The *Initial Conditions* boundary type fixes the boundary field variables (for example, pressure, temperature, or solute concentration) to the initial values of the field variables at the node adjacent to the boundary surface. This boundary type is invariant with time. *Outflow* boundary types are applicable only to solute and energy boundary conditions. This boundary type considers only advectively transported solute or energy to exit the computational domain. Diffusion transport across the boundary surface is neglected. The solute concentration boundary types (for example, *Volumetric Concentration*, *Aqueous Conc.*, or *Gas Conc.*) are equivalent to *Dirichlet* boundary types for solute transport. These boundary types differ by their definitions of solute concentration.

Time variations of the boundary conditions are controlled through declaring multiple boundary times. All *Boundary Time* inputs are referenced against the *Initial Time* specified on the *Solution Control* card or obtained from a restart file. A boundary condition declared with a single *Boundary Time* implies the

boundary condition is time invariant; the specified *Boundary Time* represents the start time for the boundary condition. Prior to the start time, the boundary surface type is assumed to be *Zero Flux*. The specified boundary condition remains in effect from the start time until the execution completion. If a boundary condition is declared with multiple *Boundary Times*, the first time listed equals the start time; the last time listed equals the stop time, and the intermediate times are transition points. For simulation times outside of the start and stop time limits, *Zero Flux* boundary conditions apply. For simulation times between two *Boundary Times*, linear interpolation of the boundary conditions is applied. Step boundary condition changes are simulated by defining duplicate *Boundary Times*; the first time indicates the completion of the previous boundary condition and the second time indicates the start of the new boundary condition. At the completion of the step boundary condition, another set of duplicate *Boundary Time* declarations is used. Step boundary conditions are convenient methods for introducing slugs of fluids, heat, or solute in conjunction with the *Neumann* boundary type.

4.5.15 Source Card

This card allows the user to control sources or sinks of mass, energy, and solutes by defining the timing-varying sources. By definition, sinks are negative sources, and sources refer to an influx of mass, energy, or solute into a node. Sources can be specified for interior or boundary nodes and are functionally analogous to *Neumann* type boundary conditions. Sources applied to inactive nodes are not recognized. Sources are time varying; however, unlike boundary conditions, application of multiple sources to a node are allowed during the same time period. The STORM simulator controls time steps to agree with time transitions in sources. Source inputs depend on the operational mode, with the required inputs becoming more complex with an increasing number of solved equations. Sinks withdraw mass, energy, or solutes from a node. The physical properties for the fluids withdrawn through sinks equal those of the node. Sources inject mass, energy, or solutes into a node. The physical properties for fluids injected through sources are computed from the specified input parameters.

Sources of type *Aqueous Volumetric* and *Aqueous Mass* inject aqueous fluid. For non-isothermal problems, the injected fluid also transports an amount of heat into the node, based on the enthalpy of the entering aqueous fluid. Sources of types *Gas Volumetric/Mass Fraction*, *Gas Volumetric/Relative Humidity*, *Gas Mass/Mass Fraction*, and *Gas Mass/Relative Humidity* are similar to the two aqueous sources, in that mass and heat injected into the node include contributions from water vapor and air. The source type suffix *Mass Fraction* indicates that water vapor and air concentrations in the gas phase are specified through inputs of mass fractions for these quantities. Similarly, the source type suffix *Relative Humidity* indicates that water vapor and air vapor concentrations in the gas phase are specified through inputs of relative humidities for the water. Energy sources are specified as either type *Power* or *Power Density*, where *Power* type sources inject energy per unit time and *Power Density* type sources inject energy per unit time per node volume. *Solute* sources inject solute mass in the assumed units for solute (for example, Ci, pCi, gm, kg, mol, or kgmol).

Time variations of sources are controlled through declaring multiple source times. All *Source Time* inputs are referenced against the *Initial Time* specified on the *Solution Control* card or are obtained from a restart file. A source declared with a single *Source Time* implies the source is time invariant; the specified *Source Time* represents the start time for the source. Prior to the start time, the source is zero and from the start time to execution completion, the source is as specified. If a source is declared with

multiple *Source Times*, the first time listed equals the start time, the last time listed equals the stop time, and the intermediate times are transition points. For simulation times outside of the start and stop time limits, zero source conditions apply. For simulation times between two *Source Times*, linear interpolation of the sources is applied. Step source changes are simulated by defining duplicate *Source Times*; the first time indicates the completion of the previous source and the second time indicates the start of the new source. At the completion of the step source another set of duplicate *Source Time* declarations is used. Step sources are convenient methods for introduction slugs of fluids, heat, or solute into an interior node.

4.5.16 Output Control Card

This card allows the user to control output written to the *output* file, *plot* file, and *screen* (that is, STDIO). The *output* file contains an interpreted and reformatted version of the *input* and simulation results for selected variables at selected *reference nodes* over the simulation period. The *plot* file contains values of geometric parameters and selected variables for the entire computational domain (both active and inactive nodes) at selected simulation times. A *plot* file always is generated at the conclusion of an execution. The output to the STDIO primarily comprises variable results of the reference node versus the simulation time or time step. The user is advised to request *screen* output, because well-chosen output may be invaluable in tracking the simulation progress and identifying possible input errors. If a suite of repetitive simulations is in progress, then *screen* output can be reduced to minimum values. As with other input cards, output options are dependent on the operational mode. With respect to this card, output options primarily refer to computed field and flux variables.

Reference node output is generated by selecting reference nodes and output variables. The user may request any number of reference nodes. However, reference node output was primarily designed for tracking the time evolution of selected variables at key nodes of interest. Reference nodes are defined with three indexes that indicate the x-, y-, and z-direction coordinates of the node. Node numbering in the STORM simulator increments in the order i, j, and k, where the indexes refer to the x-, y-, and z-directions, respectively, for Cartesian coordinate systems and r-, q-, and z-directions, respectively, for cylindrical coordinate systems. *Reference Node Screen Output Frequency* and *Reference Node Output File Frequency* are parameters that indicate how often, with respect to time step, reference node output is written to STDIO and the *output* file. A frequency value of 1 indicates reference node output occurs every time step, whereas a frequency value of 10 indicates reference node output occurs every 10 time steps. The user controls the output time and length units and the number of significant digits reported to the various output media. Unless declared through the *Output Time Units* or *Output Length Units* input items, values for time and lengths recorded to the output media are expressed in units of seconds and meters, respectively. These inputs allow the user to customize time- and length-scale units to those most appropriate for the solved problem. The *Screen Significant Digits*, *Output File Significant Digits*, and *Plot File Significant Digits* input items allow the user to customize the number of significant digits that appear in field and flux variable results written to the STDIO, *output* file, and *plot* file. Default values for the number of significant digits is 5; the minimum number of significant digits is 4. Field and flux variables output for the reference nodes are selected from the list shown in Appendix A for each operational mode. The same list of variables for each operational is available for output to the *plot* files. Output units for all variables that have units can be specified immediately following the variable name. Variables without units require a *null* entry for the variable units. The *null* entries for variables with units yield default output units that are expressed in SI units.

Plot files are written by default at the conclusion of an execution and at each requested *Plot File Output Time*. Plot files contain geometrical data and selected field and flux variable results for every node in the computational domain. These files represent a snapshot of the simulation at a certain point in time. Requests for *Plot File Output Times* can be specified with user defined units. A *restart* file is generated with every *plot* file. Both restart and plot files are suffixed with an file name extension of a dot followed by an integer (for example, plot.567, restart.32). The extension integer corresponds with the time step for which the file was written. Both *plot* and *restart* files are written at the conclusion of a time step. Field and flux variables recorded to *plot* files are selected from the list shown for each operational mode in Appendix A (refer to the reference node variable options). Output units for all variables with units are specified in the input item immediately following the variable name. Variables without units require a *null* entry for the variable units. *Null* entries for variables with units yield default output units that are expressed in SI.

4.5.17 Surface Flux Card

This card allows the user to define surfaces to track fluxes of fluid mass, fluid volume, heat, or solutes. A surface defined with this card can be composed of rectangular areas of coplanar surfaces on exterior boundaries or between interior nodes. Output from the surface flux integration routines are written to the *surface* file and contain flux rate and integral data for each defined surface at every time step. The types of fluxes that can be tracked depend on the operational mode. Declaration of surfaces is similar to defining boundary condition surfaces. Surfaces are defined by referencing a group of coplanar nodes and a surface direction with respect to the nodes. For the Cartesian coordinate system, the terms West, South, and Bottom refer to the negative x-, y-, and z-directions, respectively; the terms East, North, and Top refer to the positive x-, y-, and z-directions, respectively. For the cylindrical coordinate system the terms West, South, and Bottom refer to the negative r-, Q-, and z-directions, respectively, and the terms East, North, and Top refer to the positive r-, Q-, and z-directions, respectively. For example, a surface to track the flux rate and integral of a particular solute entering the water table is defined for a simulation with saturated conditions along the bottom boundary surface by referencing the node group along the bottom of the computational grid and defining the *Surface Flux Orientation* as *Bottom*. One surface flux rate and integral value is computed for each defined surface and represents the summation of surface flux contributions from the individual surfaces in the coplanar group of surfaces.

4.5.18 Reactive Transport Control Card

This card lists several parameters that control the execution of the reactive transport subroutines. The first line requires specification of the reactive transport *Execution Mode*. Currently, only one *Execution Mode* is available for the reactive transport subroutines: Normal. In the *Normal* mode, the simulation executes from initial conditions specified with the *Reaction IC Card.*

The second line requires the user to select the reactive transport *Solution Mode*. Two solution modes are available: *Fully Coupled mode*, in which the transport equations and the chemical reactions are solved simultaneously, and *Operator Split* mode, in which advective-diffusive transport equations and the chemical reactions are solved sequentially.

The third line lists eight integer values that must be set to either zero or one (Table 4.6).

Table 4.6. Description of Reactive Transport Execution Control Switches

Description Of Variable	0	1
Aitken extrapolation scheme	off	on
Column scan switch for 2-D problems	off	on
Non-reacting solver switch	off	on
Effective reaction area	off	on
Texture solver coupled with transport solver	off	on
Porosity updated with precipitation/dissolution	off	on
Lower boundary condition for all species	No flux	C = 0
Water consumption in chemical reactions coupled with water flow	off	on
Gas consumption in chemical reactions coupled with gas flow	off	on

The "Aitken extrapolation scheme" accelerates the convergence of the Newton-Raphson iteration scheme related to the reactive transport solver. The "Column scan switch for 2-D problems" enables the Gauss-Seidel iterative solver to scan in the horizontal, as well as the vertical direction when solving 2-dimensional problems. The "non-reacting solver switch" allows the user to solve problems with pure transport (no reactions) in the *Fully Coupled* solution mode. The "Effective reaction area" switch allows recalculation of the effective reaction surface area for each mineral at each node, as the minerals precipitate or dissolve. The "Texture solver coupled with transport solver" switch allows the recalculation of the mineral volume and radius as minerals precipitate and dissolve in slow reactions. The "Porosity updated with precipitation/dissolution" switch allows changes in porosity to be passed back to the water or gas flow subroutines. The "Lower boundary condition for all species" switch allows either a no flux or a specified concentration of zero at the lower boundary for all aqueous species. The "Water consumption in chemical reactions coupled with water flow" switch allows the net water consumption rate, due to all chemical reactions, to be coupled with the water flow subroutines. The "Gas consumption in chemical reactions coupled with water flow" switch allows the net gas consumption rate, due to all chemical reactions, to be coupled with the gas flow subroutines.

The fourth line lists seven real variables that control the convergence of the reactive transport solver.

The Courant number is defined as $Cr = V\Delta t/\Delta l$, where Δt is the initial time step, Δl is the minimum horizontal and vertical grid spacing, and V is the average linear pore water velocity. The time stepping parameter is used to select the time-stepping scheme for reactive transport: a value of 0.0 gives an explicit scheme, 0.5 gives a Crank-Nicholson scheme, and 1.0 provides a fully implicit scheme. A fully implicit scheme is likely to be the most stable. The other six input variables allow the user to specify the maximum error allowed in the solution of various reactive transport subroutines.

4.5.19 Aqueous Species Card

This card lists the aqueous species to be considered in the simulation. Examples of aqueous species include ions, such as HCO_3^- and dissolved gases, such as O_2(aq). Required input includes the overall

Table 4.7. Reactive Transport Convergence Control Variables

Description Of Variable	Range Of Appropriate Values
Initial time step Courant number	1 to 1.e-6
Time stepping parameter	0.0 to 1.0
Error in non-reacting species	1.e-2 to 1.e-7
Error in equation point solver	1.e-2 to 1.e-7
Error in transport point solver	1.e-2 to 1.e-7
Error in texture solver	1.e-2 to 1.e-7

charge of the aqueous species and the hard core diameter. Values of these input parameters for many aqueous species are found in the EQ3/6 database file data0.com.R2, for example. Also required is a list of the elements contained in each species.

4.5.20 Gas Species Card

This card lists gas phase species to be considered in the simulation. Examples of gas phase species include $CO_2(g)$ and $O_2(g)$. These species must be related by Henry's Law Constant to an aqueous species, specified in the Aqueous Species Card. Required input includes the diffusion coefficient of the gas phase species and the Henry's Law equilibrium coefficient. The Henry's Law equilibrium coefficient may be specified as a constant or as a polynomial function of temperature, with a user-specified number of terms. Additionally, a list of the elements contained in each gaseous species is required.

4.5.21 Components Card

This card lists the components that consist of the groups aqueous species related by a single element. Components provide a way to keep track of the total mass of a given element in solution. For instance, the component Al(total) can consist of two aqueous species: $Al(OH)_3(aq)$ and $Al(OH)_4^-$.

4.5.22 Solid Species Card

This card lists and describes all solid species in the simulation. Examples of solid species include silicate or carbonate minerals, metals or soil organic matter. Solid species are defined by specifying the mass density of the solid species and the mole fraction (stoichiometric coefficient) and name of each element in the solid species.

4.5.23 Fast Reactions Card

This card lists and describes all aqueous fast (equilibrium) reactions considered in the simulation. Fast reactions are defined by specifying the number of moles of each aqueous species participating in the reaction. The equilibrium coefficient must also be specified, either as a constant or as a polynomial function of temperature with a user-specified number of terms.

4.5.24 Kinetic Aqueous Reactions Card

This card lists and describes all kinetic reactions involving only aqueous species. An example of kinetic aqueous reactions is the biodegradation of dissolved organic carbon.

4.5.25 Slow Reactions Card

This card lists all kinetic reactions involving at least one solid species. Each reaction may involve one or two solid species. Examples of slow reactions include mineral dissolution or precipitation, metal corrosion, or biodegradation of soil organic matter. Slow reactions are defined by specifying the number of moles of each aqueous and solid species participating in the reaction. The equilibrium coefficient must also be specified, either as a constant or as a polynomial function of temperature, with a user-specified number of terms. Various parameters related to the rate law must also be defined. Three different types of rate law may be specified.

4.5.26 Fluid Decay Card

The option to simulate the radioactive decay of aqueous species is not currently implemented.

4.5.27 Solid Decay Card

The option to consider the radioactive decay of solid species is not currently implemented.

4.5.28 Lithology Card

This card specifies the relative fraction of each solid species found in each of the porous materials initially defined in the *Rock/Soil Zonation* Card Card, described in Section 4.5.4.

4.5.29 Reaction BC Card

This card lists the boundary conditions, specified at the upper boundary, for all aqueous and gas species. This simplification was originally introduced into the code because the upper boundary is usually the location of the inlet of a 1-dimensional column. In the future, the ability will be added to define specified concentration (Dirichlet) or specified flux (Neumann) conditions along any boundary segment of the domain.

4.5.30 Reaction IC Card

Currently, the only option is to set the initial aqueous species concentrations equal to those specified at the upper boundary.

5.0 Parameter Files

5.1 Introduction

This section describes the format and contents of the parameters file and the parameters.astct file, that are required to compile and execute the STORM simulator. Parameters are used by the FORTRAN programming language and compilers to allocate memory for storage of variables. The FORTRAN language is unable to allocate memory dynamically; therefore, all memory storage requirements must be defined at compilation time. No execution errors occur if the memory allocated is greater that required by the simulation, unless the memory requirements exceed the computer capabilities. Unless necessary, the user avoids executing simulations that require the use of virtual memory. The time required to swap data between the virtual memory storage device and the active memory typically yields poor execution speeds. The STORM simulator requires definitions of two types of parameters (declared and computed), prior to compilation. The user is responsible for properly assigning all of the declared parameters. Declared parameters are assigned by modifying the parameters file supplied with the STORM simulator using a text editor (word processor) or by creating a new parameters file. The equations for the computed parameters must be included in each parameters file following the declared parameters. The parameter definitions given in this manual represent minimum acceptable values. All declared parameters, except for switch type parameters, must have minimum values of one. Undersized parameters will generally yield execution errors that may or may not be detected by the system. Oversized parameters are permissible, but can result in excessive memory allocation.

5.2 Parameters File

5.2.1 Solution/Simulation Parameters

The "LNOTES" parameter equals the number of lines in the *Simulation Notes* field and should equal the variable *Number of Simulation Note Lines* on the *Simulation Title* card. The "LEPD" parameter equals the number of execution periods and should equal the variable *Number of Execution Periods* on the *Solution Control* card. A simulation with seven lines of simulation notes and four execution periods would have a solution/simulation parameter set that appeared as

PARAMETER(LNOTES=7, LEPD=4)

5.2.2 Computational Domain Parameters

The "LFX," "LFY," and "LFZ" parameters equal the number of nodes in the x-, y-, and z-directions, respectively, for Cartesian coordinate systems or the number of nodes in the r-, -, and z-directions, respectively, for cylindrical coordinate systems. These parameters equal the variables *X-Dir. Nodes*, *Y-Dir. Nodes*, and *Z-Dir. Nodes* on the *Grid* card. The parameter "LAN" equals the number of active nodes and should equal the total number of nodes minus the number of inactive nodes. The parameter

"LAD" equals the number of active dimensions, where active dimensions are coordinate directions with more than one node. The number of active dimensions is a number between one and three, inclusive. The parameter "LMNP" equals the minimum plane size and should equal the minimum of the following three products: "LFX*LFY," "LFY*LFZ," and "LFZ*LFX." A simulation with 2 active dimensions, having 22, 1, and 103 nodes in the x-, y-, and z- directions, respectively, and 51 inactive nodes has a computational domain parameter set that appeared as

PARAMETER(LFX=22, LFY=1, LFZ=103)
PARAMETER(LAN=2215, LAD=2, LMNP=22)

5.2.3 Operation Mode Switch Parameters

The parameters "LT," "LL," "LG," "LN," and "LC" are switches for the energy, water mass, air mass, VOC mass, and solute conservation equations. For these switch-type parameters, a value of one indicates the equation is solved and a value of zero indicates the equation is unsolved. The parameter "LFC" is a switch for freezing conditions. The parameter "LS" is a switch for coupled solute transport. A value of zero indicates nonfreezing conditions, whereas a value of one indicates freezing conditions. The switch combinations set with these parameters agrees with the operational mode. A simulation using the *Water-Air/Transport* operational mode has a operational mode parameter set that appeared as

PARAMETER(LT=0, LL=1, LG=1, LN=0, LC=1, LFC=0, LS=0)

5.2.4 Linear System Solver Switch Parameters

The parameters "LBD" and "LCG" are switches for the banded and conjugate gradient linear system solvers. For these switch type parameters, a value of one indicates the solver is active and value of zero indicates the solver is inactive. Only one solver can be active for a simulation, either the banded matrix or the conjugate gradient solver. These parameters switches, similar to a toggle, are the only means the user has for declaring a linear equation solution scheme. A simulation that used the banded matrix linear system solver has a linear system solver parameter set that appeared as

PARAMETER(LBD=1, LCG=0)

5.2.5 Boundary Condition Parameters

The parameters "LBC" and "LBTM" equal the number of boundary surfaces and maximum number of boundary condition times. A *Boundary Condition Domain* as declared on the *Boundary Conditions* card may contain more than one boundary surface. The parameter "LBC" indicates the total number of boundary surfaces, not the number of boundary condition domains. Although they may refer to the same computational domain surface, boundary surfaces declared in one boundary condition domain differ from those declared in another. The maximum number of boundary condition times equals the maximum number of times declared for all boundary condition domains. A simulation with three boundary condition domains, the first with 6 boundary surfaces and 13 boundary condition times, the second with

2 boundary condition surfaces and 26 boundary condition times, and the third with 34 boundary condition surfaces and 2 boundary condition times has a boundary parameter set that appeared as

PARAMETER(LBC=42, LBTM=26)

5.2.6 Source Parameters

The parameters "LSR" and "LSTM" equal the number of sources and maximum number of source times. Unlike the boundary condition parameters, a single source may contain more than one node, but is only counted as one with respect to the parameter "LSR." The maximum number of source times equals the maximum number of times declared for all sources. A simulation with 3 source domains, the first with 6 nodes and 13 source times, the second with 2 sources and 26 source times, and the third with 34 sources and 2 source times would have a source parameter set that appears as

PARAMETER(LSR=3, LSTM=26)

5.2.7 Rock Type and Solute Transport Parameters

The parameters "LRC" and "LSOLU" equal the number of rock types and number of transported solutes. The number of rock types equals the number of rock/soil types listed on the *Rock/Soil Zonation* card. Because one rock/soil type can define the rock/soil type for more than one rock/soil zonation domain, the number of rock/soil types does not equal the *Number of Rock/Soil Zonation Domains* declared on the *Rock/Soil Zonation* card. Each rock/soil type has a unique name. The number of solutes should equal the number of solutes defined on the *Solute/Fluid Interactions* card. Each solute must have a unique name. A simulation with 14 rock/soil zonation domains, 3 rock/soil types, 7 solutes for the *Water-Air/Transport* operational mode has a rock types and solutes parameter set that appeared as

PARAMETER(LRC=3, LSOLU=7)

5.2.8 Output Parameters

The parameters "LREF," "LPTM," and "LSF" equal the number of reference nodes, number of *plot* file output times, and the number of flux surfaces, respectively. The number of reference nodes equals the *Number of Reference Nodes* input on the *Output Control* card. The number of *plot* file output times equals the *Number of Plot File Times* input on the *Output Control* card. The *plot* file that is generated, by default at the conclusion of an execution is not counted as a *plot* file time. The number of flux surfaces should equal the *Number of Surface Flux Inputs* input on the *Surface Flux* card. A simulation with 4 reference nodes, 6 plot file output times (other than the *plot* file generated at the conclusion of the execution), and 23 flux surfaces would have an output parameter set that appeared as

PARAMETER(LREF=4, LPTM=6, LSF=23)

5.2.9 k-S-P Function Parameters

The parameters "LTBL" and "LPATH" equal the total number of table entries and the number of scanning paths for hysteretic saturation functions, respectively. The number of table entries equals the sum of *Number of Table Entries* on the *Saturation Function*, *Aqueous Relative Permeability Function*, and *Gas Relative Permeability Function* cards. The number of scanning paths equals the *Number of Scanning Paths* input for hysteretic saturation functions on the *Saturation Function* card. The recommended number of scanning paths for a hysteretic saturation function is seven. For non-hysteretic saturation functions, the number of scanning paths should equal one. A *Water* operational mode simulation with 2 rock/soil types, 34 tabular entries for the saturation function for the first rock/soil type, a declared non-hysteretic saturation function for the second rock/soil type, 27 tabular entries for the aqueous relative permeability for the first rock/soil type, and 31 tabular entries for the aqueous relative permeability for the second rock/soil type has a *k-S-P* function parameter set that appears as

PARAMETER(LTBL=92, LPATH=7)

5.2.10 Computed Parameters

Computed parameters are arithmetic combinations of the declared parameters and must follow the declared parameters in the parameters file. Computed parameters related to the conjugate gradient linear system solver are declared within the source code. Definitions of the computed parameters in the parameters file are given in Table 5.1. The computed parameter set for all simulations appears as

```
PARAMETER(LUK=LT+LL+LG+LN+LS, LPH=LL+LG+LN)
PARAMETER(LHBW=LUK*LMNP+LUK-1)
PARAMETER(LCOL=LBD*LAN*LUK + LCG*(2*LAD+1))
PARAMETER(LROW=LBD*(3*LHBW+1) + LCG*LAN*LUK)
PARAMETER(LSCG=LBD + LCG*LAN*LUK)
PARAMETER(LSBD=LBD*LAN*LUK + LCG)
PARAMETER(LSOL=LAN*LUK)
PARAMETER(LSV=LUK+2, LSFV=2*LUK+1)
PARAMETER(LFD=LFX*LFY*LFZ)
PARAMETER(LSX=(LFX+1)*LFY*LFZ)
PARAMETER(LSY=LFX*(LFY+1)*LFZ)
PARAMETER(LSZ=LFX*LFY*(LFZ+1))
PARAMETER(LFDT=LFD**LT,LFDL=LFD**LL,LFDG=LFD**LG,LFDN=LFD**LN)
PARAMETER(LFDC=LFD**LC, LFDI=LFD**LFC, LFDS=LFD**LS)
PARAMETER(LSXT=LSX**LT,LSXL=LSX**LL,LSXG=LSX**LG,LSXN=LSX**LN)
PARAMETER(LSXC=LSX**LC, LSXS=LSX**LS)
PARAMETER(LSYT=LSY**LT,LSYL=LSY**LL,LSYG=LSY**LG,LSYN=LSY**LN)
PARAMETER(LSYC=LSY**LC, LSYS=LSY**LS)
PARAMETER(LSZT=LSZ**LT,LSZL=LSZ**LL,LSZG=LSZ**LG,LSZN=LSZ**LN)
PARAMETER(LSZC=LSZ**LC, LSZS=LSZ**LS)
PARAMETER(LRCT=LRC**LT,LRCL=LRC**LL,LRCG=LRC**LG,LRCN=LRC**LN)
```

```
PARAMETER(LRCC=LRC**LC, LRCI=LRC**LFC, LRCS=LRC**LS)
PARAMETER(LBCT=LBC**LT,LBCL=LBC**LL,LBCG=LBC**LG,LBCN=LBC**LN)
PARAMETER(LBCC=LBC**LC, LBCI=LBC**LFC, LBCS=LBC**LS)
PARAMETER(LBCU=LUK+LPH, LBCV=LBCU+LSOLU, LOUPV=100+11*(LSOLU))
```

5.3 parameters.astct File

5.3.1 Specified Parameters

The parameter *maxxd* specifies the maximum number of points in the vertical (Z) direction, and is always set equal to the value of LFZ+1. The parameter *maxyd* specifies the maximum number of points in the horizontal (X) direction, and is always set equal to the value of LFX+1. The parameter *maxaqs* specifies the maximum number of aqueous species. The parameter *maxsld* specifies the maximum number of solid species. The parameter *maxfrxn* specifies the maximum number of fast reactions. The parameter *maxsrxn* specifies the maximum number of slow reactions. The parameter *maxfdec* specifies the maximum number of fluid decays. The parameter *maxsdec* specifies the maximum number of solid decays. The parameter *maxkrxn* specifies the maximum number of kinetic aqueous reactions. The parameter *maxlith* specifies the maximum number of lithologic units, and is always set equal to the value of LRC. The parameter *maxelem* specifies the maximum number of elements in one species. The parameter *maxgas* specifies the maximum number of gaseous species. An example of the specified parameters in a parameters.astct file is

```
parameter(maxxd=822,maxyd=26)
parameter(maxaqs=40,maxsld=20)
parameter(maxfrxn=20,maxsrxn=20)
parameter(maxfdec=1,maxsdec=1)
parameter(maxkrxn=1)
parameter(maxlith=6)
parameter(maxelem=14)
parameter(maxgas=3)
```

5.3.2 Computed Parameters

The parameter *maxrxn* specifies the maximum total number of reactions. The last line in the parameters.astct file is, therefore,

```
parameter(maxrxn=maxfrxn+maxkrxn+maxsrxn+maxfdec+maxsdec)
```

Table 5.1. Computed Parameter Definitions

Parameter	Definition
LUK	Number of solved coupled equations
LPH	Number of phases
LHBW	Block banded matrix half-band width
LCOL	Number of columns in the Jacobian matrix
LROW	Number of rows in the Jacobian matrix
LSCG	Number of unknowns for the conjugate gradient solver
LSBD	Number of unknowns for the banded matrix solver
LSOL	Number of unknowns
LSV	Number of field variable indexes
LSFV	Number of flux variable indexes
LFD	Number of nodes
LSX	Number of surfaces in the x- or r-directions
LSY	Number of surfaces in the y- or ÿ-directions
LSZ	Number of surfaces in the z-direction
LFDT	Number of energy field variables
LFDL	Number of aqueous field variables
LFDG	Number of gas field variables
LFDC	Number of solute transport equation field variables
LFDI	Number of solute transport equation field variables
LSXT	Number of energy flux variables in the x-direction
LSXL	Number of aqueous flux variables in the x-direction
LSXG	Number of gas flux variables in the x-direction
LSXC	Number of solute flux variables in the x-direction
LSYT	Number of energy flux variables in the y-direction
LSYL	Number of aqueous flux variables in the y-direction
LSYG	Number of gas flux variables in the y-direction
LSYC	Number of solute equation surfaces in the y-direction
LSZT	Number of energy flux variables in the z-direction
LSZL	Number of aqueous flux variables in the z-direction
LSZG	Number of gas flux variables in the z-direction
LSZC	Number of solute equation surfaces in the z-direction
LRCT	Number of energy variable rock/soil types
LRCL	Number of aqueous variable rock/soil types
LRCG	Number of gas variable rock/soil types
LRCC	Number of solute variable rock/soil types
LBCT	Number of energy boundary condition variables
LBCL	Number of aqueous boundary condition variables

Table 5.1. Computed Parameter Definitions (contd)

Parameter	Definition
LBCG	Number of gas boundary condition variables
LBCC	Number of solute boundary condition variables
LBCU	Number of coupled boundary condition variables
LBCV	Number of total boundary condition variables
LOUPV	Number of output variables

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6.0 Compilation and Execution

6.1 Introduction

The STORM simulator was designed primarily for execution on computers with UNIX(1) operating systems. An assembled source code, however, can be compiled and executed on any computer with an ANSI FORTRAN compiler, if the computer has sufficient memory. Although a general correspondence is present in computer design between memory size and execution speed, sufficient memory to compile and execute does not guarantee the machine has sufficient execution speeds to complete a simulation within a reasonable time period. The STORM simulator should be thought of as a collection of source code libraries. The libraries that become part of the executable code are dependent on the operational mode. Each operational mode requires a particular group of library source codes. The normal procedure for building an executable version for a particular operational mode involves compiling the required group of library source codes, using the declared and computed parameters in the parameters and parameters.astc files to define memory requirements, and linking the compiled object files to create an executable. An alternate option is to assemble or concatenate all of the source code libraries required for a particular operational mode into a single file and, subsequently, compile the assembled source code. Either procedure can be performed manually or automatically. The *make* utility (Talbott 1988) that generates a sequence of commands for execution by the UNIX shell, can be used to automatically compile and link the required source code libraries for a particular operational mode. A *makefile*, which contains a *make* utility instruction set is designed to generate an executable or assembly source code for the STORM simulator.

6.2 Compilation

Executing the make command compiles and links all of the source and object coding required for an operational mode into a single executable file. Operational mode options are specified on the command line by specifying the name of the executable. As an example, the following UNIX shell command string on a computer that supports the *make* utility generates an optimized executable of the *Water-Air-Energy* operational mode

make storm3

where a file named "storm3" is generated. Table 6.1 shows the correspondence between the name of the executable and operational modes.

(1) UNIX is a registered trademark of AT&T Information Systems.

Table 6.1. Glossary of Operational Mode Indexes

Index	Operational Mode
storm1	*Water/Reactive Transport*
storm2	*Water-Air/Reactive Transport*
storm3	*Water-Air-Energy/Reactive Transport*

Assembly options are entered on a line within the file named *Makefile*, and assigned to a variable named FFLAGS. For example, the following line compiles the code on a SUN workstation with the options to generate a fast executable with the extended source code line length (132 characters) turned on.

FFLAGS = -fast -e

The assembly process has certain requirements with respect to source files, the commons file, the parameters file, and the *make* description file. Storing all of the source files (those files that have *.f* or *.c* extensions) and the commons file in a single directory is recommended. A path name to this directory can be defaulted into the make description file.

Executing make produces object files, with *.o* extensions for every required FORTRAN source file. These object files appear in the current directory but are not necessary for code execution and can be discarded. Any modifications to the parameters file would require that the code be recompiled and linked. Executing make following a modification to the parameter file automatically regenerates the object and executable files. Because of the updating features in make, any recompilation using a different assembly option requires the user to remove all of the object files from the current directory.

6.3 Execution

Executing the STORM simulator is straightforward and only requires that an input file named *input* resides in the current directory. For restart simulations, a restart file named *restart* must also reside in the current directory. Because restart files are created with an extension that corresponds with the generating time step, the user must rename the appropriate restart file to restart. For a UNIX operating system, execution is started by typing in the path to and the name of the executable file. Execution is indicated by printing a STORM title banner and program disclaimer to the standard input/output device (for example, a monitor).

6.3.1 Error Messages

Two types of error messages can be generated during a STORM execution. The first type is a system-generated message that typically indicates a memory error, FORTRAN error, or other system error identified by the system. The second type of error messages is that generated by the STORM code that typically refer to input, parameter, or convergence failure type messages. STORM-generated messages are divided into three categories, according to severity. The most severe are the ERROR messages that abort the program execution. Undersized parameters are typical of errors that yield

ERROR messages because execution of the simulator with undersized parameters may yield gross errors, or even worse, subtle errors that can pass undetected in the results. Next on the severity level are the WARNING messages that generally indicates to the user that a problem with the input file probably exists. The least severe are NOTE messages that are used to record events such as the absence of an optional input card.

When an execution is terminated with a STORM-generated ERROR message two types of information appear on the standard input/output device. The first piece of information is an error message with or without related data that indicates the nature of the error. To a limited degree, the STORM simulator also traps input formatting errors. Unfortunately, the resulting input error message that results may not always agree with the actual location of the identified input error. This situation arises because the original error may have skipped detection. For example, a missing input item on an input line is not identified until STORM identifies an incorrect data type or the end of the line was reached. The user will expect to find input errors slightly before the location indicated by the generating error message. The second type of information, which is generated with an ERROR message, is a calling sequence. The calling sequence is a slash delineated list of routine names that were called prior to the identified error. The calling sequence for an input error on the *Aqueous Relative Permeability* card for the *Water* operational mode appears as

/STORM1/RDINPT1/RDRPL/WRMSG

where the called routine names are delineated with a forward slash. For this example, the main routine STORM1 called the subroutine RDINPT1 to read the input file for the *Water* operational mode. It in turn, called RDRPL, the global routine, to read the *Aqueous Relative Permeability* card that identified an error and called WRMSG to write an error message to the standard input/output device.

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7.0 Output Files

7.1 Introduction

The STORM simulator can generate, depending on the requested output and saturation function type, two data files for restarting a simulation and three simulation result files. Every execution produces an *output* file. If the simulation concludes without a fatal error, a *restart* and *plot* file are also generated. *Restart* and *plot* files names include an extension that corresponds to the time step at which the file was written. For example, a restart file named *restart.39* was written at the conclusion of the 39th time step. Simulations involving hysteretic saturation functions also produce a *hyster* file that contains saturation history records. *Hyster* file names also include an extension that corresponds to the time step at which the file was written. A *surface* file is only generated when a *Surface Flux* card is included in an input file. All output files generated by the STORM simulator are ASCII text files.

7.2 Output File

An *output* file is generated with every execution. If a file named *output* already exists in the current directory, the file is erased and overwritten. The user is responsible for renaming previous *output* files prior to executing the STORM simulator. An *output* file begins with a welcome statement, a disclaimer, and a banner that appear similar to

Welcome to ...

STORM
Subsurface Transport Over Reactive Multiphases

This file was produced by STORM, a numerical simulator
developed by the Pacific Northwest National Laboratory
with support from the U.S. Department of Energy.

Results from this version of STORM should not be used
for license related applications. Distribution of the
STORM source code is strictly prohibited.

For inquiries or assistance: Call (509) 372-6132

--- OUTPUT ---

Following this banner is an input record that documents the simulation input. An input record is included on the *output* file to document the simulation in the event the *input* file is destroyed or becomes separated from the *output* file. The input record is formatted differently that an *input* file, but contains all of the information listed on an input file. Optional cards that are not included in the *input* file are noted in the input record. If an input error is identified by the STORM simulator, an error message appears in the input record at the point the error was noted. Input cards are read by the STORM simulator in a specific order and appear in that order in the input record. Because input cards can be organized randomly on the *input* file, the card order on the input record may not match that on the *input* file.

7.3 Refnod File

The *refnod* (reference node) output file is a table of simulation data and selected reference node variables that are printed according the frequency requested on the *Output Control* card with the input item *Reference Node Output File Frequency*. Every 10 print records a table column header is printed to delineate the columns. Each print record shows simulation data and reference node variable data for each reference node requested. Simulation data comprises the time step, the reference node number, the simulation time, the simulation time step, and the number of Newton-Raphson iterations required to reach convergence. Reference node variable data comprise values of the variables specified on the *Output Control* card through the *Reference Node Variable* inputs. Reference nodes are indexed by node number. The corresponding x-, y-, and z-direction indexes are shown for each reference node on the line preceding the column headers. For example, a simulation with reference node 272 at x-, y-, and z-direction indexes of 2, 3, and 6, respectively, has a reference node header line that appeared as

Reference Node(s) (2, 3, 6: 272)

Column headers for reference node variables are delineated with an abbreviated title and associated units. Units are enclosed in brackets below the variable abbreviation. A portion of a reference node output record for a horizontal heat pipe problem, involving 50 nodes for time steps 70 through 73, appears as

Reference Node(s) (1, 1, 1: 1) (50, 1, 1: 50)

Step	Node	Time [day]	Timestep [day]	Itr	T [c]	SL	PL [pa]
70	1	2.837E+01	1.793E+00	8	7.1893E+01	9.9893E-01	1.0133E+05
70	50	2.837E+01	1.793E+00	8	1.3564E+02	2.0992E-02	-1.9896E+08
71	1	3.061E+01	2.242E+00	9	7.1895E+01	9.9903E-01	1.0133E+05
71	50	3.061E+01	2.242E+00	9	1.4039E+02	1.9265E-02	-2.2722E+08
72	1	3.341E+01	2.802E+00	9	7.1878E+01	9.9933E-01	1.0133E+05
72	50	3.341E+01	2.802E+00	9	1.4598E+02	1.7489E-02	-2.6050E+08
73	1	3.692E+01	3.503E+00	8	7.1869E+01	9.9951E-01	1.0133E+05
73	50	3.692E+01	3.503E+00	8	1.5225E+02	1.5759E-02	-2.9758E+08

The reference nodes are nodes 1 and 50; the reference node variable data includes the temperature, reported in degrees Celsius, the aqueous saturation, and the aqueous pressure, reported in Pascal (absolute).

7.4 Plot File

A *plot* file is generated by default at the conclusion of every execution and, additionally when requested on the *Output Control* card with the *Plot File Output Times* input items. If a file named *plot.xx* (where *xx* refers to the time step extension) already exists in the current directory, the file is erased and overwritten. The user is responsible for renaming previous *plot.xx* files prior to executing the STORM simulator. A *plot* file begins with a welcome statement, a disclaimer, and a banner that appear similar to

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--- PLOT ---

Following this header are data on the current time step, simulation time, and number of nodes in three coordinate directions. The remaining portion of a *plot* file comprises arrays of geometric and variable data. These data are arranged in groups, each with a title line that indicates the type of data that follows. Data groups are arranged in rows with 10 data items per row. Each group of data contains a field or surface variable listed sequentially for every node or surface in the computational domain. The first four groups of data appear in every plot file and contain the x- or r-direction node positions, y- or θ-direction node positions, z-direction node positions, and node volumes for every node in the computational domain. The remaining groups of data correspond to the requested *Plot File Variables*. Field variable data groups list the value of the field variable at the node centroid. Surface variables or fluxes are written twice to the plot file. The first flux variable data group lists the value of the flux variable at the node centroid, whereas the second group lists the value at the node surfaces. Node centroid values for flux variables are simple arithmetic averages of the two node surface values.

Two post-processing programs are available, d_plot1d and d_plot2d. The program d_plot1d parses output data from a 1-dimensional simulation into columnar format. The program d_plot2d parses data from a 2-dimensional simulation into Spyglass Transform format.

7.5 Surface File

A *surface* file is generated during an execution if surfaces are defined on the *Surface Flux* card If a file named *surface* already exists in the current directory, the file is erased and overwritten. The user is responsible for renaming previous *surface* files prior to executing the STORM simulator. A *surface* file begins with a welcome statement, a disclaimer, and a banner that appear similar to

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--- SURFACE ---

Following the header, are columns of surface flux rate and integral data. Surface flux information is written to the *surface* file at the conclusion of every time step. The first column of data in the *surface* file is the time step in units that are specified with the *Output Time Units* variable on the *Output Control* card. Each surface flux output is written in two columns: the first column is the surface flux rate at the current time step and the column is the integral of the surface flux rate from the beginning of the current simulation. Surface flux integral data are not carried over on restart simulations. Each column in the *surface* file is titled with an abbreviated header and associated units shown in brackets under the column title. Definitions of the header abbreviations for the *surface* file are given in Table 7.1. Each header title is followed with an integer enclosed in parentheses. The integer refers to the surface flux number, as defined on the *Surface Flux* card (that is, the surface flux definition order).

7.6 Restart File

A *restart* file is generated by default at the conclusion of every execution and also when requested on the *Output Control* card with the *Plot File Output Times* input items. If a file named *restart.xx* (where *xx* refers to the time step extension) already exists in the current directory, the file is erased and overwritten.

Table 7.1. Surface Flux Column Title Abbreviations

Abbreviation	Definition
UGM	Gas mass flux rate (x-direction)
UGMS	Gas mass flux integral (x-direction)
ULM	Aqueous mass flux rate (x-direction)
ULMS	Aqueous mass flux integral (x-direction)
UGV	Gas volumetric flux rate (x-direction)
UGVS	Gas volumetric flux integral (x-direction)
ULV	Aqueous volumetric flux rate (x-direction)
ULVS	Aqueous volumetric flux integral (x-direction)
UQV	Energy flux rate (x-direction)
UQVS	Energy flux integral (x-direction)
VGM	Gas mass flux rate (y-direction)
VGMS	Gas mass flux integral (y-direction)
VLM	Aqueous mass flux rate (y-direction)
VLMS	Aqueous mass flux integral (y-direction)
VGV	Gas volumetric flux rate (y-direction)
VGVS	Gas volumetric flux integral (y-direction)
VLV	Aqueous volumetric flux rate (y-direction)
VLVS	Aqueous volumetric flux integral (y-direction)
VQV	Energy flux rate (y-direction)
VQVS	Energy flux integral (y-direction)
WGV	Gas volumetric flux rate (z-direction)
WGVS	Gas volumetric flux integral (z-direction)
WLV	Aqueous volumetric flux rate (z-direction)
WLVS	Aqueous volumetric flux integral (z-direction)
WGM	Gas mass flux rate (z-direction)
WGMS	Gas mass flux integral (z-direction)
WLM	Aqueous mass flux rate (z-direction)
WLMS	Aqueous mass flux integral (z-direction)
WQV	Energy flux rate (z-direction)
WQVS	Energy flux integral (z-direction)

The user is responsible for renaming previous restart.xx files prior to executing the STORM simulator. A *restart* file begins with a welcome statement, a disclaimer, and a banner that appear similar to

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--- RESTART ---

All data values in *restart* files are in SI units with pressures expressed in gauge. The first data line of a *restart* file contains the following timing and simulation information: time, time step, maximum time step, time step acceleration factor, convergence criterion, maximum number of Newton-Raphson iterations, number of time steps, and number of nodes. The remaining lines are node data lines that contain the following field variable data for the current time step for every node (one line per node): temperature, aqueous pressure, gas pressure, water vapor pressure, aqueous saturation, and gas saturation. If the simulation includes solute transport, the node data lines also contain solute volumetric concentrations for each solute. Moreover, if the simulation includes freezing water conditions, the node data lines also contain the frozen water pressure and frozen water saturation. All node data lines are terminated with an integer value for the phase condition. Refer to the STOMP Theory Manual (White and Oostrom 1996) for a discussion of phase conditions.

8.0 Model Verification

8.1 Aqueous Phase Advection and Diffusion

For the case of 1-dimensional, steady state diffusion and advection of a single aqueous species, with constant production from a single reaction with depth, Equations **(2.17)** through **(2.27)**simplify to

$$W = -\left(\theta_a \mathbf{D}^a\right)\frac{\partial^2 C^a}{\partial z^2} + \left(\theta_a \mathbf{V}_a\right)\frac{\partial C^a}{\partial z} \tag{8.1}$$

Assuming production occurs over a finite depth $0<z<L$, with a specified concentration (C_0^a) at the top boundary ($z = 0$) and no diffusive flux at the lower boundary (z = L), the aqueous phase concentration of that gas species is given by

$$C_z^a = \frac{\mathbf{D}\left(e^{\frac{L\mathbf{v}}{\mathbf{D}}} - e^{\frac{(L-z)\mathbf{v}}{\mathbf{D}}}\right)W + \mathbf{v}\left(C_0^a\mathbf{v} - Wz\right)}{\mathbf{v}^2} \tag{8.2}$$

where $\mathbf{V} = \theta_a \mathbf{V}_a$ and $\mathbf{D} = \theta_a \mathbf{D}^a$. A STORM simulation of Halite dissolution was run that corresponds to this analytical solution. Both the *Fully Coupled* and the *Operator Split* solution modes were used. Output from STORM was compared to the analytical solution. The model parameters are listed in Table 8.1; the results are shown in Figure 8.1. Results for STORM run in the *Fully Coupled* solution mode and the analytical solution agree well. Results for STORM run in the *Operator Split* mode agree, if the time step is constrained to a maximum value of 0.5 hour.

Table 8.1. Simulation Parameters for Gas Phase Diffusion

Parameter	Value
Temperature, C	25
C_0^a, mol kg^{-1}	1.0×10^{-7}
D^a, m^2 s^{-1}	5.0×10^{-4}
V_a, m s^{-1}	1.6×10^{-8}
θ_a	5.2×10^{-2}
W, mol m^{-3} s^{-1}	1.2×10^{-9}

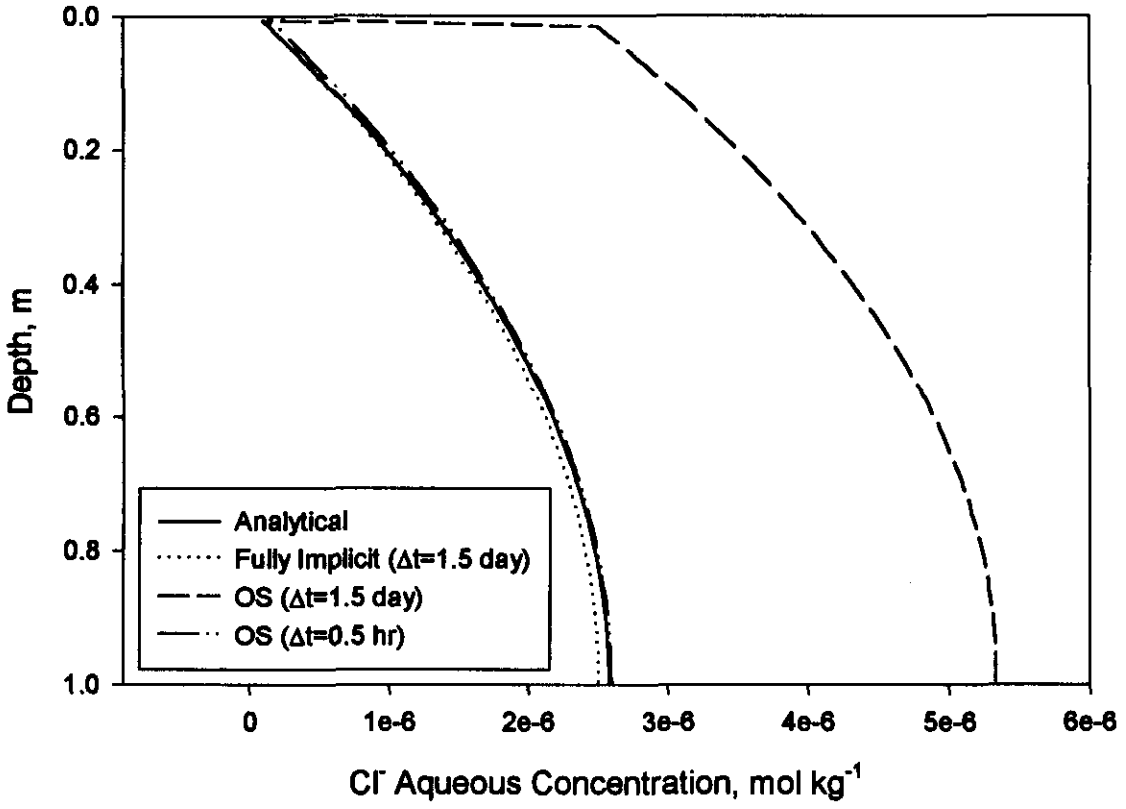

Figure 8.1. Comparison of STORM Results Using Either *Fully Coupled* or *Operator Split* Solution Modes to Analytical Solution for Constant Source, Advection, and Diffusion

Data File 8.1. Input File for Aqueous Phase Advection and Diffusion Test Case

```
~Simulation Title Card
1,
Organic matter decomposition,
DH Bacon,
Pacific Northwest National Laboratory,
August 1998,
00:00:00 AM PDT,
0,

~Solution Control Card
Restart,
Water w/ Transport,
1,
0.0,hr,1000.,yr,1.,s,5.,yr,1.005,8,1.0e-6,
1.e+30,yr,1.e+30,yr,100000,
0,
```

```
~Grid Card
Uniform Cartesian,
1,1,100,
1.0,cm,
1.0,cm,
1.0,cm,

~Rock/Soil Zonation Card
2,
TopSoil,1,1,1,1,1,50,
BottomSoil,1,1,1,1,51,100,

~Mechanical Properties Card
TopSoil,2.72,g/cm^3,0.371,0.371,1.e-5,1/m,Millington and Quirk,
BottomSoil,2.72,g/cm^3,0.371,0.371,1.e-5,1/m,Millington and Quirk,

~Hydraulic Properties Card
TopSoil,9467.28,hc m/yr,,,9467.28,hc m/yr,Constant,
BottomSoil,9467.28,hc m/yr,,,9467.28,hc m/yr,Constant,

~Saturation Function Card
TopSoil,Nonhysteretic van Genuchten,6.83,1/m,2.08,0.1213,,
BottomSoil,Nonhysteretic van Genuchten,6.83,1/m,2.08,0.1213,,

~Aqueous Relative Permeability Card
TopSoil,Mualem,,
BottomSoil,Mualem,,

~Gas Relative Permeability Card
TopSoil,Mualem,,
BottomSoil,Mualem,,

~Boundary Conditions Card
2,
Top,Neumann Aqueous,Initial Cond,Initial Cond,Initial Cond,Initial Cond,Initial
Cond,Initial Cond,
1,1,1,1,100,100,1,
0.0,hr,-0.05,cm/yr,,,,,,,,,,,,
Bottom,Free Gradient,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,
1,1,1,1,1,1,1,
0.0,hr,,,,,,,,,,,,,,

~Source Card
1,
Aqueous Mass,1,1,1,1,1,1,100,1,
0.,s,0.,kg/s,,

~Output Control Card
1,
1,1,100,
1,1,hr,cm,3,5,5,
```

```
0,
14,
0.0,yr,
1.0,min,
1.0,day,
1.0,wk,
4.3,wk,
1.0,yr,
2.0,yr,
5.0,yr,
10.0,yr,
50.0,yr,
100.0,yr,
500.0,yr,
1000.0,yr,
5000.0,yr,
14,
Gas Pressure,Pa,
Aqueous Pressure,Pa,
Gas Saturation,,
Aqueous Saturation,,
Aqueous Density,kg/m^3,
Rock/Soil Type,,
Diffusive Porosity,,
Aqueous Relative Permeability,,
z Aqueous Volumetric Flux,m/s,
Solute Aqueous Conc,H+,1/m^3,
Solute Aqueous Conc,H2O,1/m^3,
Solute Aqueous Conc,OH-,1/m^3,
Solute Aqueous Conc,Na+,1/m^3,
Solute Aqueous Conc,Cl-,1/m^3,

~Surface Flux Card
1,
Aqueous Volumetric Flux,m^3/s,m^3,Top,1,1,1,1,100,100,

~Reactive Transport Control card
Normal,
Fully Coupled,
0,1,0,1,1,0,0,0,0,
 2.00000E-06, 1.00000E+00, 1.00000E-06, 1.00000E-07, 1.00000E-06, 5.00000E-03,
1.00000E-06,

~Solute/Fluid Interaction Card
5,
H+,Constant,5.0e-4,m^2/s,Continuous,1.e20,yr,
H2O,Constant,5.0e-4,m^2/s,Continuous,1.e20,yr,
OH-,Constant,5.0e-4,m^2/s,Continuous,1.e20,yr,
Na+,Constant,5.0e-4,m^2/s,Continuous,1.e20,yr,
Cl-,Constant,5.0e-4,m^2/s,Continuous,1.e20,yr,
0,
```

```
~Solute/Porous Media Interaction Card
TopSoil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
Na+,0.0,m^3/kg,
Cl-,0.0,m^3/kg,
BottomSoil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
Na+,0.0,m^3/kg,
Cl-,0.0,m^3/kg,

~Aqueous Species card
 5,
'H+          ', 1.0000, 9.0000, 1,
 1.0000,' H',
'H2O         ', 0.0000,-4.0000, 2,
 2.0000,' H',
 1.0000,' O',
'OH-         ',-1.0000, 3.0000, 2,
 1.0000,' H',
 1.0000,' O',
'Na+         ', 1.0000, 4.0000, 1,
 1.0000,'Na',
'Cl-         ',-1.0000, 3.0000, 1,
 1.0000,'Cl',

~Gas Species card
   0,

~Components card
   0,

~Solid Species card
  1,
'Halite', 2.1633,  2,
 1.0000,'Na',
 1.0000,'Cl',

~Fast Reactions card
   1,
   3,
-1.0000,'H2O         ',
 1.0000,'H+          ',
 1.0000,'OH-         ',
   5,    1.00000,
-1.49400E+01, 4.17100E-02,-1.91700E-04, 4.95000E-07,-6.15900E-10,
```

```
~Kinetic Aqueous Reactions card
   0,

~Slow Reactions card
 1,
 0, 1,
-1.0000,'Halite',
   2,
 1.00000E+00,'Na+          ', 1.0000, 1.0000,
 1.00000E+00,'Cl-          ', 1.0000, 1.0000,
    -22.2669,  0.,    1.00000,  0.0, 1,
1.5855,

~Fluid Decay card
   0,

~Solid Decay card
   0,

~Lithology card
'top soil    ', 1,
'Halite', 1.00000E+00, 0.50000E-02,
'bottom soil ', 1,
'Halite', 1.00000E+00, 0.50000E-02,

~Reaction BC card
   1,
1,1,
   0,
   0,
   0,
   4,
  0.10000E+01,  1,
 1.0000,'H2O         ',
  0.10000E-06,  1,
 1.0000,'H+          ',
  0.10000E-06,  1,
 1.0000,'Na+         ',
  0.10000E-06,  1,
 1.0000,'Cl-                '

~Reaction IC card
   1,
```

8.2 Gas Phase Advection and Diffusion

For the case of 1-dimensional, steady state diffusion of a single gas species, with constant production from a single reaction with depth, Equation **(2.17)** simplifies to

$$W = -\left(\theta_g \mathbf{D}^g K_H'^{-1} + \theta_a \mathbf{D}^a\right)\frac{\partial^2 C^a}{\partial z^2} \tag{8.3}$$

Assuming production occurs over a finite depth $0<z<L$, with a specified concentration (C_0^a) at the top boundary ($z = 0$) and no diffusive flux at the lower boundary (z = L), the aqueous phase concentration of that gas species is given by

$$C_z^a = C_0^a + \frac{W}{\left(\theta_g \mathbf{D}^g K_H'^{-1} + \theta_a \mathbf{D}^a\right)}\left(zL - \frac{z^2}{2}\right) \tag{8.4}$$

and the gas phase concentration may be determined using Equation **(2.16)**. A STORM simulation was run that corresponds to this analytical solution. The model parameters are listed in Table 8.2.

Results for simulations with two different CO_2(g) production rates are shown in Figure 8.2 (open and closed diamond symbols). Results for STORM and the analytical solution agree quite well. Concentrations of CO_2(g) shown are reasonable values found in vadose zones where organic matter is being decomposed by aerobic bacteria.

Table 8.2. Simulation Parameters for Gas Phase Diffusion

Parameter	Value
Temperature, C	15
C_0^a, atm	3×10^{-4}
K_H'	1.088
D^g, $m^2\ s^{-1}$	1.6×10^{-6}
D^a, $m^2\ s^{-1}$	5×10^{-9}
θ_g	0.24
θ_a	0.0266
W, mol $m^{-3}\ s^{-1}$	4.65×10^{-9} or 9.60×10^{-9}

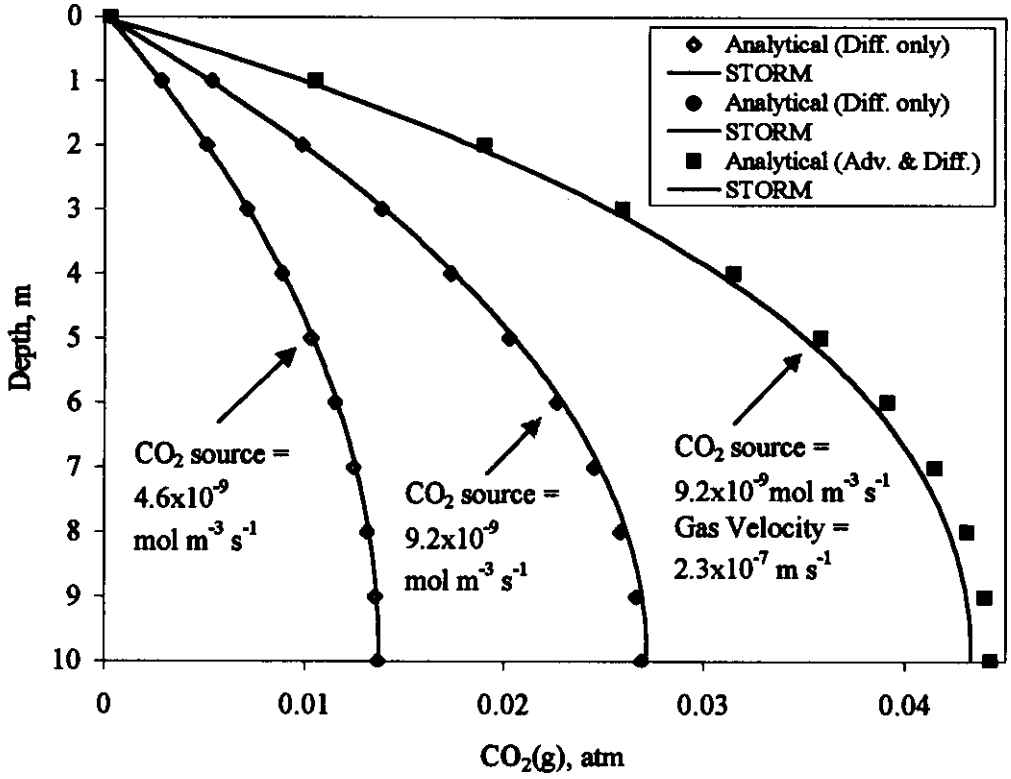

Figure 8.2. Results of Gas Phase Diffusion and Advection Test Cases, Comparing STORM with Analytical Solutions for Constant Gas-Phase Production and Diffusion, with and without Advection

Data File 8.2. STORM Input Data File for Gas Phase Advection and Diffusion Test Case

```
~Simulation Title Card
1,
Organic matter decomposition,
DH Bacon,
Pacific Northwest National Laboratory,
August 1998,
00:00:00 AM PDT,
1,
With O2(g) and CO2(g) diffusion

~Solution Control Card
Restart w/ no flow,
Water w/ air w/ transport,
1,
0.0,hr,1000.,yr,1.,min,5.,yr,1.005,8,1.0e-6,
1.e+30,yr,1.e+30,yr,100000,
Variable Aqueous Diffusion,
```

```
Variable Gas Diffusion,
1,
Aqueous Relative Permeability,Geometric,

~Grid Card
Uniform Cartesian,
1,1,100,
1.0,cm,
0.1,cm,
10.0,cm,

~Rock/Soil Zonation Card
2,
TopSoil,1,1,1,1,1,50,
BottomSoil,1,1,1,1,51,100,

~Mechanical Properties Card
TopSoil,2650.0,kg/m^3,0.2667,0.2667,,,Millington and Quirk,
BottomSoil,2650.0,kg/m^3,0.2667,0.2667,,,Millington and Quirk,

~Hydraulic Properties Card
TopSoil,,,,,3.156e-5,hc cm/s,Constant,
BottomSoil,,,,,3.156e-5,hc cm/s,Constant,

~Saturation Function Card
TopSoil,Nonhysteretic van Genuchten,0.044,1/cm,2.2,0.08494,,
BottomSoil,Nonhysteretic van Genuchten,0.044,1/cm,2.2,0.08494,,

~Aqueous Relative Permeability Card
TopSoil,Tabular,33,
3.5026E-09,3.1593E-07,
0.01225919,6.7082E-07,
0.02977233,1.7099E-06,
0.04728546,3.8458E-06,
0.0647986,7.8611E-06,
0.08231173,1.4901E-05,
0.117338,4.5067E-05,
0.15236427,0.00011488,
0.18739054,0.00025837,
0.22241681,0.00052812,
0.25744308,0.00100111,
0.29246935,0.0017854,
0.32749562,0.00302769,
0.36252189,0.00492173,
0.39754816,0.00771754,
0.43257443,0.01173155,
0.4676007,0.01735761,
0.50262697,0.02507879,
0.53765324,0.03548017,
0.57267951,0.04926245,
0.60770578,0.06725641,
```

```
0.64273205,0.09043837,
0.67775832,0.11994642,
0.71278459,0.15709761,
0.74781086,0.20340604,
0.78283713,0.26060184,
0.8178634,0.330651,
0.85288967,0.41577624,
0.88791594,0.51847864,
0.92294221,0.64156028,
0.95796848,0.78814774,
0.99299475,0.96171657,
1,1,
BottomSoil,Tabular,33,
3.5026E-09,3.1593E-07,
0.01225919,6.7082E-07,
0.02977233,1.7099E-06,
0.04728546,3.8458E-06,
0.0647986,7.8611E-06,
0.08231173,1.4901E-05,
0.117338,4.5067E-05,
0.15236427,0.00011488,
0.18739054,0.00025837,
0.22241681,0.00052812,
0.25744308,0.00100111,
0.29246935,0.0017854,
0.32749562,0.00302769,
0.36252189,0.00492173,
0.39754816,0.00771754,
0.43257443,0.01173155,
0.4676007,0.01735761,
0.50262697,0.02507879,
0.53765324,0.03548017,
0.57267951,0.04926245,
0.60770578,0.06725641,
0.64273205,0.09043837,
0.67775832,0.11994642,
0.71278459,0.15709761,
0.74781086,0.20340604,
0.78283713,0.26060184,
0.8178634,0.330651,
0.85288967,0.41577624,
0.88791594,0.51847864,
0.92294221,0.64156028,
0.95796848,0.78814774,
0.99299475,0.96171657,
1,1,

~Gas Relative Permeability Card
TopSoil,Tabular,33,
1,1,
0.98774081,0.99999139,
```

```
0.97022767,0.99994918,
0.95271454,0.99987151,
0.9352014,0.99975797,
0.91768827,0.99960795,
0.882662,0.99919528,
0.84763573,0.99862545,
0.81260946,0.99788751,
0.77758319,0.99696733,
0.74255692,0.99584706,
0.70753065,0.99450437,
0.67250438,0.99291148,
0.63747811,0.99103385,
0.60245184,0.98882835,
0.56742557,0.98624081,
0.5323993,0.98320258,
0.49737303,0.97962579,
0.46234676,0.9753964,
0.42732049,0.97036419,
0.39229422,0.96432763,
0.35726795,0.95701052,
0.32224168,0.94802483,
0.28721541,0.93680881,
0.25218914,0.92251973,
0.21716287,0.90383668,
0.1821366,0.87857318,
0.14711033,0.84284783,
0.11208406,0.78910152,
0.07705779,0.70059708,
0.04203152,0.53266493,
0.00700525,0.13244732,
0,0,
BottomSoil,Tabular,33,
1,1,
0.98774081,0.99999139,
0.97022767,0.99994918,
0.95271454,0.99987151,
0.9352014,0.99975797,
0.91768827,0.99960795,
0.882662,0.99919528,
0.84763573,0.99862545,
0.81260946,0.99788751,
0.77758319,0.99696733,
0.74255692,0.99584706,
0.70753065,0.99450437,
0.67250438,0.99291148,
0.63747811,0.99103385,
0.60245184,0.98882835,
0.56742557,0.98624081,
0.5323993,0.98320258,
0.49737303,0.97962579,
0.46234676,0.9753964,
```

```
0.42732049,0.97036419,
0.39229422,0.96432763,
0.35726795,0.95701052,
0.32224168,0.94802483,
0.28721541,0.93680881,
0.25218914,0.92251973,
0.21716287,0.90383668,
0.1821366,0.87857318,
0.14711033,0.84284783,
0.11208406,0.78910152,
0.07705779,0.70059708,
0.04203152,0.53266493,
0.00700525,0.13244732,
0,0,

~Boundary Conditions Card
2,
Top,Neumann Aqueous,Neumann Gas,Initial Cond,Initial Cond,Initial Cond,Initial
Cond,Initial Cond,Initial Cond,
1,1,1,1,100,100,1,
0.0,hr,-8.4333E-12,m/s,,5.5e-08,m/s,1.,,,,,,,,,,,,
Bottom,Dirichlet Aqueous,Dirichlet
Gas,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,
1,1,1,1,1,1,1,
0.0,hr,3.3100E+04,Pa,,101325.0,Pa,1.,,,,,,,,,,,,

~Source Card
1,
Aqueous Mass,1,1,1,1,1,100,1,
0.,s,60000.,Pa,0.,kg/s,,
Gas Mass,1,1,1,1,1,100,1,
0.,s,60000.,Pa,0.,kg/s,,

~Output Control Card
1,
1,1,100,
1,1,hr,cm,3,5,5,
0,
14,
0.0,yr,
1.0,min,
1.0,day,
1.0,wk,
4.3,wk,
1.0,yr,
2.0,yr,
5.0,yr,
10.0,yr,
50.0,yr,
100.0,yr,
500.0,yr,
```

```
1000.0,yr,
5000.0,yr,
11,
Gas Pressure,Pa,
Aqueous Pressure,Pa,
Gas Saturation,,
Aqueous Saturation,,
Aqueous Density,kg/m^3,
Gas Density,kg/m^3,
Rock/Soil Type,,
Diffusive Porosity,,
Aqueous Relative Permeability,,
z Aqueous Volumetric Flux,m/s,
z Gas Volumetric Flux,m/s,

~Surface Flux Card
1,
Aqueous Volumetric Flux,m^3/s,m^3,Top,1,1,1,1,100,100,

~Reactive Transport Control card
Normal,
Fully Coupled,
0,0,0,0,1,0,0,0,0,
 2.00000E-06, 1.00000E+00, 1.00000E-06, 1.00000E-07, 1.00000E-06, 5.00000E-03,
1.00000E-06,

~Aqueous Species card
 6,
'H+          ', 1.0000, 9.0000, 1,
 1.0000,' H',
'H2O         ', 0.0000,-4.0000, 2,
 2.0000,' H',
 1.0000,' O',
'OH-         ',-1.0000, 3.0000, 2,
 1.0000,' H',
 1.0000,' O',
'CO2(aq)     ', 0.0000, 0.0000, 2,
 1.0000,' C',
 2.0000,' O',
'O2(aq)      ', 0.0000, 3.0000, 1,
 2.0000,' O',
'Cl-         ',-1.0000, 3.0000, 1,
 1.0000,'Cl',

~Solute/Fluid Interaction Card
6,
H+,5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
H2O,5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
OH-,5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
CO2(aq),5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
O2(aq),5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
```

```
Cl-,5.0e-9,m^2/s,0.,m^2/s,Constant,0.,m^3/m^3,Continuous,1.e20,yr,
0,

~Solute/Porous Media Interaction Card
TopSoil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
CO2(aq),0.0,m^3/kg,
O2(aq),0.0,m^3/kg,
Cl-,0.0,m^3/kg,
BottomSoil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
CO2(aq),0.0,m^3/kg,
O2(aq),0.0,m^3/kg,
Cl-,0.0,m^3/kg,

~Gas Species card
   2,
'CO2(g)      ', 'CO2(aq)     ', 'diffusion', 1.69443E-06, 2,
 1.0000,' C',
 2.0000,' O',
 4,
-1.096100E+00,-1.796793E-02, 1.321931E-04,-3.982381E-07,
'O2(g)       ', 'O2(aq)      ', 'diffusion', 2.40000E-06, 1,
 2.0000,' O',
 4,
-2.656700E+00,-1.224250E-02, 1.117390E-04,-3.440481E-07,

~Components card
   0,

~Solid Species card
  1,
'Organic Matter', 2.5200,  3,
 1.0000,' C',
 2.0000,' H',
 1.0000,' O',

~Fast Reactions card
   1,
   3,
-1.0000,'H2O         ',
 1.0000,'H+          ',
 1.0000,'OH-         ',
   5,    1.00000,
-1.49400E+01, 4.17100E-02,-1.91700E-04, 4.95000E-07,-6.15900E-10,

~Kinetic Aqueous Reactions card
```

```
   0,

~Slow Reactions card
 1,
 0, 1,
-1.0000,'Organic Matter',
   3,
-3.60900E-02,'O2(aq)      ', 0.0000, 0.0000,
 1.08800E+00,'CO2(aq)     ', 0.0000, 0.0000,
 0.00000E+00,'Cl-         ', 1.0000, 1.0000,
    -22.2669,  0.,    1.00000,  0.0, 1,
-1.00000E+00,

~Fluid Decay card
   0,

~Solid Decay card
   0,

~Lithology card
'top soil    ', 1,
'Organic Matter', 1.00000E+00, 0.50000E-02,
'bottom soil ', 1,
'Organic Matter', 1.00000E+00, 0.50000E-02,

~Reaction BC card
   1,
1,1,
   0,
   0,
   2,
'CO2(g)      ', 3.00000E-04,
'O2(g)       ', 2.10000E-01,
   3,
  0.10000E+01,  1,
 1.0000,'H2O         ',
  0.10000E-06,  1,
 1.0000,'H+          ',
  2.15331E-03,  1,
 1.0000,'Cl-                '

~Reaction IC card
   1,
```

For the case of 1-dimensional, steady state diffusion and advection of a single gas species, with constant production from a single reaction with depth, Equation **(2.17)** simplifies to

$$W = -\left(\theta_g \mathbf{D}^g K_H'^{-1} + \theta_a \mathbf{D}^a\right)\frac{\partial^2 C^a}{\partial z^2} + \left(\theta_g \mathbf{V}_g K_H'^{-1} + \theta_a \mathbf{V}_a\right)\frac{\partial C^a}{\partial z} \tag{8.5}$$

Assuming production occurs over a finite depth $0<z<L$, with a specified concentration (C_0^a) at the top boundary ($z = 0$) and no diffusive flux at the lower boundary (z = L), the aqueous phase concentration of that gas species is given by

$$C_z^a = \frac{\mathbf{D}\left(e^{\frac{Lv}{\mathbf{D}}} - e^{\frac{(L-z)v}{\mathbf{D}}}\right)W + \mathbf{v}\left(C_0^a\mathbf{v} - Wz\right)}{\mathbf{v}^2} \tag{8.6}$$

where $\mathbf{V} = \theta_g \mathbf{V}_g K_H'^{-1} + \theta_a \mathbf{V}_a$ and $\mathbf{D} = \theta_g \mathbf{D}^g K_H'^{-1} + \theta_a \mathbf{D}^a$. The gas phase concentration may be determined using Equation **(2.16)**. A STORM simulation was run that corresponds to this analytical solution. The model parameters are listed in Table 8.2. The results are shown in green in Figure 8.2. Results for STORM and the analytical solution again agree quite well. The upward gas velocity of $2.3\text{x}10^{-7}$ m s^{-1} increases the CO_2(g) concentrations found at any given depth, as compared to a similar test case without gas advection (Figure 8.2, square symbols).

8.3 Gas Phase Mass Balance

A simple simulation runs where oxygen is consumed in one kinetic reaction. Hand calculations are used to verify that oxygen consumption rate is passed correctly to the flow routines and that overall gas mass balance is preserved. A 10-year simulation with a constant sink term for O_2(g) is used to test whether gas consumption rates are passed correctly from the transport subroutines to the flow subroutines, and whether the total air mass is conserved.

The O_2(g) consumption rate was specified as a constant $-4.04\text{x}10^{-9}$ mol m^{-3} s^{-1}. In the STORM subroutine D_WATERSINK that calculates the water and air consumption rates passed to the flow routines, the total mass consumption rate of air in units of kg s^{-1} is calculated using

$$R_{\text{Air}} = R_{O_2} M_{O_2} V_{\text{node}} \tag{8.7}$$

where R_{O_2} is the O_2(g) consumption rate in mol m^{-3} s^{-1}, M_{O_2} is the molecular weight of oxygen in kg mol^{-1}, and V_{node} is the node volume in m^3. Using Equation (8.7), and assuming a molecular weight of $3.2\text{x}10^{-2}$ kg mol^{-1} for O_2(g) and a node volume of $1\text{x}10^{-6}$ m^3, the calculated R_{Air} should be

$$R_{\text{Air}} = \left(-4.04\times10^{-9}\text{mol m}^{-3}\text{s}^{-1}\right)\left(3.2\times10^{-2}\text{kg s}^{-1}\right)\left(1\times10^{-6}\text{m}^3\right) = 1.29\times10^{-16}\text{kg s}^{-1}. \tag{8.8}$$

As shown in Table 8.3, this value agrees with that calculated by the transport subroutine D_WATERSINK.

Table 8.3. STORM Input/Output Variables for Test Case 3

Variable	Where Calculated	Initial	10 Years
Total Air Mass, kg	Flow subroutine	2.9366E-07	2.5289E-07
Air Mass Source Integral, kg	Flow subroutine	0.0000E+00	-4.0761E-08
Air Rate, kg s^{-1}	Transport subroutine	-1.2917E-16	-1.2915E-16
O_2(g) Rate, mol m^{-3} s^{-1}	Transport subroutine	-4.0368E-09	-4.0362E-09

Over a period of 10 years, or 3.156×10^8 s, the total mass of air consumed is equal to $(-1.2916 \times 10^{-16}$ kg $s^{-1})(3.156 \times 10^8$ s) = -4.076×10^{-7} kg. This figure is equal to the Air Mass Source Integral calculated by the flow subroutines, indicating the Air Mass Source Rate is being passed correctly from the transport subroutines to the flow subroutines. The difference of the Total Air Mass between the beginning and the end of the simulation is equal to 2.5289×10^{-7} kg – 2.9366×10^{-7} kg = -4.077×10^{-7} kg, indicating that total air mass is being conserved. The small error in these calculations is due to the small decrease in R_{O_2} over the course of the simulation. As the solid (organic matter) decay reaction responsible for the consumption of O_2(g) proceeds, the surface area of organic matter decreases slightly, thus lowering R_{O_2}.

8.4 Quartz Dissolution

The chemical reaction solver of STORM is verified by comparing STORM results to EQ3/6. In STORM, advective and diffusive transport were made negligible by assuming a very low hydraulic conductivity for the porous media and very small aqueous diffusion coefficients for aqueous species. As an example of a simple kinetic reaction path, quartz sand reacts at 100°C with deionized water according to the reaction

$$\text{Quartz} \; f \quad SiO_2(aq) \tag{8.9}$$

Quartz dissolves according to the pH-independent rate law (Rimstidt and Barnes 1980)

$$r_{qtz} = A_s k \left(1 - \frac{Q}{K}\right) \tag{8.10}$$

where r_{qtz} is the dissolution rate (mol s^{-1}), A_s is the surface area of the mineral (500 m^2), k is the reaction rate constant (2×10^{-11} mol m^{-2} s^{-1}), K is the equilibrium coefficient ($10^{-3.9993}$ at 100°C), and Q is the activity product, in this case equal to the concentration of SiO_2(aq).

After 8 days, 1 kg of water is saturated with SiO_2(aq) (Figure 8.3). The results from EQ3/6 and STORM are nearly identical.

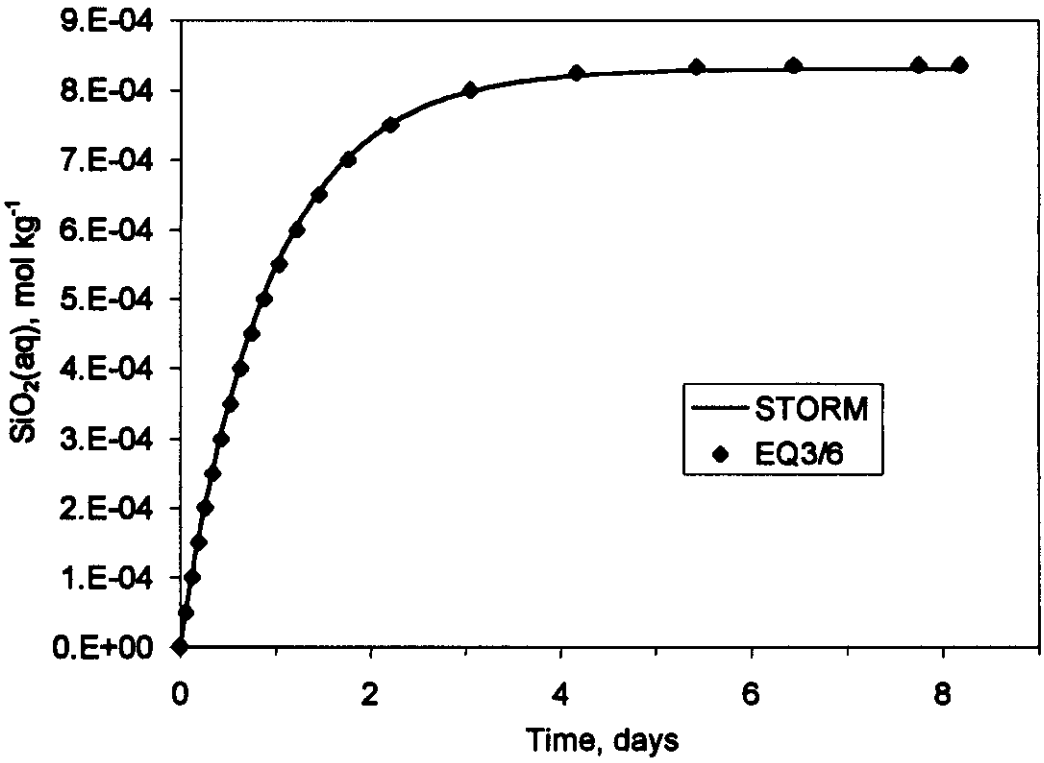

Figure 8.3. Aqueous Silica Concentration as Quartz Dissolves to Equilibrium in Deionized Water at 100°C

Data File 8.3. STORM Input File for Quartz Dissolution Test Case

```
~Simulation Title Card
1,
Glass PA 1-dimensional unsaturated flow,
DH Bacon,
Pacific Northwest National Laboratory,
July 1997,
00:00:00 AM PDT,
1,
Dissolve quartz for comparison to EQ3/6

~Solution Control Card
Normal,
Water w/ Transport,
1,
0.0,hr,8.179,day,1.,s,1.,hr,1.05,8,1.0e-6,
1.e+30,yr,1.e+30,yr,95001,
1,
```

```
Aqueous Relative Permeability,Geometric,

~Grid Card
Uniform Cartesian,
1,1,20,
1.0,m,
0.1,m,
0.1,m,

~Rock/Soil Zonation Card
1,
Soil,1,1,1,1,1,20,

~Mechanical Properties Card
Soil,2650.0,kg/m^3,0.5,0.5,1.e-5,1/m,Millington and Quirk,

~Hydraulic Properties Card
Soil,,,,,3.156e-5,hc cm/s,Constant,

~Saturation Function Card
Soil,Nonhysteretic van Genuchten,0.044,1/cm,2.2,0.08494,,

~Aqueous Relative Permeability Card
Soil,Tabular,33,
3.5026E-09,3.1593E-07,
0.01225919,6.7082E-07,
0.02977233,1.7099E-06,
0.04728546,3.8458E-06,
0.0647986,7.8611E-06,
0.08231173,1.4901E-05,
0.117338,4.5067E-05,
0.15236427,0.00011488,
0.18739054,0.00025837,
0.22241681,0.00052812,
0.25744308,0.00100111,
0.29246935,0.0017854,
0.32749562,0.00302769,
0.36252189,0.00492173,
0.39754816,0.00771754,
0.43257443,0.01173155,
0.4676007,0.01735761,
0.50262697,0.02507879,
0.53765324,0.03548017,
0.57267951,0.04926245,
0.60770578,0.06725641,
0.64273205,0.09043837,
0.67775832,0.11994642,
0.71278459,0.15709761,
0.74781086,0.20340604,
0.78283713,0.26060184,
0.8178634,0.330651,
```

```
0.85288967,0.41577624,
0.88791594,0.51847864,
0.92294221,0.64156028,
0.95796848,0.78814774,
0.99299475,0.96171657,
1,1,

~Gas Relative Permeability Card
Soil,Tabular,33,
1,1,
0.98774081,0.99999139,
0.97022767,0.99994918,
0.95271454,0.99987151,
0.9352014,0.99975797,
0.91768827,0.99960795,
0.882662,0.99919528,
0.84763573,0.99862545,
0.81260946,0.99788751,
0.77758319,0.99696733,
0.74255692,0.99584706,
0.70753065,0.99450437,
0.67250438,0.99291148,
0.63747811,0.99103385,
0.60245184,0.98882835,
0.56742557,0.98624081,
0.5323993,0.98320258,
0.49737303,0.97962579,
0.46234676,0.9753964,
0.42732049,0.97036419,
0.39229422,0.96432763,
0.35726795,0.95701052,
0.32224168,0.94802483,
0.28721541,0.93680881,
0.25218914,0.92251973,
0.21716287,0.90383668,
0.1821366,0.87857318,
0.14711033,0.84284783,
0.11208406,0.78910152,
0.07705779,0.70059708,
0.04203152,0.53266493,
0.00700525,0.13244732,
0,0,

~Initial Conditions Card
Gas Pressure,Aqueous Saturation,
3,
Gas Pressure,101325.0,Pa,0.0,1/m,0.0,1/m,0.0,1/m,1,1,1,1,1,20,
Aqueous Saturation,0.2,,0.0,1/cm,0.0,1/cm,0.0,1/cm,1,1,1,1,1,20,
Temperature,100.,C,,,,,,,1,1,1,1,1,20,

~Boundary Conditions Card
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2,
Top,Neumann Aqueous,Initial Cond,Initial Cond,Initial Cond,Initial Cond,
1,1,1,1,20,20,1,
0.0,hr,-2.00E-10,m/s,,,,,,,,,
Bottom,Free Gradient,Outflow,Outflow,Outflow,Outflow,
1,1,1,1,1,1,1,
0.0,hr,,,,,,,,,,,,,

~Source Card
1,
Aqueous Mass,1,1,1,1,1,20,1,
0.,s,0.,kg/s,,

~Output Control Card
1,
1,1,19,
1,1,day,m,3,5,5,
1,
Solute Aqueous Conc,SiO2(aq),1/m^3,
9,
0.0,yr,
1.0,s,
1.0,min,
1.0,hr,
1.0,day,
2.0,day,
3.0,day,
4.0,day,
5.0,day,
11,
Gas Pressure,Pa,
Aqueous Pressure,Pa,
Aqueous Saturation,,
Rock/Soil Type,,
Diffusive Porosity,,
Aqueous Relative Permeability,,
z Aqueous Volumetric Flux,m/s,
Solute Aqueous Conc,H+,1/m^3,
Solute Aqueous Conc,H2O,1/m^3,
Solute Aqueous Conc,OH-,1/m^3,
Solute Aqueous Conc,SiO2(aq),1/m^3,

~Surface Flux Card
1,
Aqueous Volumetric Flux,m^3/s,m^3,Top,1,1,1,1,20,20,

~Reactive Transport Control card
Normal,
Fully Coupled,
0,0,0,0,1,0,0,0,0,
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 2.00000E-06, 1.00000E+00, 1.00000E-06, 1.00000E-07, 1.00000E-03, 5.00000E-03,
2.00000E-03,

~Solute/Fluid Interaction Card
4,
H+,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
H2O,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
OH-,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
SiO2(aq),Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
0,

~Solute/Porous Media Interaction Card
soil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
SiO2(aq),0.0,m^3/kg,

~Aqueous Species card
   4,
'H+          ', 1.0000, 9.0000, 1,
 1.0000,' H',
'H2O         ', 0.0000,-4.0000, 2,
 2.0000,' H',
 1.0000,' O',
'OH-         ',-1.0000, 3.0000, 2,
 1.0000,' H',
 1.0000,' O',
'SiO2(aq)    ', 0.0000, 4.0000, 2,
 1.0000,'Si',
 2.0000,' O',

~Gas Species card
   0,

~Components card
   1,
'Si(total)   ',28.0855,  1,
 1.0000,'SiO2(aq)    ',

~Solid Species card
   1,
'Quartz      ', 2.6480,  2,
 1.0000,'Si',
 2.0000,' O',

~Fast Reactions card
   1,
   3,
-1.0000,'H2O         ',
 1.0000,'H+          ',
```

```
 1.0000,'OH-          ',
   5,    1.00000,
-1.49400E+01, 4.17100E-02,-1.91700E-04, 4.95000E-07,-6.15900E-10,

~Kinetic Aqueous Reactions card
   0,

~Slow Reactions card
    1,
  1,  1,
-1.0000,'Quartz      ',
   1,
 1.00000E+00,'SiO2(aq)    ', 1.0000, 1.0000,
-2.46350e+01,  0.,    1.00000, 0., 1,
    -3.0782,

~Fluid Decay card
   0,

~Solid Decay card
   0,

~Lithology card
'soil        ',  1,
'Quartz      ', 1.00000E+00, 0.60000E-05,

~Reaction BC card
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1,1,
   0,
   0,
   0,
   3,
  1.00000E+00,  1,
 1.0000,'H2O          ',
  1.00000E-07,  1,
 1.0000,'H+           ',
  1.00000E-12,  1,
 1.0000,'SiO2(aq)     ',

~Reaction IC card
   1,
```

8.5 Calcite Precipitation

As an example of a slightly more complicated kinetic reaction path, calcite precipitates from supersaturated solution at 25°C according to the reaction

$$Calcite + H^+ \leftrightarrow Ca^{2+} + HCO_3^- \tag{8.11}$$

Calcite dissolves according to the rate law (Reddy et al. 1981)

$$r_{calcite} = A_s k\left(1 - \frac{Q}{K}\right) \tag{8.12}$$

where $r_{calcite}$ is the dissolution rate (mol s^{-1}), A_s is the surface area of the mineral (0.24168 m^2), k is the reaction rate constant ($7x10^{-7}$ mol m^{-2} s^{-1}), K is the equilibrium coefficient ($10^{1.8487}$ at 25°C), and Q is the ion-activity product, in this case equal to

$$Q = \frac{[Ca^{2+}][HCO_3^-]}{[H^+]} \tag{8.13}$$

Several other species participate in equilibrium reactions (Table 8.4) and are included in the simulations. The CO_2(g) partial pressure is fixed at a partial pressure of $10^{-1.5421}$ bars. The initial total Ca concentration is $1.2732x10^{-2}$ mol kg^{-1} and the initial pH is 7.5815.

Precipitation of calcite in 1 kg of water proceeds rapidly, and virtually ceases after the solution has reached saturation (0.12 days). Results from EQ3/6 and STORM are nearly identical (Figure 8.4).

Table 8.4. Aqueous Species, Equilibrium Reactions, and Equilibrium Constants Related to Calcite Dissolution

Reaction	Log K At 25°C
$OH^- + H^+ \leftrightarrow H_2O$	13.9951
$CO_2(aq) + H_2O \leftrightarrow H^+ + HCO_3^-$	-6.3447
$CO_2(g) \leftrightarrow CO_2(aq)$	-1.4689
$CaHCO_3^+ \leftrightarrow Ca^{2+} + HCO_3^-$	-1.0467
$CaCO_3(aq) + H^+ \leftrightarrow Ca^{2+} + HCO_3^-$	7.0017
$CO_3^{2-} + H^+ \leftrightarrow HCO_3^-$	10.3288
$CaOH^+ + H^+ \leftrightarrow Ca^{2+} + H_2O$	12.8500

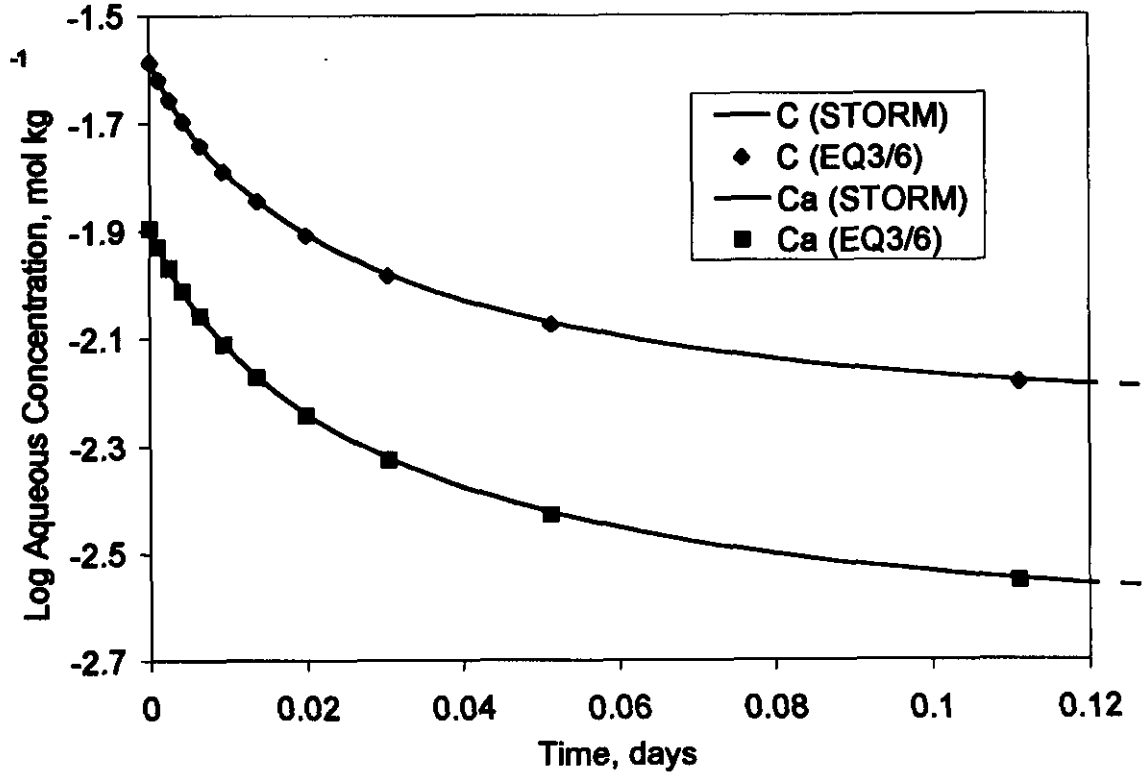

Figure 8.4. Total C and Ca Aqueous Concentrations as Calcite Precipitates from Supersaturated Solution

Data File 8.4. STORM Input File for Calcite Precipitation Test Case

```
~Simulation Title Card
1,
Glass PA 1-dimensional unsaturated flow,
DH Bacon,
Pacific Northwest National Laboratory,
July 1997,
00:00:00 AM PDT,
1,
Precipitate Calcite for comparison to EQ3/6

~Solution Control Card
Normal,
Water w/ Transport,
1,
0.0,hr,0.13,day,0.1,s,10.,day,1.05,8,1.0e-6,
1.e+30,yr,1.e+30,yr,95001,
1,
Aqueous Relative Permeability,Geometric,
```

```
~Grid Card
Uniform Cartesian,
1,1,20,
1.0,m,
0.1,m,
0.1,m,

~Rock/Soil Zonation Card
1,
Soil,1,1,1,1,1,20,

~Mechanical Properties Card
Soil,2650.0,kg/m^3,0.5,0.5,1.e-5,1/m,Millington and Quirk,

~Hydraulic Properties Card
Soil,,,,,3.156e-5,hc cm/s,Constant,

~Saturation Function Card
Soil,Nonhysteretic van Genuchten,0.044,1/cm,2.2,0.08494,,

~Aqueous Relative Permeability Card
Soil,Tabular,33,
3.5026E-09,3.1593E-07,
0.01225919,6.7082E-07,
0.02977233,1.7099E-06,
0.04728546,3.8458E-06,
0.0647986,7.8611E-06,
0.08231173,1.4901E-05,
0.117338,4.5067E-05,
0.15236427,0.00011488,
0.18739054,0.00025837,
0.22241681,0.00052812,
0.25744308,0.00100111,
0.29246935,0.0017854,
0.32749562,0.00302769,
0.36252189,0.00492173,
0.39754816,0.00771754,
0.43257443,0.01173155,
0.4676007,0.01735761,
0.50262697,0.02507879,
0.53765324,0.03548017,
0.57267951,0.04926245,
0.60770578,0.06725641,
0.64273205,0.09043837,
0.67775832,0.11994642,
0.71278459,0.15709761,
0.74781086,0.20340604,
0.78283713,0.26060184,
0.8178634,0.330651,
0.85288967,0.41577624,
0.88791594,0.51847864,
```

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0.92294221,0.64156028,
0.95796848,0.78814774,
0.99299475,0.96171657,
1,1,

~Gas Relative Permeability Card
Soil,Tabular,33,
1,1,
0.98774081,0.99999139,
0.97022767,0.99994918,
0.95271454,0.99987151,
0.9352014,0.99975797,
0.91768827,0.99960795,
0.882662,0.99919528,
0.84763573,0.99862545,
0.81260946,0.99788751,
0.77758319,0.99696733,
0.74255692,0.99584706,
0.70753065,0.99450437,
0.67250438,0.99291148,
0.63747811,0.99103385,
0.60245184,0.98882835,
0.56742557,0.98624081,
0.5323993,0.98320258,
0.49737303,0.97962579,
0.46234676,0.9753964,
0.42732049,0.97036419,
0.39229422,0.96432763,
0.35726795,0.95701052,
0.32224168,0.94802483,
0.28721541,0.93680881,
0.25218914,0.92251973,
0.21716287,0.90383668,
0.1821366,0.87857318,
0.14711033,0.84284783,
0.11208406,0.78910152,
0.07705779,0.70059708,
0.04203152,0.53266493,
0.00700525,0.13244732,
0,0,

~Initial Conditions Card
Gas Pressure,Aqueous Saturation,
3,
Gas Pressure,101325.0,Pa,0.0,1/m,0.0,1/m,0.0,1/m,1,1,1,1,1,20,
Aqueous Saturation,0.2,,0.0,1/cm,0.0,1/cm,0.0,1/cm,1,1,1,1,1,20,
Temperature,25.,C,,,,,,,1,1,1,1,1,20,

~Boundary Conditions Card
2,
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Top,Neumann Aqueous,Initial Cond,Initial Cond,Initial Cond,Initial Cond,Initial
Cond,Initial Cond,Initial Cond,Initial Cond,Initial Cond,Initial Cond,
1,1,1,1,20,20,1,
0.0,hr,-2.00E-10,m/s,,,,,,,,,,,,,,,,,,,,,
Bottom,Free
Gradient,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,Outflow,Outfl
ow,
1,1,1,1,1,1,1,
0.0,hr,,,,,,,,,,,,,,,,,,,,,,,,

~Source Card
1,
Aqueous Mass,1,1,1,1,1,20,1,
0.,s,0.,kg/s,,

~Output Control Card
1,
1,1,19,
1,1,day,m,3,5,5,
8,
Solute Aqueous Conc,H+,1/m^3,
Solute Aqueous Conc,CO2(aq),1/m^3,
Solute Aqueous Conc,HCO3-,1/m^3,
Solute Aqueous Conc,CO3--,1/m^3,
Solute Aqueous Conc,Ca++,1/m^3,
Solute Aqueous Conc,CaHCO3+,1/m^3,
Solute Aqueous Conc,CaCO3(aq),1/m^3,
Solute Aqueous Conc,CaOH+,1/m^3,
1,
0.1,s,
3,
Aqueous Saturation,,
Z Aqueous Volumetric Flux,cm/day,
Total Water Mass,kg,


~Surface Flux Card
1,
Aqueous Volumetric Flux,m^3/s,m^3,Top,1,1,1,1,20,20,

~Reactive Transport Control card
Normal,
Fully Coupled,
0,0,0,0,1,0,0,0,0,
 1.00000E-07, 1.00000E+00, 1.00000E-07, 1.00000E-07, 1.00000E-07, 1.00000E-07,
1.00000E-07,

~Solute/Fluid Interaction Card
10,
H+,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
H2O,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
```

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OH-,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
HCO3-,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
Ca++,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
CO2(aq),Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
CaHCO3+,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
CaCO3(aq),Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
CO3--,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
CaOH+,Constant,5.0e-9,m^2/s,Continuous,1.e20,yr,
0,

~Solute/Porous Media Interaction Card
soil,0.,m,0.,m,
H+,0.0,m^3/kg,
H2O,0.0,m^3/kg,
OH-,0.0,m^3/kg,
HCO3-,0.0,m^3/kg,
Ca++,0.0,m^3/kg,
CO2(aq),0.0,m^3/kg,
CaHCO3+,0.0,m^3/kg,
CaCO3(aq),0.0,m^3/kg,
CO3--,0.0,m^3/kg,
CaOH+,0.0,m^3/kg,

~Aqueous Species card
  10,
'H+          ', 1.0000, 9.0000, 1,
 1.0000,' H',
'H2O         ', 0.0000,-4.0000, 2,
 2.0000,' H',
 1.0000,' O',
'OH-         ',-1.0000, 3.0000, 2,
 1.0000,' H',
 1.0000,' O',
'HCO3-       ',-1.0000, 4.0000, 3,
 1.0000,' H',
 1.0000,' C',
 3.0000,' O',
'Ca++        ', 2.0000, 6.0000, 1,
 1.0000,'Ca',
'CO2(aq)     ', 0.0000, 3.0000, 2,
 1.0000,' C',
 2.0000,' O',
'CaHCO3+     ', 1.0000, 4.0000, 4,
 1.0000,'Ca',
 1.0000,' H',
 1.0000,' C',
 3.0000,' O',
'CaCO3(aq)   ', 0.0000, 0.0000, 3,
 1.0000,'Ca',
 1.0000,' C',
 3.0000,' O',
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'CO3--       ', 2.0000, 5.0000, 2,
 1.0000,' C',
 3.0000,' O',
'CaOH+       ', 1.0000, 4.0000, 3,
 1.0000,'Ca',
 1.0000,' O',
 1.0000,' H',

~Gas Species card
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'CO2(g)      ', 'CO2(aq)     ', 'fixed', 1.69443E-06, 2,
 1.0000,' C',
 2.0000,' O',
 1,
-1.4689,

~Components card
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'CO2(total)  ',44.0100,  5,
 1.0000,'CO2(aq)     ',
 1.0000,'HCO3-       ',
 1.0000,'CO3--       ',
 1.0000,'CaHCO3+     ',
 1.0000,'CaCO3(aq)   ',
'Ca(total)   ',40.07800, 4,
 1.0000,'Ca++        ',
 1.0000,'CaHCO3+     ',
 1.0000,'CaCO3(aq)   ',
 1.0000,'CaOH+       ',

~Solid Species card
   1,
'Calcite', 2.7099,  3,
 1.0000,'Ca',
 1.0000,' C',
 3.0000,' O',

~Fast Reactions card
   6,
   2,
-1.0000,'OH-         ',
-1.0000,'H+          ',
   1,    1.00000,
13.9951,
   3,
-1.0000,'CO2(aq)     ',
 1.0000,'H+          ',
 1.0000,'HCO3-       ',
   1,    1.00000,
-6.3447,
   3,
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-1.0000,'CaHCO3+      ',
 1.0000,'Ca++         ',
 1.0000,'HCO3-        ',
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-1.0467,
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-1.0000,'CaCO3(aq)    ',
-1.0000,'H+           ',
 1.0000,'Ca++         ',
 1.0000,'HCO3-        ',
   1,    1.00000,
7.0017,
   3,
-1.0000,'CO3--        ',
-1.0000,'H+           ',
 1.0000,'HCO3-        ',
   1,    1.00000,
10.3288,
   3,
-1.0000,'CaOH+        ',
-1.0000,'H+           ',
 1.0000,'Ca++         ',
   1,    1.00000,
12.8500,

~Kinetic Aqueous Reactions card
   0,

~Slow Reactions card
    1,
 -1, 1,
-1.0000,'Calcite',
   3,
-1.0000,'H+      ', -1.0000, -1.0000,
 1.0000,'Ca++    ',  1.0000,  1.0000,
 1.0000,'HCO3-   ',  1.0000,  1.0000,
-14.172,       0.,  1.0000,  0.0000, 1,
 1.8487,

~Fluid Decay card
   0,

~Solid Decay card
   0,

~Lithology card
'soil         ',  1,
'Calcite      ', 1.00000E+00, 1.24131E-02,

~Reaction BC card
   1,
```

```
1,1,
   0,
   0,
   1,
'CO2(g)      ', 2.8701E-02,
   3,
  1.0000E+00,  1,
 1.0000,'H2O          ',
  2.6209E-08,  1,
 1.0000,'H+           ',
  1.2732E-02,  4,
 1.0000,'Ca++         ',
 1.0000,'CaHCO3+      ',
 1.0000,'CaCO3(aq)    ',
 1.0000,'CaOH+        ',

~Reaction IC card
   1,
```

9.0 Example Simulations

Three simulations are presented to demonstrate unique features of STORM. The first simulation presents a 2-dimensional, waste-form-alone-design simulation of steady-state unsaturated flow and transient reactive transport of aqueous species released as the glass waste dissolves. In the first simulation, glass dissolves according to a rate law dependent on aqueous phase silica concentration and pH. The approach is new in that a full set of recent experimentally derived rate parameters for LD-5412 glass is used. The second simulation demonstrates how exchange of hydrogen for sodium in the glass enhances the rate of glass dissolution. This simulation approach is also new in that mass balance is preserved by tracking the masses of altered and unaltered glass separately. The third simulation demonstrates how gas phase diffusion of CO_2 may increase the dissolution rate of the glass. Transient gas phase transport is a new feature added to the code this fiscal year.

9.1 Base Case

The disposal facility is modeled as a 2-dimensional domain where the waste form, a borosilicate waste glass (LD6-5412), is surrounded by backfill soil above several layers of Hanford sediments and the water table (Figure 9.1). Laboratory-measured hydraulic properties are used for each porous material (Rockhold et al. 1993); the glass waste is assumed to have hydraulic properties equivalent to that of a gravel (Fayer et al. 1997). These properties are used to calculate the water saturation distribution below a surface barrier designed to allow a water flux of no more than 0.5 mm yr^{-1}. The coarse glass acts as a hydraulic barrier, causing water to pond on top of the waste form and flow around the sides (Figure 9.2).

Included in the reactive transport portion of the simulation were 22 aqueous species, 1 gaseous species, 9 minerals, 11 equilibrium reactions, and 9 kinetic reactions (Table 9.1).

The corrosion of silicate glasses in water is represented by a special type of irreversible dissolution reaction. A conventional transition state kinetic rate equation (Aagaard and Helgeson 1982) is used to develop a constitutive relationship to compute the flux of any element i released from the glass into the aqueous phase. Currently, H^+ is the only aqueous species shown to directly influence the dissolution rate, that gives

$$J_i^a = \upsilon_i k e^{-\frac{E_a}{RT}} a_{H^+}^{-\eta} \left[1 - \left(\frac{Q}{K} \right)^{\sigma} \right], i = 1,2,\ldots,N \qquad (9.1)$$

where J_i^a is the flux of element i (mol m^{-2} s^{-1}), υ_i is the stoichiometric coefficient of element i in the glass, k is the intrinsic rate constant (mol m^{-2} s^{-1}), E_a is the activation energy (J mol^{-1}), R is the gas constant (J mol^{-1} K^{-1}), T is the temperature (K), a_{H^+} is the hydrogen ion activity, η is the order of the hydrogen ion activity dependence, Q is the ion-activity product of the rate controlling phase, K is the

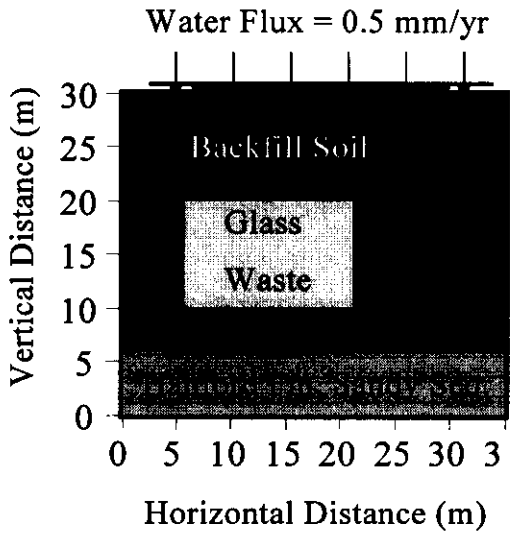

Figure 9.1. Sediment Types and Flow Boundary Condition Used in the Simulations

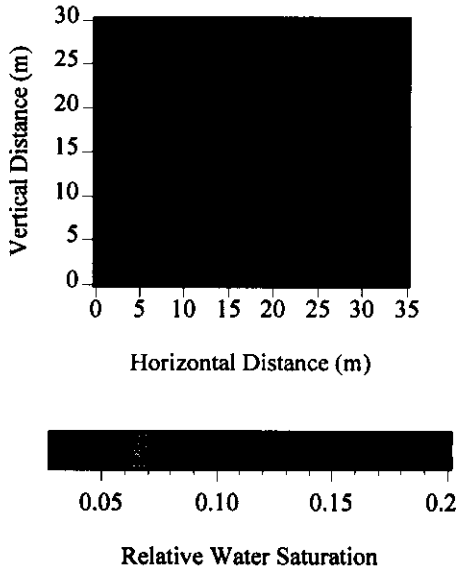

Figure 9.2. Steady State Unsaturated Flow Field

Table 9.1. List of Reactions

(Note: 1-11 are equilibrium reactions, 12-21 are kinetic reactions)	
1.	$H_2O = H^+ + OH^-$
2.	$CO_2(g) = CO_2(aq)$
3.	$CO_2(aq) + H_2O = H^+ + HCO_3^-$
4.	$HCO_3^- = H^+ + CO_3^{2-}$
5.	$Al(OH)_4^- + H^+ = Al(OH)_3 + H_2O$
6.	$H_2SiO_4^{2-} + 2H^+ = SiO_2(aq) + 2H_2O$
7.	$H_2SiO_3^- + H^+ = SiO_2(aq) + 2H_2O$
8.	$BO_2^- + H^+ + H_2O = B(OH)_3(aq)$
9.	$CaCO_3(aq) + H^+ = Ca^{2+} + HCO_3^-$
10.	$CaHCO_3^+ = Ca^{2+} + HCO_3^-$
11.	$CaOH^+ + H^+ = Ca^{2+} + H_2O$
12.	$Glass + 0.5OH^- + 0.45H_2O = 0.0202K^+ + 0.4208Na^+ 0.046Ca^{2+} + 0.094BO_2^- + 0.154Al(OH)_3(aq) + 0.2712HSiO_3^- + 0.3348H_2SiO_4^{2-} + 1.6172x10^{-6}TcO_4^{2-}$
13.	$Quartz + OH^- = HSiO_3^-$
14.	$Calcite = Ca^{2+} + CO_3^{2-}$
15.	$Albite(high) + 2OH^- = Na^+ + Al(OH)_3(aq) + 3HSiO_3^-$
16.	$K-feldspar + 2OH^- = K^+ + Al(OH)_3(aq) + 3HSiO_3^-$
17.	$Illite + 2.4OH^- = 0.6K^+ + 0.25Mg^{2+} + 2.3Al(OH)_3(aq) + HSiO_3^-$
18.	$Analcime + 0.96H^+ = 0.96Na^+ + 0.96Al(OH)_3(aq) + 2.04SiO_2(aq) + 5.04H_2O$
19.	$Chalcedony = SiO_2(aq)$
20.	$NaAlSi_2O_6 \cdot 6H_2O + OH^- = Na^+ + Al(OH)_3(aq) + 2HSiO_3^- + 4H_2O$

equilibrium constant of the rate controlling phase, and σ is the net reaction order. Assigning K to a simple SiO_2 polymorph, such as chalcedony, yields the best agreement with experimental data for LD6-5412 glass (McGrail et al. 1997). Consequently, K, the equilibrium constant for chalcedony, is assigned for the simulations discussed here. Experiments utilizing a single-pass flow-through apparatus for measuring glass dissolution rates at various pH and temperatures yield values for the parameters in Equation **(2.16)**, as shown in Table 9.2.

Table 9.2. Glass Dissolution Rate Parameters

Parameter	Value
$\tilde{k}$	$10^{2.05}$ g m^{-2} s^{-1}
η	0.40
E_a	74.8 kJ mol^{-1}
σ	1

The subsurface is assumed open to the atmosphere, and the subsurface gas phase concentrations are not limited by diffusion, so that $CO_2(g)$ concentrations are a constant 0.035 percent by volume. The diffusion coefficient for all species in pure water is assumed to be $5x10^{-9}$ m^2 s^{-1}. As time advances, the pH rises to a maximum value of 8.1 because dissolution of the glass releases alkali metals (Na, K) (Figure 9.3). The largest glass dissolution rates ($6.3x10^{-11}$ mol s^{-1}) appear at the interface between the vault and the surrounding soil because the steep concentration gradient into the soil lowers the concentration of Si near the interface (Figure 9.4). Concentrations of ^{99}Tc are smooth because under the oxidizing conditions in the disposal facility, ^{99}Tc is highly soluble as a pertechnitate ($^{99}TcO_4^-$) anion and so is subject to aqueous phase diffusion (Figure 9.5). A maximum $^{99}TcO_4^-$ concentration of $1.9x10^{-9}$ mol kg^{-1} is observed at the bottom of the waste form. Concentrations of ^{99}Tc are presented because this species provides the dominant contribution to the drinking water dose (Mann et al. 1998).

9.2 Ion Exchange

Experimental results (McGrail et al. 1997) suggest the exchange of sodium for hydrogen in the glass waste form

$$\text{GlassL } 0.4208\text{Na} + 0.4208\text{H}^+ = \text{GlassL } 0.4208\text{H} + 0.4208\text{Na}^+ \qquad (9.2)$$

is important at the low temperatures expected in the waste form. When this reaction is included, the maximum pH in the waste form increases by one pH unit to a value of 9.1 (Figure 9.6). As would be predicted by Equation **(2.15)**, the higher pH causes the glass dissolution rate to increase to a maximum value of $7.4x10^{-11}$ mol s^{-1} at the edges of the waste form (Figure 9.7). The increase in glass dissolution results in the maximum Tc concentration (Figure 9.8) also increasing to a value of $3.0x10^{-9}$ mol kg^{-1}. The increases in pH and Tc concentrations are significantly less than those predicted in previous analyses (Mann et al. 1998), due to the buffering capacity provided by assuming a fixed partial pressure of $CO_2(g)$.

9.3 Gas Diffusion

In the previous two simulations, the assumption is that partial pressure of CO_2 in the gas phase was constant, implying the diffusion rate of $CO_2(g)$ through the vadose zone

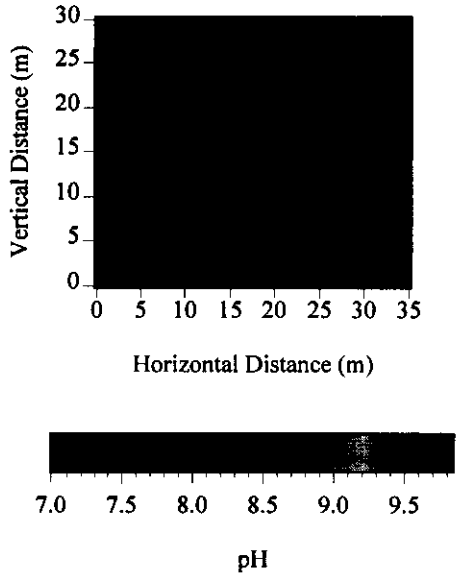

Figure 9.3. pH After 20,000 Years, No Ion Exchange, Fixed P_{CO_2}

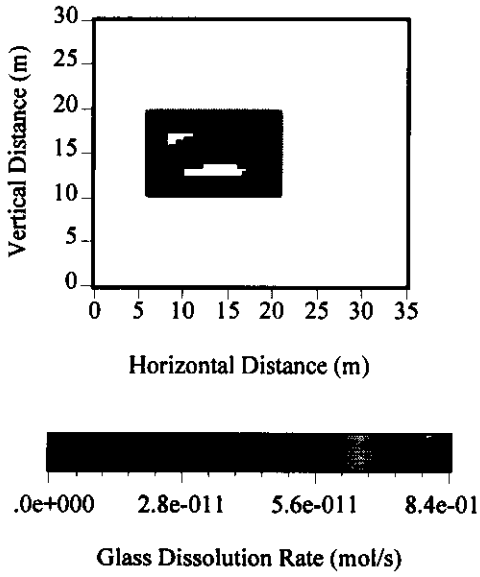

Figure 9.4. Glass Dissolution Rate After 20,000 Years, No Ion Exchange, Fixed P_{CO_2}

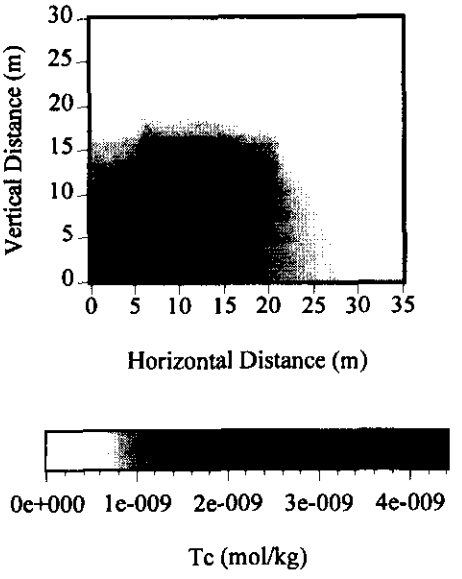

Figure 9.5. Tc Concentration After 20,000 Years, No Ion Exchange, Fixed P_{CO_2}

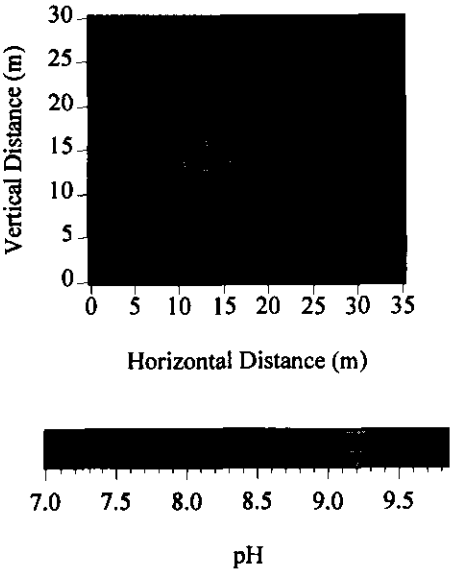

Figure 9.6. pH After 20,000 Years, with Ion Exchange, Fixed P_{CO_2}

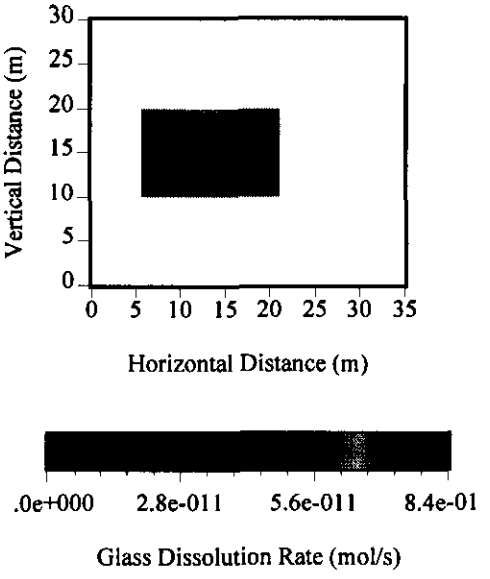

Figure 9.7. Glass Dissolution Rate After 20,000 Years, with Ion Exchange, Fixed P_{CO_2}

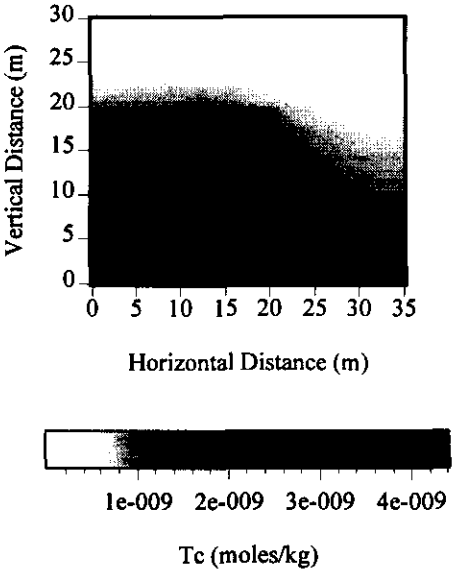

Figure 9.8. Tc Concentration After 20,000 Years, with Ion Exchange, Fixed P_{CO_2}

is fast relative to the rate of consumption of $CO_2(aq)$ in aqueous complexation and dissolution-precipitation reactions. This assumption is relaxed by assuming a diffusion coefficient for $CO_2(g)$ of $1.6x10^{-6}$ m^2 s^{-1} and allowing STORM to transport $CO_2(g)$ throughout the spatial domain. The results (Figure 9.9) show that $CO_2(g)$ concentrations in the center of the vault decrease to a partial pressure nearly an order of magnitude below atmospheric pressure. This reduces the concentration of carbonic acid produced from dissolution of $CO_2(g)$ into the pore water, thus causing the pH to increase to a maximum value of 9.8 (Figure 9.10). Again, the increase in pH causes the glass dissolution rate (Figure 9.11), both on the edges and at the center of the waste form, and the aqueous Tc concentrations (Figure 9.12) to increase accordingly.

9.4 Conclusions

These three simulations demonstrate the long-term performance of the low-activity waste glasses can be successfully simulated with the STORM code under realistic field conditions of 2-phase flow of water and air. The results show that ion exchange and gas phase diffusion can have a significant effect on radionuclide release rates from the glass waste form. Assuming equilibrium with atmospheric $CO_2(g)$ throughout the spatial domain does not appear to be appropriate and can lead to non-conservative radionuclide release rates from the disposal system.

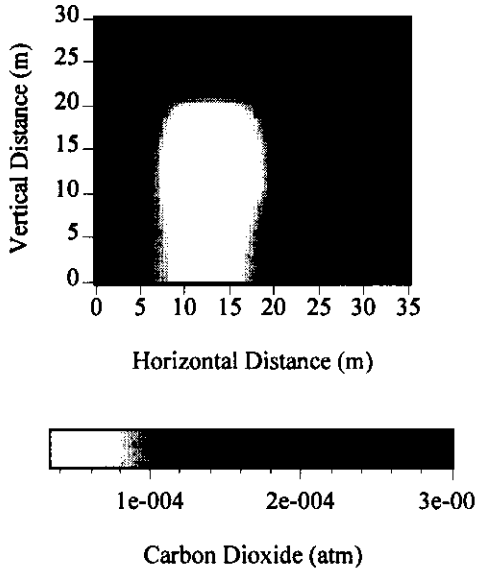

Figure 9.9. Gas Phase CO_2 Concentrations After 20,000 Years, with Ion Exchange and CO_2 Diffusion

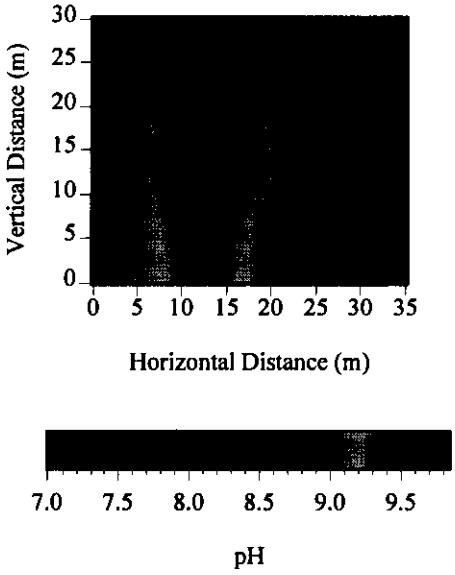

Figure 9.10. pH After 20,000 Years, with Ion Exchange and CO_2 Diffusion

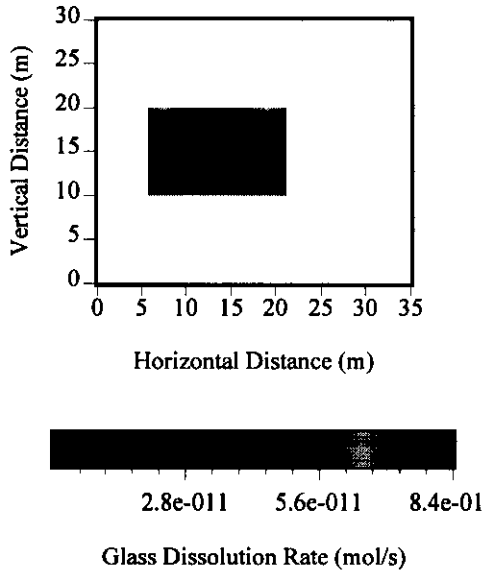

Figure 9.11. Glass Dissolution Rate After 20,000 Years, with Ion Exchange and CO_2 Diffusion

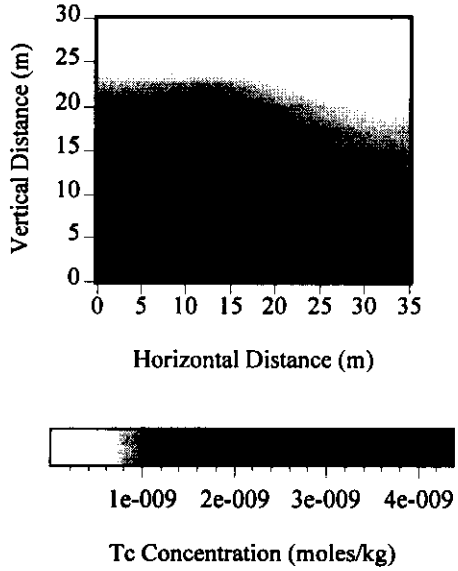

Figure 9.12. Tc Concentrations After 20,000 Years, with Ion Exchange and CO_2 Diffusion

10.0 References

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Appendix A

STORM Version 2 Input Data Format

STORM Version 2 Input Data Format

A.1 Simulation Title Card

Card Title[a] { ~Simulation [Title Card] }
Format: *Char*[a]

Version Number[a] **Format**: *Integer*[a],

Simulation Title[a] **Format**: *Char*[a],

User Name[a] **Format**: *Char*[a],

Company Name[a] **Format**: *Char*[a],

Input Creation Date[a] **Format**: *Char*[a],

Input Creation Time[a] **Format**: *Char*[a],

Number of Simulation Note Lines[a] **Format**: *Integer*[a],

For: Number of Simulation Note Lines

Simulation Notes[a] **Format**: *Char*[a] *(maximum of 132 characters per line)*

Endfor: Number of Simulation Note Lines

Endcard: Simulation Title Card

A.2 Simulation Title Card Examples

```
~Simulation Title Card
1,
Evaporation/Condensation Heat Pipe,
MD White,
Pacific Northwest Laboratory,
June 18 1994,
10:04 AM PDT,
4,
This application problem follows the heat-pipe problem solved
semi-analytically by Udell and Fitch.  The soil moisture retention
function has been changed to a modified van Genuchten function to
allow saturations for all matric suctions.
```

```
~Simulation Title Card
1,
Field Test #12,
MD White,
PNNL,
Monday April 5 1996,
12:34,
2,
Simulation of field test #12 at Edwards AFB.
Starting time 1/3/96 14:19, Ending time 1/8/96 9:19.
```

```
~Simulation Title Card
1,
Henry's Problem for Salt Water Intrusion,
MD White,
Pacific Northwest Laboratory,
August 9 1995,
8:30:00 AM PDT,
1,
STOMP Application Guide Problem 4.1
```

A.3 Solution Control Card

Card Title[a] {~Solution [Control Card] }
Format: *Char*[a]

Execution Mode Option[a]
If: Operational Mode Option = { Water }
{ Normal [No Flow] [Dynamic Domain] }
{ Restart[{ No Flow] [Dynamic Domain] }
{ Initial Conditions }
Else:
{ Normal }
{ Restart }
{ Initial Conditions }
Endif:
Format: *Char*[a],

Operational Mode Option[a]
{ Water }
{ Water-Air }
{ Water-Air-Energy }
Format: *Char*[a],

If: Execution Mode Option = { Initial Conditions }
Endcard: Solution Control Card
Endif:

Number of Execution Time Periods[a]
Format: *Integer*[a],

For: Number of Execution Time Periods

If: Execution Mode Option = { Normal }
Initial Time[a], Units[b] (s), Final Time[c], Units[d] (s),
Initial Time Step[e], Units[f] (s),
Maximum Time Step[g], Units[h] (s),
Time Step Acceleration Factor[i],
Maximum Number of Newton-Raphson Iterations[j],
Convergence Criterion[k]
Format: *Real*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Char*[f], *Real*[g], *Char*[h], *Real*[i], *Integer*[j], *Real*[k],

ElseIf: Execution Mode Option = { Restart }
Initial Time[a], Units[b] (s), Final Time[c], Units[d] (s),
Initial Time Step[e], Units[f] (s),
Maximum Time Step[g], Units[h] (s),
Time Step Acceleration Factor[i],
Maximum Number of Newton-Raphson Iterations[j],
Convergence Criterion[k]
Format: *Real[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Integer[j], Real[k],*
Endif:

Endfor: Number of Execution Time Periods

Maximum CPU Time[a], Units[b] (s),
Maximum Clock Time[c], Units[d] (s),
Maximum Number of Time Steps[e]
Format: *Real[a], Char[b], Real[c], Char[d],Integer[e],*

If: Operational Mode Option = { Water-Air } { Water-Air-Energy }
Aqueous Diffusion Option[a]
{ Zero }
{ Constant }
{ Variable }
If: Aqueous Diffusion Option = { Constant }
Dissolved Air Diffusion Coefficient[b], Unit[c] (m^2/s)
Format: *Char[a], Real[b], Char[c],*
Else:
Format: *Char[a],*
Endif:
Endif:

If: Operational Mode Option = { Water-Air } { Water-Air-Energy }
Gas Diffusion Option[b]
{ Zero }
{ Constant }
{ Variable }
{ Enhanced }
If: Gas Diffusion Option = { Constant }
Water Vapor Diffusion Coefficient[b], Unit[c] (m^2/s)
Format: *Char[a], Real[b], Char[c],*

Elseif: Gas Diffusion Option = { Enhanced }

Clay Mass Fraction[b]
Format: *Char[a], Real[b],*
Endif:
Endif:

Number of Interfacial Averaging Variables[a]
Format: *Integer[a],*

For: Number of Interfacial Averaging Variables

Surface Variable Option[a]
{ Aqueous Density } { Aqueous Relative Permeability }
{ Aqueous Viscosity } { Dissolved Air Diffusion }
{ Gas Density } { Gas Relative Permeability }
{ Gas Viscosity } { Hydraulic Dispersion }
{ Intrinsic Permeability } { Thermal Conductivity }
{ Water Vapor Diffusion }
Interfacial Averaging Scheme Option[b]
{ Harmonic } { Geometric } { Arithmetic } { Upwind }
Format: *Char[a], Char[b],*

Endfor: Number of Interfacial Averaging Variables

Endcard: Solution Control Card

A.4 Solution Control Card Examples

```
~Solution Control Card
Normal,
Water-Air-Energy,
1,
0,day,876.6,day,10,S,100,day,1.25,16,1.E-06,
1,day,1,day,1000,
Variable Aqueous Diffusion,
Variable Gas Diffusion,
# Interfacial average defaults
3,
Gas Relative Permeability, Upwind,
Aqueous Relative Permeability, Upwind,
Intrinsic Permeability, Harmonic,
```

A.5 Grid Card

Card Title[a] { ~Grid [Card] }
Format: *Char*[a]

Coordinate System Option[a]
{ Cartesian }
{ Cylindrical }
{ Uniform Cartesian }
{ Uniform Cylindrical }
{ Tilted Cartesian }

If: Coordinate System Option { Tilted Cartesian }
Format: *Char*[a],
Elseif:
X-Z Plane Tilt Angle[b], Units[c] (deg),
Y-Z Plane Tilt Angle[d], Units[e] (deg),
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e],
Endif:

Number of X-Dir. Nodes[a],
Number of Y-Dir. Nodes[b], (note: cannot be greater than 1 in current version)
Number of Z-Dir. Nodes[c]
Format: *Integer*[a], *Integer*[b], *Integer*[c],

If: Coordinate System Option = { Cartesian }

For: Number of X-Dir. Nodes
< Surface Position[a], Units[b] (m), > or < Count[a] @ Node Width[b], Units[c] (m), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of X-Dir. Nodes

For: Number of Y-Dir. Nodes
< Surface Position[a], Units[b] (m), } or < Count[a] @ Node Width[b], Units[c] (m), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of Y-Dir. Nodes

For: Number of Z-Dir. Nodes
< Surface Position[a], Units[b] (m), > or < Count[a] @ Node Width[b], Units[c] (m), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of Z-Dir. Nodes

Elseif: Coordinate System Option = { Cylindrical }

For: Number of Radial-Dir. Nodes

< Surface Position[a], Units[b] (m), > or < Count[a] @ Node Width[b], Units[c] (m), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of Radial-Dir. Nodes

For: Number of Azimuthal-Dir. Nodes
< Surface Position[a], Units[b] (deg), > or < Count[a] @ Node Width[b], Units[c] (deg), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of Azimuthal-Dir. Nodes

For: Number of Z-Dir. Nodes
< Surface Position[a], Units[b] (m), > or < Count[a] @ Node Width[b], Units[c] (m), >
Format: < *Real*[a], *Char*[b], > or < *Integer*[a]@*Real*[a], *Char*[b], >
Endfor: Number of Z-Dir. Nodes

Elseif: Coordinate System Option = { Uniform Cartesian }

X-Dir. Node Dimension[a], Units[b] (m)
Format: *Real*[a], *Char*[b],

Y-Dir. Node Dimension[a], Units[b] (m)
Format: *Real*[a], *Char*[b],

Z-Dir. Node Dimension[a], Units[b] (m)
Format: *Real*[a], *Char*[b],

Elseif: Coordinate System Option = { Uniform Cylindrical }

Radial-Dir. Node Dimension[a], Units[b] (m)
Format: *Real*[a], *Char*[b],

Azimuthal-Dir. Node Dimension[a], Units[b] (deg)
Format: *Real*[a], *Char*[b],

Z-Dir. Node Dimension[a], Units[b] (m)
Format: *Real*[a], *Char*[b],

Endif:

Endcard: Grid Card

A.6 Grid Card Examples

```
#----------------------
~Grid Card
#----------------------
Uniform Cartesian,
20,1,10,
10,cm,
10,cm,
10,cm,
```

```
~Grid Card
Cylindrical,
50,1,113,
#Nonuniform grid spacing
0,in,3.125,in,5.125,in,8,in,12,in,18@6,in,10@12,in,10@24,in,8@48,in,
0,deg,45,deg,
0,in,113@6,in,
```

```
~Grid Card
Uniform Cartesian,
1,1,92,
4.25388924,cm,
4.25388924,cm,
0.125,cm,
```

A.7 Inactive Nodes Card

Card Title[a] { ~Inactive [Nodes Card] }
Format: *Char*[a]

Number of Inactive Node Domains[a]
Format: *Integer*[a],

For: Number of Inactive Node Domains

I-Start Index[a], I-End Index[b],

J-Start Index[c], J-End Index[d],
K-Start Index[e], K-End Index[f]
Format: *Integer[a], Integer[b], Integer[c], Integer[d], Integer[e], Integer[f],*

Endfor: Number of Inactive Node Domains

Endcard: Inactive Nodes Card

A.8 Inactive Nodes Card Examples

```
~Inactive Nodes Card
4,
1,1,1,1,14,113,
2,2,1,1,14,33,
2,2,1,1,101,113,
2,2,1,1,70,70,
```

```
#----------
~Inactive
#----------
1,
2,2,1,1,14,20
```

```
#
~Inactive Nodes Card
#
0, no inactive nodes
```

A.9 Boundary Conditions Card

Card Title[a] {~Boundary [Conditions Card] }
Format: *Char[a]*

Number of Boundary Condition Domains[a],
Format: *Integer[a]*,

For: Number of Boundary Condition Domains

Boundary Surface Direction Option[a],
{ Bottom } { South } { West } { East } { North } { Top }

If: Operational Mode Option: Solution Control Card = { Water }
Aqueous-Phase Boundary Type Option[b],
{ Dirichlet } { Neumann } { Zero Flux } { Saturated } { Unit Gradient }
{ Free Gradient } { Hydraulic Gradient } { Initial Condition }
Format: *Char[a], Char[b], <Char[c],>*

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
Aqueous-Phase Boundary Type Option[b]
{ Dirichlet } { Neumann } { Zero Flux } { Unit Gradient }
{ Hydraulic Gradient } { Initial Condition }
Gas-Phase Boundary Type Option[c]
{ Dirichlet } { Neumann } { Zero Flux } { Unit Gradient }
{ Hydraulic Gradient } { Initial Condition }
Format: *Char[a], Char[b], Char[c], <Char[d],>*

Elseif: Operational Mode Option: Solution Control Card = { Water-Air-Energy }
Energy Boundary Type Option[b]
{ Dirichlet } { Neumann } { Zero Flux }
{ Outflow } { Initial Condition }
Aqueous-Phase Boundary Type Option[c]
{ Dirichlet } { Neumann } { Zero Flux }
{ Unit Gradient } { Hydraulic Gradient } { Initial Condition }
Gas-Phase Boundary Type Option[d]
{ Dirichlet } { Neumann } { Zero Flux }
{ Unit Gradient } { Hydraulic Gradient } { Initial Condition }
Format: *Char[a], Char[b], Char[c], Char[d], <Char[e],>*

I-Start Index[a], I-End Index[b], J-Start Index[c], J-End Index[d],
K-Start Index[e], K-End Index[f], Number of Boundary Times[g]
Format: *Integer[a], Integer[b], Integer[c], Integer[d], Integer[e], Integer[f], Integer[g],*

If: Operational Mode Option: Solution Control Card = { Water }
For: Number of Boundary Times
Boundary Time[a], Units[b] (s),
If: Aqueous Boundary Type Option = { Dirichlet } { Zero Flux }
Aqueous Pressure[c], Units[d] (Pa),

Elseif: Aqueous-Phase Boundary Type Option = { Neumann }
Aqueous Volumetric Flux[c], Units[d] (m/s),
Elseif: Aqueous-Phase Boundary Type Option = { Hydraulic Gradient }
Base Aqueous Pressure[c], Units[d] (Pa),
Else: Null[c], Null[d],
Endif:
Format: *Real[a], Char[b], Real[c], Char[d], Real[e], Char[f],*
Real[e], Char[f], <Real[e], Char[f],>
Endfor: Number of Boundary Times

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
For: Number of Boundary Times
Boundary Time[a], Units[b] (s),
If: Aqueous-Phase Boundary Type Option = { Dirichlet } { Zero Flux }
Aqueous Pressure[e], Units[f] (Pa),
Elseif: Aqueous-Phase Boundary Type Option = { Neumann }
Aqueous Volumetric Flux[e], Units[f] (m/s),
Elseif: Aqueous-Phase Boundary Type Option = { Hydraulic Gradient }
Base Aqueous Pressure[e], Units[f] (Pa),
Else: Null[e], Null[f],
Endif:
If: Gas-Phase Boundary Type Option = { Dirichlet } { Zero Flux }
Gas Pressure[g], Units[h] (Pa),
Elseif: Gas-Phase Boundary Type Option = { Neumann }
Gas Volumetric Flux[g], Units[h] (m/s),
Elseif: Gas-Phase Boundary Type Option = { Hydraulic Gradient }
Base Gas Pressure[g], Units[h] (Pa),
Else: Null[g], Null[h],
Endif:
Water Vapor Relative Humidity[i]
Format: *Real[a], Char[b], Real[c], Char[d], Real[e], Char[f],*
Real[g], Char[h], Real[g], Char[h], <Real[g], Char[h],>
Endfor: Number of Boundary Times

Elseif: Operational Mode Option: Solution Control Card = { Water-Air-Energy }
For: Number of Boundary Times
Boundary Time[a], Units[b] (s),
If: Energy Boundary Type Option = { Dirichlet }
Temperature[c], Units[d] (C)
Elseif: Energy Boundary Type Option = { Neumann }
Energy Flux[c], Units[d] (W/m^2)
Else: Null[c], Null[d],
Endif:

If: Aqueous-Phase Boundary Type Option = { Dirichlet } { Zero Flux }
Aqueous Pressure[e], Units[f] (Pa),
Elseif: Aqueous-Phase Boundary Type Option = { Neumann }
Aqueous Volumetric Flux[e], Units[f] (m/s),
Elseif: Aqueous-Phase Boundary Type Option = { Hydraulic Gradient }
Base Aqueous Pressure[e], Units[f] (Pa),
Else: Null[e], Null[f],
Endif:
If: Gas-Phase Boundary Type Option = { Dirichlet } { Zero Flux }
Gas Pressure[g], Units[h] (Pa),
Elseif: Gas-Phase Boundary Type Option = { Neumann }
Gas Volumetric Flux[g], Units[h] (m/s),
Elseif: Gas-Phase Boundary Type Option = { Hydraulic Gradient }
Base Gas Pressure[g], Units[h] (Pa),
Else: Null[g], Null[h],
Endif:
Water Vapor Relative Humidity[i]
Format: *Real[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Real[j], Char[k], Real[j], Char[k], <Real[j], Char[k],>*
Endfor: Number of Boundary Times

Endfor: Number of Boundary Condition Domains

Endcard: Boundary Conditions Card

A.10 Boundary Conditions Card Examples

```
#-----------------------------------------------------
~Boundary Conditions Card
#-----------------------------------------------------
2,
East,Hydraulic Gradient,
50,50,1,1,1,113,1,
0,day,183254,Pa,
West,Neumann,Outflow,
3,3,1,1,14,33,6,
0,min,-0.00021209,ft/sec,,,
37.4675,min,-0.00021209,ft/sec,,,
74.9232,min,-0.000200628,ft/sec,,,
112.379,min,-0.000201526,ft/sec,,,

149.835,min,-0.000203923,ft/sec,,,
187.29,min,-0.000206671,ft/sec,,,
```

```
~Boundary Conditions Card
2,
West,Dirichlet Energy,Dirichlet Aqueous,Dirichlet Gas,
1,1,1,1,1,1,1,
0,day,70,C,101330,Pa,101330,Pa,1,
East,Neumann Energy,Zero Flux Aqueous,Zero Flux Gas,
50,50,1,1,1,1,1,
0,Day,-100,W/m^2,,,,,,
```

```
~Boundary Conditions Card
2,
West,Neumann,
1,1,1,1,1,10,1,
0,yr,6.6e-5,m/s,
East,Hydraulic Gradient,
20,20,1,1,1,10,1,
0,yr,121557.98,Pa,
```

```
~Boundary Conditions Card
2,
Top,Neumann,Zero Flux,
1,1,1,1,92,92,1,
0,hr,-3.32,cm/hr,,,
Bottom,Dirichlet,Dirichlet,
1,1,1,1,1,1,1,
0,hr,111119.948,Pa,111119.948,Pa,
```

A.11 Output Control Card

Card Title[a] { ~Output [Control Card] }
Format: *Char*[a]

Number of Reference Nodes[a],
Format: *Integer*[a],

For: Number of Reference Nodes
I Index[a], J Index[b], K Index[c],
Endfor: Number of Reference Nodes
Format: *Integer*[a], *Integer*[b], *Integer*[c],

Reference Node Screen Output Frequency[a],
Reference Node Output File Frequency[b],

Output Time Units[c] (s),
Output Length Units[d] (m),
Screen Significant Digits[e],
Output File Significant Digits[f],
Plot File Significant Digits[g]
Format: *Integer[a], Integer[b], Char[c], Char[d], Integer[e], Integer[f], Integer[g],*

Number of Reference Node Variables[a],
Format: *Integer[a],*

For: Number of Reference Node Variables
Reference Node Variable Option[a], Reference Node Variable Units[b],
Format: *Real[a], Char[b],*
Endfor: Number of Reference Node Variables

Number of Plot File Times[a]
Format: *Integer[a],*

For: Number of Plot File Times
Plot File Output Time[a], Units[b] (s)
Format: *Real[a], Char[b],*
Endfor: Number of Plot File Times

Number of Plot File Variables[a]
Format: *Integer[a],*

For: Number of Plot File Variables
Plot File Variable Option[a], Plot File Variable Units[b],
Format: *Char[a], Char[b],*
Endfor: Number of Plot File Variables

Note: Refer to the following pages for Plot File Variable Options and Units.

Endcard: Output Control Card

Reference Node Variable and Plot File Variable Options

If: Operational Mode Option: Solution Control Card = { Water }
{ apparent water sat [uration] } { aqueous gauge pressure }
{ aqueous moisture cont [ent] } { water aqueous mass frac [tion]}
{ aqueous pressure } { aqueous sat [uration] }
{ aqueous matrix sat [uration] } { aqueous fracture sat [uration] }
{ air aqueous mass frac [tion] } { aqueous relative perm [eability] }
{ aqueous hydraulic head } { aqueous density }
{ water aqueous conc [entration] } { air aqueous conc [entration] }
{ diffusive porosity } { effective trapped air sat [uration] } { gas fracture sat [uration] }
{ gas sat [uration] } { gas pressure } { gas matrixsat [uration] }
{ phase condition } { rock/soil type }
{ temperature } { total water mass }
{ water source [integral] }
{ x aqueous vol [umetric flux (lower surface)] }
{ xnc aqueous vol [umetric flux (node centered)] }
{ y aqueous vol [umetric flux (lower surface)] }
{ ync aqueous vol [umetric flux (node centered)] }
{ z aqueous vol [umetric flux (lower surface)] }
{ znc aqueous vol [umetric flux (node centered)] }

Reference Node Variable and Plot File Variable Options

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
{ air source [integral] } { apparent water sat [uration] }
{ air aqueous mass frac [tion] } { water aqueous mass frac [tion] }
{ aqueous fracture sat [uration] } { aqueous hydraulic head }
{ aqueous density } { aqueous relative perm [eability] }
{ aqueous matrix sat [uration] } { air aqueous conc [entration] }
{ aqueous pressure } { aqueous gauge pressure }
{ aqueous sat [uration] } { water aqueous conc [entration] }
{ aqueous moisture cont [ent] } { diffusive porosity }
{ water gas conc [entration] } { gas fracture sat [uration] }
{ gas air mole frac [tion] } { water gas mole frac [tion] }
{ gas density } { gas matrix sat [uration] }
{ gas air conc [entration] } { water gas mass frac [tion] }
{ gas sat [uration] } { gas gauge pressure } { gas pressure }
{ gas air mass frac [tion] } { gas hydraulic head }
{ gas relative perm [eability] } { phase condition }
{ rock/soil type }
{ temperature } { total water mass } { total air mass }
{ effective trapped air sat [uration] } { water source [integral] }
{ x aqueous vol [umetric flux (lower surface)] }
{ x gas vol [umetric flux (lower surface)] }
{ xnc aqueous vol [umetric flux (node centered)] }
{ xnc gas vol [umetric flux (node centered)] }

{ y aqueous vol [umetric flux (lower surface)] }
{ y gas vol [umetric flux (lower surface)] }
{ ync aqueous vol [umetric flux (node centered)] }
{ ync gas vol [umetric flux (node centered)] }
{ z aqueous vol [umetric flux (lower surface)] }
{ z gas vol [umetric flux (lower surface)] }
{ znc aqueous vol [umetric flux (node centered)] }
{ znc gas vol [umetric flux (node centered)] }

Reference Node Variable and Plot File Variable Options

Elseif: Operational Mode Option: Solution Control Card = { Water-Air-Energy }
{ air source [integral] } { apparent water sat [uration] }
{ air aqueous mass frac [tion] } { water aqueous mass frac [tion] }
{ aqueous hydraulic head } { air aqueous conc [entration] }
{ water aqueous conc [entration] } { aqueous relative perm [eability] }
{ aqueous moisture cont [ent] } { aqueous density }
{ aqueous fracture sat [uration] } { aqueous gauge pressure }
{ aqueous matrix sat [uration] } { aqueous sat [uration] } { aqueous pressure }
{ diffusive porosity } { energy source [integral] } { gas matrix sat [uration] }
{ gas air mole frac [tion] } { water gas conc [entration] } { water gas mole frac [tion] }
{ gas air conc [entration] } { gas fracture sat [uration] } { gas sat [uration] }
{ gas gauge pressure } { gas pressure } { water gas mass frac [tion] }
{ gas air mass frac [tion] }
{ gas relative perm [eability] } { gas density } { gas hydraulic head }
{ phase condition } { rock/soil type }
{ temperature } { total water mass } { total air mass }
{ effective trapped air sat [uration] } { water source [integral] }
{ x aqueous vol [umetric flux (lower surface)] }
{ x gas vol [umetric flux (lower surface)] }
{ x heat flux [(lower surface)] }
{ x thermal cond [uctivity] }
{ xnc aqueous vol [umetric flux (node centered)] }
{ xnc gas vol [umetric flux (node centered)] } { xnc heat flux [(node centered)] }
{ y aqueous vol [umetric flux (lower surface)] }
{ y gas vol [umetric flux (lower surface)] }
{ y heat flux [(lower surface)] }
{ y thermal cond [uctivity] }
{ ync aqueous vol [umetric flux (node centered)] }
{ ync gas vol [umetric flux (node centered)] } { ync heat flux [(node centered)] }
{ z aqueous vol [umetric flux (lower surface)] }
{ z gas vol [umetric flux (lower surface)] }
{ z heat flux [(lower surface)] }
{ z thermal cond [uctivity] }

{ znc aqueous vol [umetric flux (node centered)] }
{ znc gas vol [umetric flux (node centered)] } { znc heat flux [(node centered)] }

Default Units for the Reference Node and Plot File Variables

Air Concentration (kg/m^3)
Water Concentration (kg/m^3)
Aqueous Relative Permeability (null)
Aqueous Volumetric Flux (m/s)
Energy Source Integral (J)
Gas Sat [uration] (null)
Gauge Pressure (Pa)
Heat Flux (W/m^2)
Phase Condition (null)
Relative Permeability (null)
Temperature (C)
Air Source Integral (kg)
Water Source Integral (kg)
Aqueous Sat [uration] (null)
Density (kg/m^3)
Gas Relative Permeability (null)
Gas Volumetric Flux (m/s)
Head (m),
Moisture Content (null)
Pressure (Pa)
Sat [uration] (null)
Thermal Conductivity (W/m K)

A.12 Output Control Card Examples

```
~Output Control Card
4,
20,1,1,
20,1,3,
20,1,6,
20,1,10,
1,1,yr,m,,,,
3,
Aqueous Pressure,Pa,
Aqueous Saturation,,
X Aqueous Volumetric Flux,m/s,
2,
1.0, s,
100,yr,
3,
Aqueous Density,kg/m^3,
Aqueous Pressure,Pa,
Aqueous Sat,,
```

A.13 Source Card

Card Title[a] { ~Source [Card] }
Format: *Char*[a]

Number of Source Domains[a],
Format: Integer[a],

For: Number of Source Domains

If: Operational Mode Option: Solution Control Card = { Water }
Source Type Option[a]
{ Aqueous Volumetric } { Aqueous Mass } { Well }
I-Start Index[b], I-End Index[c], J-Start Index[d], J-End Index[e],
K-Start Index[f], K-End Index[g], Number of Source Times[h],
Format: *Char*[a], *Integer*[b], *Integer*[c], *Integer*[d], *Integer*[e], *Integer*[f], *Integer*[g], *Integer*[h],

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
Source Type Option[a]
{ Aqueous Volumetric } { Aqueous Mass } { Gas Volumetric w/ Mass Fraction }
{ Gas Volumetric w/ Relative Humidity } { Gas Mass w/ Mass Fraction }
{ Gas Mass w/ Relative Humidity }
I-Start Index[b], I-End Index[c], J-Start Index[d], J-End Index[e],
K-Start Index[f], K-End Index[g], Number of Source Times[h],
Format: *Char*[a], *Integer*[b], *Integer*[c], *Integer*[d], *Integer*[e], *Integer*[f], *Integer*[g], *Integer*[h],

Elseif: Operational Mode Option: Solution Control Card = { Water-Air-Energy }
Source Type Option[a]
{ Power } { Power Density } { Aqueous Volumetric } { Aqueous Mass }
{ Gas Volumetric w/ Mass Fraction } { Gas Volumetric w/ Relative Humidity }
{ Gas Mass w/ Mass Fraction } { Gas Mass w/ Relative Humidity }
I-Start Index[b], I-End Index[c], J-Start Index[d], J-End Index[e],
K-Start Index[f], K-End Index[g], Number of Source Times[h],
Format: *Char*[a], *Integer*[b], *Integer*[c], *Integer*[d], *Integer*[e], *Integer*[f], *Integer*[g], *Integer*[h],

If: Operational Mode Option: Solution Control Card = { Water }
For: Number of Source Times
Source Time[a], Units[b] (s),

If: Source Type Option = { Aqueous Volumetric }
Aqueous Volumetric Rate[c], Units[d] (m^3/s),
Elseif: Source Type Option = { Aqueous Mass }
Aqueous Mass Rate[c], Units[d] (kg/s),
Elseif: Source Type Option = { Well }
Aqueous Mass Rate[c], Units[d] (kg/s),
Borehole Radius[e], Units[f] (m),
Well Bottom Pressure Constraint[g], Units[h] (Pa),
Format: *Real[a], Char[b], Real[c], Char[d], [Real[e], Char[f], Real[g], Real[h], Char[i], Real[j],]*
Endfor: Number of Source Times

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
For: Number of Source Times
Source Time[a], Units[b] (s),
If: Source Type Option = { Aqueous Volumetric }
Pressure[c], Units[d] (Pa), Aqueous Volumetric Rate[e], Units[f] (m^3/s),
Dissolved Air Mass Fraction[g]
Elseif: Source Type Option = { Aqueous Mass }
Pressure[c], Units[d] (Pa), Aqueous Mass Rate[e], Units[f] (kg/s),
Dissolved Air Mass Fraction[g]
Elseif: Source Type Option = { Gas Mass w/ Mass Fraction }
Pressure[c], Units[d] (Pa), Gas Mass Rate[e], Units[f] (kg/s),
Water Vapor Mass Fraction[g]
Elseif: Source Type Option = { Gas Mass w/ Relative Humidity }
Pressure[c], Units[d] (Pa), Gas Mass Rate[e], Units[f] (kg/s),
Water Vapor Relative Humidity[g]
Elseif: Source Type Option = { Gas Volumetric w/ Mass Fraction }
Pressure[c], Units[d] (Pa), Gas Volumetric Rate[e], Units[f] (m^3/s),
Water Vapor Mass Fraction[g]
Elseif: Source Type Option = { Gas Volumetric w/ Relative Humidity }
Pressure[c], Units[d] (Pa), Gas Volumetric Rate[e], Units[f] (m^3/s),
Water Vapor Relative Humidity[g]
Format: *Real[a], Char[b], Real[c], Char[d], [Real[e], Char[f], Real[g],]*
Endfor: Number of Source Times

Elseif: Operational Mode Option: Solution Control Card = { Water-Air-Energy }
For: Number of Source Times
Source Time[a], Units[b] (s),
If: Source Type Option = { Power }
Power[c], Units[d] (W)
Elseif: Source Type Option = { Power Density }
Power Density[c], Units[d] (W/m^3)

Elseif: Source Type Option = { Aqueous Volumetric }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Aqueous Volumetric Rate[g], Units[h] (m^3/s), Dissolved Air Mass Fraction[i]
Elseif: Source Type Option = { Aqueous Mass }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Aqueous Mass Rate[g], Units[h] (kg/s), Dissolved Air Mass Fraction[i]
Elseif: Source Type Option = { Gas Mass w/ Mass Fraction }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Gas Mass Rate[g], Units[h] (kg/s), Water Vapor Mass Fraction[i]
Elseif: Source Type Option = { Gas Mass w/ Relative Humidity }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Gas Mass Rate[g], Units[h] (kg/s), Water Vapor Relative Humidity[i]
Elseif: Source Type Option = { Gas Volumetric w/ Mass Fraction }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Gas Volumetric Rate[g], Units[h] (m^3/s), Water Vapor Mass Fraction[i]
Elseif: Source Type Option = { Gas Volumetric w/ Relative Humidity }
Temperature[c], Units[d] (C), Pressure[e], Units[f] (Pa),
Gas Volumetric Rate[g], Units[h] (m^3/s), Water Vapor Relative Humidity[i]
Format: *Real[a], Char[b], Real[c], Char[d], [Real[e], Char[f], Real[g], Char[h], Real[i],]*
Endfor: Number of Source Times

A.14 Source Card Examples

```
~Source Card
1,
Aqueous Volumetric,2,2,1,1,71,71,6,
0,min,0.319307,gal/min,
37.4675,min,0.319307,gal/min,
74.9232,min,0.30205,gal/min,
112.379,min,0.303402,gal/min,
149.835,min,0.307011,gal/min,
187.29,min,0.311148,gal/min,
```

```
~Source Card
1,
Well,1,1,1,1,1,20,1,
0,s,-0.5,ft^3/s,4.0,in,101325.0,Pa,
```

A.15 Saturation Function Card

Card Title[a] { ~Saturation Function [Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

If: Operational Mode Option: Solution Control Card = { Water } { Water-Air } or { Water-Air-Energy }
Rock/Soil Name[a],
Saturation Function[b],
{ Nonhysteretic van Genuchten } { Nonhysteretic Brooks and Corey }
{ Hysteretic van Genuchten } { Hysteretic Brooks and Corey }
{ Haverkamp } { Tabular [Water Content] }
If: Saturation Function Option = { Nonhysteretic van Genuchten }
If: Rock/Soil Name = {{ Fractured }}
Matrix "α" Parameter[c], Units[d] (1/m)', Matrix "n" Parameter[e], Matrix Minimum Saturation[f],
Fracture "α" Parameter[g], Units[h] (1/m)', Fracture "n" Parameter[i], Fracture Minimum Saturation[j],
Matrix "m" Parameter[k], Fracture "m" Parameter[l],
Format: *Char*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Real*[f], *Real*[g], *Char*[h], *Real*[i], *Real*[j], *Real*[k], *Real*[l],
Else:
"α" Parameter[c], Units[d] (1/m)', "n" Parameter[e],
Minimum Saturation[f], "m" Parameter[g]
Format: *Char*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Real*[f], *Real*[g],
Endif:
Elseif: Saturation Function Option = { Nonhysteretic Brooks and Corey }
If: Rock/Soil Name = {{ Fractured }}
Matrix Entry Head[c], Units[d] (m), Matrix "λ" Parameter[e], Matrix Minimum Saturation[f],
Fracture Entry Head[g], Units[h] (m), Fracture "λ" Parameter[i], Fracture Minimum Saturation[j]
Format: *Char*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Real*[f], *Real*[g], *Char*[h], *Real*[i], *Real*[j],
Else:
Entry Head[c], Units[d] (m), "λ" Parameter[e], Minimum Saturation[f]
Format: *Char*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Real*[f],
Endif:
Elseif: Saturation Function Option = { Hysteretic van Genuchten }
"α" Drainage[c], Units[d] (1/m), "α" Imbibition[e], Units[f] (1/m),
"n" Parameter[g], Minimum Saturation[h],
Maximum Effective Air Residual Saturation - Air/Water[i],
Initial Hysteretic Branch Index Option[j]
{ Main Drainage } { Main Imbibition } { Drainage Scanning Curve }
Number of Scanning Paths[k],
"m" Parameter[l]
Format: *Char*[a], *Char*[b], *Real*[c], *Char*[d], *Real*[e], *Char*[f], *Real*[g], *Real*[h], *Real*[i], *Char*[j], *Integer*[k], *Real*[l],

Elseif: Saturation Function Option = { Hysteretic Brooks and Corey }
"λ" Parameter[g], Minimum Saturation[h],
Maximum Effective Air Residual Saturation - Air/Water[i],
Initial Hysteretic Branch Index Option[j]
{ Main Drainage } { Main Imbibition } { Drainage Scanning Curve }
Number of Scanning Paths[k]
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Real[h], Real[i], Char[j], Integer[k],*
Elseif: Saturation Function Option = { Haverkamp }
"ψ" Parameter[c], Units[d] (m), "α" Parameter[e], "β" Parameter[f], Minimum Saturation[g],
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g],*
Elseif: Saturation Function Option = { Tabular }
Number of Table Entries[a],
Format: Char[a], Char[b], Integer[a]
For: Number of Table Entries
Air-Water Capillary Head[a], Units[b] (m), Aqueous Saturation[c]
Format: *Real[a], Char[b], Real[c],*
Endfor: Number of Table Entries
Endif:

A.16 Saturation Function Card Examples

```
~Saturation Function Card
Sand1,Nonhysteretic Van Genuchten,0.0283,1/cm,7.6,0.32,1.0,1.8,2.25,,
```

```
~Saturation Function Card
Sand,Nonhysteretic Van Genuchten,1.563,1/m,5.4,0.15,,
```

```
~Saturation Function Card
Geologic Media,Nonhysteretic van Genuchten,0.2,1/cm,1.8,0.0,,
```

```
~Saturation Function Card
72.0,dynes/cm,47.8,dynes/cm,,,
20/30 Ottawa Sand,Entrapment van
Genuchten,1.885,1/cm,5.359,0.1,72.0,dynes/cm,0.12665,5.e-5,,1.0,
```

```
~Saturation Function Card
SP1,Nonhysteretic Brooks and Corey,4.32,cm,0.528,,
SP2,Nonhysteretic Brooks and Corey,6.41,cm,0.415,,
SM-ML1,Nonhysteretic Brooks and Corey,10.0,cm,0.383,,
SM-SP1,Nonhysteretic Brooks and Corey,9.0,cm,0.430,,
SP3,Nonhysteretic Brooks and Corey,10.7,cm,0.494,,
SW1,Nonhysteretic Brooks and Corey,1.17,cm,0.346,,
```

A.17 Initial Conditions Card

Card Title[a] { ~Initial [Conditions Card] }
Format: *Char*[a]

If: Operational Mode Option: Solution Control Card = { Water } { Water-Air }
{ Water-Air-Energy }
Initial Saturation Option[a], Initial Saturation Option[b],
{ Gas Pressure, Aqueous Pressure }
{ Gas Pressure, Aqueous Saturation }
{ Aqueous Pressure, Aqueous Saturation }
Format: *Char*[a], *Char*[b],

Number of Initial Conditions Domains[a]
Format: *Integer*[a],

For: Number of Initial Conditions Domains

If: Operational Mode Option: Solution Control Card = { Water }
Variable Name Option[a]
{ Aqueous Pressure } { Gas Pressure } { Temperature } { Aqueous Saturation }

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
or { Water-Air-Energy }
Variable Name Option[a]
{ Aqueous Pressure } { Gas Pressure } { Temperature }
{ Aqueous Saturation } { Air Partial Pressure } { Air Gas Mole Fraction }
{ Air Aqueous Mole Fraction } { Trapped Air Saturation }

If: Variable Name Option = { Pressure }
Pressure[b], Units[c] (Pa),
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],
J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]
Format: *Char[a], Real[b], Char[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Elseif: Variable Name Option = { Temperature }
Temperature[b], Units[c] (C),
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],
J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]
Format: *Char[a], Real[b], Char[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Elseif: Variable Name Option = { Saturation }
Saturation[b],Null[c],
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],
J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]
Format: *Char[a], Real[b],Null[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Elseif: Variable Name Option = { Mass Fraction }
Mole Fraction[b],Null[c],
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],

J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]
Format: *Char[a], Real[b],Null[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Elseif: Variable Name Option = { Mole Fraction }
Mole Fraction[b],Null[c],
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],
J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]
Format: *Char[a], Real[b],Null[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Elseif: Variable Name Option = { Relative Humidity }
Relative Humidity[b],Null[c],
X-Dir. Gradient[d], Units[e] (1/m),
Y-Dir. Gradient[f], Units[g] (1/m),
Z-Dir. Gradient[h], Units[i] (1/m),
I-Start Index[j], I-End Index[k],
J-Start Index[l], J-End Index[m],
K-Start Index[n], K-End Index[o]

Format: *Char[a], Real[b],Null[c], Real[d], Char[e], Real[f], Char[g], Real[h],*
Char[i], Integer[j], Integer[k], Integer[l], Integer[m], Integer[n], Integer[o],

Endfor: Number of Initial Conditions Domains

Endcard: Initial Conditions Card

A.18 Initial Conditions Card Examples

```
~Initial Conditions Card
Aqueous Pressure,Gas Pressure,
4,
Temperature,20,C,0,1/m,0,1/m,0,1/m,1,52,1,1,1,113,
Aqueous Pressure,183254,Pa,0,1/m,0,1/m,-9793.52,1/m,1,52,1,1,1,113,
```

```
Aqueous Pressure,92956,Pa,0,1/m,0,1/m,0,1/m,2,2,1,1,71,100,
Gas Pressure,92956,Pa,0,1/m,0,1/m,0,1/m,1,52,1,1,1,113,
```

```
~Initial Conditions Card
Gas Pressure, Aqueous Pressure,
1,
Aqueous Pressure,121325.,Pa,,,,,-9793.5331,1/m,1,20,1,1,1,10,
```

```
~Initial Conditions Card
Aqueous Saturation,Gas Pressure,
3,
Aqueous Saturation,0.5,,,,,,,,1,50,1,1,1,1,
Gas Pressure,101330,Pa,,,,,,,1,50,1,1,1,1,
Temperature,70.0,C,,,,,,,1,50,1,1,1,1,
```

A.19 Mechanical Properties Card

Card Title[a] { ~Mechanical [Properties Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

If: Operational Mode Option: Solution Control Card = { Water }
Rock/Soil Name[a],
Particle Density[b] (2650.0), Units[c] (kg/m^3),
If: Rock/Soil Name = {{ Fractured }}
Matrix Total Porosity[d], Matrix Diffusive Porosity[e],
Fracture Total Porosity[f], Fracture Diffusive Porosity[g],
Specific Storativity[h], Units[i] (1/m),
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Real*[e], *Real*[f], *Real*[g], *Real*[h], *Char*[i],
Else:
Total Porosity[d], Diffusive Porosity[e],
Specific Storativity[f], Units[g] (1/m),
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Real*[e], *Real*[f], *Char*[g],
Endif:

Elseif: Operational Mode Option: Solution Control Card = { Water-Air } { Water-Air-Energy }
Rock/Soil Name[a],

Particle Density[b] (2650.0), Units[c] (kg/m^3),
If: Rock/Soil Name = {{ Fractured }}
Matrix Total Porosity[d], Matrix Diffusive Porosity[e],
Fracture Total Porosity[f], Fracture Diffusive Porosity[g],
Specific Storativity[h], Units[i] (1/m),
Tortuosity Function Option[j]
{ Constant } { Millington and Quirk }
If: Tortuosity Function Option = { Constant }
Aqueous-Phase Tortuosity[k], Gas-Phase Tortuosity[l],
Format: *Char[a], Real[b], Char[c], Real[d], Real[e], Real[f], Real[g], Real[h], Char[i], Char[j], Real[k], Real[l],*
Else:
Format: *Char[a], Real[b], Char[c], Real[d], Real[e], Real[f], Real[g], Real[h], Char[i], Char[j],*
Endif:
Else:
Total Porosity[d], Diffusive Porosity[e],
Specific Storativity[f], Units[g] (1/m),
Tortuosity Function Option[h]
{ Constant } { Millington and Quirk }
If: Tortuosity Function Option = { Constant }
Aqueous-Phase Tortuosity[i], Gas-Phase Tortuosity[j],
Format: *Char[a], Real[b], Char[c], Real[d], Real[e], Real[f], Char[g], Char[h], Real[i], Real[j],*
Else:
Format: *Char[a], Real[b], Char[c], Real[d], Real[e], Real[f], Char[g], Char[h],*
Endif:
Endif:

Endfor: Number of Rock/Soil Types

Endcard: Mechanical Properties Card

A.20 Mechancial Properties Card Examples

```
~Mechanical Properties Card
SP1,2.63,g/cm^3,0.19,0.19,,,,
SP2,2.63,g/cm^3,0.24,0.24,,,,
SM-ML1,2.63,g/cm^3,0.35,0.35,,,,
SM-SP1,2.63,g/cm^3,0.37,0.37,,,,
SP3,2.63,g/cm^3,0.27,0.27,,,,
SW1,2.63,g/cm^3,0.28,0.28,,,,
US,2.63,g/cm^3,0.96,0.96,,,,
```

```
~Mechanical Properties Card
Sand1,2650,kg/m^3,0.34,0.34,0,,Millington and Quirk,,,
```

```
~Mechanical Properties Card
Sand,2650,kg/m^3,0.4,0.4,,,Constant,0.5,0.5,
```

```
~Mechanical Properties Card
Geologic Media,,,0.35,0.35,,,Constant Diffusion,1.0,
```

```
~Mechanical Properties Card
20/30 Ottawa Sand,2650,kg/m^3,0.3431,0.3431,0,1/m,Millington and Quirk,
```

A.21 Hydraulic Properties Card

Card Title[a] { ~Hydraulic [Properties Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types
Rock/Soil Name[a],
If: Rock/Soil Name = {{ Fractured }}
X-Dir. Matrix Intrinsic Perm. or Hydraulic Cond.[b], Units[c] (m^2 or hc m/s),
Y-Dir. Matrix Intrinsic Perm. or Hydraulic Cond.[d], Units[e] (m^2 or hc m/s),
Z-Dir. Matrix Intrinsic Perm. or Hydraulic Cond.[f], Units[g] (m^2 or hc m/s),
X-Dir. Fracture Intrinsic Perm. or Hydraulic Cond.[h], Units[i] (m^2 or hc m/s),
Y-Dir. Fracture Intrinsic Perm. or Hydraulic Cond.[j], Units[k] (m^2 or hc m/s),
Z-Dir. Fracture Intrinsic Perm. or Hydraulic Cond.[l], Units[m] (m^2 or hc m/s),
Intrinsic Permeability Function[n],
{Constant } {Kozeny and Carmen } { Fair and Hatch }
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e], *Real*[f], *Char*[g],
Real[h], *Char*[i], *Real*[j], *Char*[k], *Real*[l], *Char*[m], *Char*[n],
Else:
X-Dir. Intrinsic Permeability or Hydraulic Conductivity[b], Units[c] (m^2 or hc m/s),
Y-Dir. Intrinsic Permeability or Hydraulic Conductivity[d], Units[e] (m^2 or hc m/s),
Z-Dir. Intrinsic Permeability or Hydraulic Conductivity[f], Units[g] (m^2 or hc m/s),
Intrinsic Permeability Function[h],
{Constant } {Kozeny and Carmen } { Fair and Hatch }

Format: *Char[a], Real[b], Char[c], Real[d], Char[e], Real[f], Char[g], Char[h],*
Endif:
Endfor: Number of Rock/Soil Types

Endcard: Hydraulic Properties Card

A.22 Hydraulic Properties Card Examples

```
~Hydraulic Properties Card
20/30 Ottawa Sand,1.6e-7,cm^2,1.6e-7,cm^2,1.6e-7,cm^2,Fair and Hatch,
```

```
~Hydraulic Properties Card
Geologic Media,1.020408e-9,m^2,,,1.020408e-9,m^2, Kozeny and Carmen,
```

```
~Hydraulic Properties Card
Sand1,,,,,7.5,hc m/day, Constant,
```

```
~Hydraulic Properties Card
SP1,4.1987e-12,m^2,,,4.1987e-12,m^2, Constant,
SP2,9.3436e-13,m^2,,,9.3436e-13,m^2, Constant,
SM-ML1,5.3223e-13,m^2,,,5.3223e-13,m^2, Constant,
SM-SP1,7.695e-12,m^2,,,5.13e-12,m^2, Constant,
SP3,5.505e-12,m^2,,,3.67e-12,m^2, Constant,
SW1,9.195e-12,m^2,,,6.13e-12,m^2, Constant,
US,1.0e+04,hc cm/hr,,,1.0e+06,hc cm/hr, Constant,
```

```
~Hydraulic Properties Card
Sand,5.0e-4,hc ft/s,5.0e-4,hc ft/s,5.0e-4,hc ft/s, Constant,
```

A.23 Thermal Properties Card

Card Title[a] { ~Thermal [Properties Card] }
Format: *Char[a]*

For: Number of Rock/Soil Types

Rock/Soil Name[a],
Thermal Conductivity Function Option[b],
{ Constant } { Parallel } { Linear } { Somerton } { Campbell }

If: Thermal Conductivity Function Option = { Constant }
X-Dir. Thermal Conductivity[c], Units[d] (W/m K),
Y-Dir. Thermal Conductivity[e], Units[f] (W/m K),
Z-Dir. Thermal Conductivity[g], Units[h] (W/m K),
Specific Heat[i], Units[j] (J/kg K)
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Char[j],*
Elseif: Thermal Conductivity Function Option = { Parallel }
X-Dir. Rock/Soil Grain Thermal Conductivity[c], Units[d] (W/m K),
Y-Dir. Rock/Soil Grain Thermal Conductivity[e], Units[f] (W/m K),
Z-Dir. Rock/Soil Grain Thermal Conductivity[g], Units[h] (W/m K),
Specific Heat[h], Units[i] (J/kg K)
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Char[j],*
Elseif: Thermal Conductivity Function Option = { Linear }
X-Dir. Rock/Soil Unsaturated Thermal Conductivity[c], Units[d] (W/m K),
Y-Dir. Rock/Soil Unsaturated Thermal Conductivity[e], Units[f] (W/m K),
Z-Dir. Rock/Soil Unsaturated Thermal Conductivity[g], Units[h] (W/m K),
X-Dir. Rock/Soil Water Saturated Thermal Conductivity[i], Units[j] (W/m K),
Y-Dir. Rock/Soil Water Saturated Thermal Conductivity[k], Units[l] (W/m K),
Z-Dir. Rock/Soil Water Saturated Thermal Conductivity[m], Units[n] (W/m K),
Specific Heat[o], Units[p] (J/kg K)
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Char[j], Real[k], Char[l], Real[m], Char[n], Real[o], Char[p],*
Elseif: Thermal Conductivity Function Option = { Somerton }
X-Dir. Rock/Soil Unsaturated Thermal Conductivity[c], Units[d] (W/m K),
Y-Dir. Rock/Soil Unsaturated Thermal Conductivity[e], Units[f] (W/m K),
Z-Dir. Rock/Soil Unsaturated Thermal Conductivity[g], Units[h] (W/m K),
X-Dir. Rock/Soil Water Saturated Thermal Conductivity[i], Units[j] (W/m K),
Y-Dir. Rock/Soil Water Saturated Thermal Conductivity[k], Units[l] (W/m K),
Z-Dir. Rock/Soil Water Saturated Thermal Conductivity[m], Units[n] (W/m K),
Specific Heat[o], Units[p] (J/kg K)
Format: *Char[a], Char[b], Real[c], Char[d], Real[e], Char[f], Real[g], Char[h], Real[i], Char[j], Real[k], Char[l], Real[m], Char[n], Real[o], Char[p],*
Endif:

Endfor: Number of Rock/Soil Types

Endcard: Thermal Properties Card

A.24 Thermal Properties Card Examples

```
~Thermal Properties Card
Sand,Somerton,0.582,W/m K,,,,,1.13,W/m K,,,,,700,J/kg K,
```

A.25 Rock/Soil Zonation Card

Card Title[a] { ~Rock/Soil [Zonation Card] }
Format: *Char*[a]

Number of Rock/Soil Zonation Domains[a]
Format: *Integer*[a],

For: Number of Rock/Soil Zonation Domains
Rock/Soil Name[a],
I-Start Index[b], I-End Index[c],
J-Start Index[d], J-End Index[e],
K-Start Index[f], K-End Index[g],
Format: *Char*[a], *Integer*[b], *Integer*[c], *Integer*[d], *Integer*[e], *Integer*[f], *Integer*[g],
Endfor: Number of Rock/Soil Zonation Domains

Endcard: Rock/Soil Zonation Card

A.26 Rock/Soil Zonation Card Examples

```
~Rock/Soil Zonation Card
1,
20/30 Ottawa Sand,1,1,1,1,1,92,
```

```
~Rock/Soil Zonation Card

7,
SP1,1,50,1,1,86,113,
SP2,1,50,1,1,63,85,
SM-ML1,1,50,1,1,69,69,
```

```
SM-SP1,1,50,1,1,46,62,
SP3,1,50,1,1,16,45,
SW1,1,50,1,1,1,15,
US,2,2,1,1,71,100,
```

```
~Rock/Soil Zonation Card
1,
Sand1,1,20,1,1,1,10,
```

A.27 Aqueous Relative Permeability Card

Card Title[a] { ~Aqueous Rel [ative Permeability Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

If: Operational Mode Option: Solution Control Card = { Water } { Water-Air }
{ Water-Air-Energy }
Rock/Soil Name[a],
Permeability Function Option[b]
{ Constant } { Mualem } { Burdine } { Fatt and Klikoff } { Corey }
{ Haverkamp } {Tauma and Vauclin } { Tabular { w/ Water Content } }
If: Permeability Function Option = { Constant }
If: Rock/Soil Name = {{ Fractured }}
Matrix Aqueous Relative Permeability[c]
Fracture Aqueous Relative Permeability[d]
Format: *Char*[a], *Char*[b], *Real*[c], *Real*[d],
Else:
Aqueous Relative Permeability[c]
Format: *Char*[a], *Char*[b], *Real*[c],
Endif:
Elseif: Permeability Function Option = { Mualem } { Burdine }
If: Saturation Function Option = { van Genuchten }
van Genuchten "m" parameter[c]
Format: *Char*[a], *Char*[b], *Real*[c],
Elseif: Saturation Function Option = { Brooks and Corey }
Brooks and Corey "λ" parameter[c]
Format: *Char*[a], *Char*[b], *Real*[c],
Elseif: Saturation Function Option = {van Genuchten}and
Rock/Soil Name = {{ Fractured }}
Matrix van Genuchten "m" parameter[c]
Fracture van Genuchten "m" parameter[d]
Format: *Char*[a], *Char*[b], *Real*[c], *Real*[d],

Elseif: Saturation Function Option = {Brooks and Corey}
and Rock/Soil Name = {{ Fractured }}
Matrix Brooks and Corey "λ" parameter[c]
Fracture Brooks and Corey "λ" parameter[d]
Format: *Char*[a], *Char*[b], *Real*[c], *Real*[d],
Endif:
Elseif: Permeability Function Option = { Fatt and Klikoff } { Corey }
Format: *Char*[a], *Char*[b],
Elseif: Permeability Function Option = { Haverkamp }
"a" Parameter[c], "γ" Parameter[d],
Format: *Char*[a], *Char*[b], *Real*[c], *Real*[d],
Elseif: Permeability Function Option = { Tauma and Vauclin }
"α" Parameter[c], "β" Parameter[d],
Format: *Char*[a], *Char*[b], *Real*[c], *Real*[d],
Elseif: Permeability Function Option = { Tabular }
Number of Table Entries[c]
Format: *Char*[a], *Char*[b], *Integer*[c],
For: Number of Table Entries
Aqueous Saturation[a], Aqueous Relative Permeability[b]
Format: *Real*[a], *Real*[b],
Endfor: Number of Table Entries
Elseif: Permeability Function Option = { Tabular } and { Content }
For: Number of Table Entries
Aqueous Moisture Content[a], Aqueous Relative Permeability[b]
Format: *Real*[a], *Real*[b],
Endfor: Number of Table Entries
Endif:

Endfor: Number of Rock/Soil Types

Endcard: Aqueous Relative Permeability Card

A.28 Aqueous Relative Permeability Card Examples

```
~Aqueous Relative Permeability Card
Sand,Mualem,,
```

```
~Aqueous Relative Permeability Card
20/30 Ottawa Sand,Mualem,0.56,
```

```
~Aqueous Relative Permeability Card
Sand,Fatt And Klikoff,
```

```
~Aqueous Relative Permeability Card
SM-ML1,Burdine,,
SW1,Burdine,,
SP3,Burdine,,
SM-SP1,Burdine,,
SP2,Burdine,,
SP1,Burdine,,
US,Touma and Vauclin,1.0,2.0,
```

A.29 Surface Flux Card

Card Title[a] { ~Surface [Flux Card] }
Format: *Char*[a]

Number of Surface Flux Inputs[a]
Format: Integer[a],

For: Number of Surface Flux Inputs:

If: Operational Mode Option: Solution Control Card = { Water }
Surface Flux Type Option[a]
{ Aqueous Volumetric Flux } { Aqueous Mass Flux }

Elseif: Operation Mode Option: Solution Control Card = { Water-Air }
Surface Flux Type Option[a]
{ Aqueous Volumetric Flux } { Aqueous Mass Flux } { Gas Volumetric Flux }
{ Gas Mass Flux }

Elseif: Operation Mode Option: Solution Control Card = { Water-Air-Energy }
Surface Flux Type Option[a]
{ Aqueous Volumetric Flux} { Aqueous Mass Flux } { Gas Volumetric Flux }
{ Gas Mass Flux } { Heat Flux }
Endif:

If: Surface Flux Type Option = { Heat Flux }
Units[b] (W), Units[c] (J),
ElseIf: Surface Flux Type Option = { Volumetric Flux }

Units[b] (m^3/s), Units[c] (m^3),
Elseif: Surface Flux Type Option = { Mass Flux }
Units[b] (kg/s), Units[c] (kg),
Endif:

Surface Flux Orientation Option[d]
{ West } { East } { South }
{ North } { Top } { Bottom }
I-Start Index[e], I-End Index[f],
J-Start Index[g], J-End Index[h],
K-Start Index[i], K-End Index[j],
Format: Char[a], Char[b], Char[c], Char[d], Integer[e], Integer[f], Integer[g], Integer[h], Integer[i], Integer[j]

Endfor: Number of Surface Flux Inputs

Endcard:

A.30 Surface Flux Card Examples

```
~Surface Flux Card
3,
Aqueous Volumetric,gal/min,gal,East,2,2,1,1,14,33,
Aqueous Volumetric,gal/min,gal,East,2,2,1,1,71,100,
Aqueous Volumetric,gal/min,gal,East,52,52,1,1,1,113,
```

A.31 Gas Relative Permeability Card

Card Title[a] { ~Gas Rel [ative Permeability Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

If: Operational Mode: Solution Control Card = { Water-Air } { Water-Air-Energy }
Rock/Soil Name[a],
Permeability Function Option[b]
{ Constant } { Mualem } { Burdine } { Fatt and Klikoff } { Corey } { Tabular }
If: Permeability Function Option = { Constant }
If: Rock/Soil Name = {{ Fractured }}
Matrix Gas Relative Permeability[c], Fracture Gas Relative Permeability[d]
Format: Char[a],Char[b],Real[c],Real[d],
Else:
Gas Relative Permeability[c]
Format: Char[a],Char[b],Real[c],
Endif:

Elseif: Permeability Function Option = { Mualem } or { Burdine }
If: Saturation Function Option = { van Genuchten }
van Genuchten "m" parameter[c]
Format: Char[a],Char[b],Real[c],
Elseif: Saturation Function Option = { Brooks and Corey }
Brooks and Corey "λ" parameter[c]
Format: Char[a],Char[b],Real[c],
Elseif: Saturation Function Option = { van Genuchten } and Rock/Soil Name = {{ Fractured }}
Matrix van Genuchten "m" parameter[c]
Fracture van Genuchten "m" parameter[c]
Format: Char[a],Char[b],Real[c],Real[d],
Elseif: Saturation Function Option = { Brooks and Corey } and Rock/Soil Name = {{ Fractured }}
Matrix Brooks and Corey "λ" parameter[c]
Fracture Brooks and Corey "λ" parameter[d]
Format: Char[a],Char[b],Real[c],Real[d],
Endif:
Elseif: Permeability Function Option = { Tabular }
Number of Table Entries[c]
Format: Char[a],Char[b],Integer[c],
For: Number of Table Entries
Gas Saturation[a], Gas Relative Permeability[b]
Format: Real[a],Real[b],
Endfor:
Endif:

Endfor: Number Rock/Soil Types

Endcard: Aqueous Relative Permeability Card

A.32 Gas Relative Permeability Card Examples

```
~Gas Relative Permeability Card
Sand,Mualem,,
```

```
~Gas Rel
20/30 Ottawa Sand,Mualem,0.56,
```

```
~Gas Relative Permeability Card
Sand,Fatt And Klikoff,
~Gas Relative Permeability
SM-ML1,Burdine,,
```

```
SW1,Burdine,,
# Tabular Input
SP3,Tabular,6,
1.0, 1.0,
0.8, 0.64,
0.6, 0.36,
0.4, 0.16,
0.2, 0.04,
0.0, 0.0,
SM-SP1,Mualem,0.5,
SP2,Burdine,,
SP1,Burdine,,
US,Touma and Vauclin,1.0,2.0,
```

A.33 Solute/Fluid Interactions Card

Card Title[a] { ~Solute/Fluid [Interactions Card] }
Format: *Char*[a]

Number of Solutes
Format: *Integer,*

For: Number of Solutes

If: Operational Mode Option: Solution Control Card = { Water }
Solute Name[a],
Effective Diffusion Option[b],
{ Constant }
{ Conventional } **Note**: $D^c_{\ell_e} = \tau_\ell \, s_\ell \, n_D \, D^c_\ell$
{ Empirical } **Note**: Kemper and van Schaik $D^c_{\ell_e} = D^c_\ell \, a \, e^{(b \, n_D \, s_\ell)}$
If: Effective Diffusion Option = { Empirical }
Solute Partition Option[c],
{ Continuous [Concentration Dependent] } **Note**: $C_\ell = \dfrac{C}{n_D \, s_\ell + (1 - n_T)\rho_s K_{s\ell}}$
{ Noncontinous [Concentration Dependent] } **Note**: $C_\ell = \dfrac{C}{s_\ell \, n_D + s_\ell (1 - n_T)\rho_s K_{s\ell}}$
IfDef: Radioactive
Half-Life[d], Units[e] (s),
Format: *Char*[a], *Char*[b], *Char*[c], *Real*[d], *Char*[e],
ElseifDef: Reactive
Number of Reactions[d],

For: Number of Reactions:
First-Order Decay Constant[e], Units[f] (s),
Endfor: Number of Reactions
Format: *Char[a], Char[b], Char[c], Integer[d],<Real[e], Char[f],>*
EndifDef:
Else:
Aqueous-Phase Molecular Diffusion Coefficient @ 20 C[c], Units[d] (m^2/s),
Solute Partition Option[e],

{ Continuous [Concentration Dependent] } **Note**: $$C_\ell = \frac{C}{n_D\, s_\ell + (1 - n_T)\rho_s K_{s\ell}}$$

{ Noncontinous [Concentration Dependent] } **Note**: $$C_\ell = \frac{C}{s_\ell\, n_D + s_\ell\,(1 - n_T)\rho_s K_{s\ell}}$$

IfDef: Radioactive
Half-Life[f], Units[g] (s),
Format: *Char[a], Char[b], Real[c], Char[d], Char[e], Real[f], Char[g],*
ElseifDef: Reactive
Number of Reactions[f],
For: Number of Reactions:
First-Order Decay Constant[g], Units[h] (s),
Endfor: Number of Reactions
Format: *Char[a], Char[b], Real[c], Char[d], Char[e], Integer[f],<Real[g], Char[h],>*
EndifDef:
Endif:

Elseif: Operational Mode Option: Solution Control Card = { Water-Air }
{ Water-Air-Energy }
Solute Name[a],
Aqueous-Phase Molecular Diffusion Coefficient @ 20 C[b], Units[c] (m^2/s),
Gas-Phase Molecular Diffusion Coefficient @ 20 C[d], Units[e] (m^2/s),
Gas-Aqueous Partition Function Option[f]
{ Constant }
{ Temperature Dependent } **Note**: $$\ln\left(K_{g\ell}\right) = a + \frac{b}{T} + c\,\ln(T) + d\,T + e\,T^2$$
If: Gas-Aqueous Partition Function Option = { Constant }
Gas-Aqueous Partition Coefficient[g], Units[h] (m^3/m^3),
IfDef: Radioactive
Half-Life[i], Units[j] (s)
Format: *Char[a], Real[b], Char[c], Real[d], Char[e], Char[f], Real[g], Char[h], Real[i], Char[j],*
ElseifDef: Reactive
Number of Parent Reactions[i],
For: Number of Reactions
First-Order Decay Constant[j], Units[k] (s),
Endfor: Number of Reactions
Format: *Char[a], Real[b], Char[c], Real[d], Char[e], Char[f], Real[g], Char[h],*

Integer[j],<*Real*[j], *Char*[k],>
EndifDef:
Elseif: Gas-Aqueous Partition Function Option = { Temperature Dependent }
a[g], b[h], c[i], d[j], e[k],
IfDef: Radioactive
Half-Life[l], Units[m] (s)
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e],
Char[f], *Real*[g], *Real*[h], *Real*[i], *Real*[j], *Real*[k], *Real*[l], *Char*[m],
ElseifDef: Reactive
Number of Parent Reactions[l],
For: Number of Reactions
First-Order Decay Constant[m], Units[n] (s),
Endfor: Number of Reactions
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e], *Char*[f], *Real*[g], *Real*[h],
Real[i], *Real*[j], *Real*[k], *Integer*[l],<*Real*[m], *Char*[n],>
EndifDef:
Endif:

Endcard:

A.34 Solute/Fluid Interactions Card Examples

```
~Solute/Fluid Interaction Card
1,
TCE,Conventional,9.6283e-6,cm^2/s,Continuous,1000,yr,
0,
```

```
~Solute/Fluid Interaction Card
4,
Tc-99,Empirical,Noncontinuous,1.e20,yr,
U-238,Empirical,Noncontinuous,1.e20,yr,
Np-237,Empirical,Noncontinuous,1.e20,yr,
Pu-239,Empirical,Noncontinuous,1.e20,yr,
0,
```

```
~Solute/Fluid Interaction Card
7,
Dithionite,Conventional,1.e-5,cm^2/s,Continuous,2,5,hr,18,hr,
Sulfite,Conventional,1.e-5,cm^2/s,Continuous,0,
Bisulfite,Conventional,1.e-5,cm^2/s,Continuous,0,
Thiosulfate,Conventional,1.e-5,cm^2/s,Continuous,0,
```

```
Fe(III),Conventional,1.e-5,cm^2/s,Continuous,0,
Fe(II),Conventional,1.e-5,cm^2/s,Continuous,0,
H+,Conventional,1.e-5,cm^2/s,Continuous,0,
6,
Dithionite,Fe(III),1,-2.0,
Dithionite,Fe(II),1,2.0,
Dithionite,Sulfite,1,2.0,
Dithionite,H+,1,4.0,
Dithionite,Bisulfite,2,1.0,
Dithionite,Thiosulfate,2,0.5,
```

A.35 Solute/Porous Media Interactions Card

Card Title[a] { ~Solute/Porous [Media Inteactions Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

Rock/Soil Name[a],
Longitudinal Dispersivity[b], Units[c] (m),
Transverse Dispersivity[d], Units[e] (m)
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e],

For: Number of Solutes
Solute Name[a],
Solid-Aqueous Partition Coefficient[b], Units[c] (m^3/kg)
If: Solute Partition Option: Solute/Fluid Interactions Card = { Concentration Dependent }
Dependent Solute Name[d],
"a" Parameter[e], "b" Parameter[f],
If: Effective Diffusion Option: Solute/Fluid Interactions Card = { Empirical }
Aqueous Molecular Diffusion Coefficient[d], Units[e] (m^2/s), a[f], b[g],
Format: *Char*[a], *Real*[b], *Char*[c], *Char*[d], *Real*[e], *Real*[f], *Real*[g], *Char*[h], *Real*[i], *Real*[j],
Else:
Format: *Char*[a], *Real*[b], *Char*[c], *Char*[d], *Real*[e], *Real*[f]
Endif:
Else:
If: Effective Diffusion Option: Solute/Fluid Interactions Card = { Empirical }
Aqueous Molecular Diffusion Coefficient[d], Units[e] (m^2/s), a[f], b[g],
Format: *Char*[a], *Real*[b], *Char*[c], *Real*[d], *Char*[e], *Real*[f], *Real*[g],
Else:
Format: *Char*[a], *Real*[b], *Char*[c],
Endif:
Endif:
Endfor: Number of Solutes

Endfor: Number of Rock/Soil Types
Endcard:

A.36 Solute/Porous Media Interaction Card Examples

```
~Solute/Porous Media Interaction Card
SP1,,,,,
TCE,0.0,m^3/kg,
SP2,,,,,
TCE,0.0,m^3/kg,
SM-ML1,,,,,
TCE,0.0,m^3/kg,
SM-SP1,,,,,
TCE,0.0,m^3/kg,
SP3,,,,,
TCE,0.0,m^3/kg,
SW1,,,,,
TCE,0.0,m^3/kg,
US,,,,,
TCE,0.0,m^3/kg,
```

```
~Solute/Porous Media Interaction Card
Backfill Soil,,,,,
Tc-99,0.,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
U-238,0.67,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Np-237,3.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Pu-239,21.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Hanford Sand,,,,,
Tc-99,0.,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
U-238,0.67,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Np-237,3.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Pu-239,21.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Hanford Gravel,,,,,
Tc-99,0.,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
U-238,0.67,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Np-237,3.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Pu-239,21.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Ringold Formation,,,,,
Tc-99,0.,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
U-238,0.67,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Np-237,3.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Pu-239,21.0,cm^3/g,7.8894e-2,m^2/yr,0.005,10.,
Glass Waste,,,,,
Tc-99,0.,cm^3/g,3.1557e-7,m^2/yr,1.,0.,
U-238,0.,cm^3/g,3.1557e-7,m^2/yr,1.,0.,
Np-237,0.,cm^3/g,3.1557e-7,m^2/yr,1.,0.,
Pu-239,0.,cm^3/g,3.1557e-7,m^2/yr,1.,0.,
```

```
~Solute/Porous Media Interaction Card
Soil,,,,,
Dithionite,0.0,m^3/kg,
Sulfite,0.0,m^3/kg,
Bisulfite,0.0,m^3/kg,
Thiosulfate,0.0,m^3/kg,
Fe(III),0.0,m^3/kg,
Fe(II),0.0,m^3/kg,
H+,0.0,m^3/kg,
```

A.37 Reactive Transport Control Card

Card Title[a] { ~Reactive [Transport Control Card] }
Format: *Char*[a]

Reactive Transport Execution Mode Option[a]
{ Normal }
Format: *Char*[a],

Reactive Transport Solution Mode Option[a]
{ Fully Coupled }
{ Operator Split }
Format: *Char*[a],

Aitken extrapolation scheme switch[a], Column scan switch[b], Non-reacting solver switch[c], Effective reaction area switch[d], Texture solver / transport solver coupling switch[e], Porosity update with precipitation/dissolution[f], Lower boundary condition switch (if 0, dC/dz=0, if 1, C=0)[g], Water consumption in chemical reactions / water flow coupling switch[h], Gas consumption in chemical reactions / gas flow coupling switch[i]
Format: Integer (0 or 1)[a], Integer (0 or 1)[b], Integer (0 or 1)[c], Integer (0 or 1)[d], Integer (0 or 1)[e], Integer (0 or 1)[f], Integer (0 or 1)[g], Integer (0 or 1)[h], Integer (0 or 1)[i]

Max. CFL[a], Crank-Nicolson parameter[b], Error in non-reacting species[c], Error in equation point solver[d], Error in transport point solver[e], Error in texture solver[f], Error in normal concentration solver[g]
Format: Real[a], Real[b], Real[c], Real[d], Real[e], Real[f], Real[g]

A.38 Reactive Transport Control Card Examples

```
~Reactive Transport Control card
Normal,
Fully Coupled,
0,0,0,0,1,0,0,0,0,
2.0E-06, 1.0E+00, 1.0E-06, 1.0E-07, 1.0E-03, 5.0E-03, 2.0E-03,
```

A.39 Aqueous Species Card

Card Title[a] { ~Aqueous Species [Card] }
Format: *Char*[a]

Number of Aqueous Species[a]
Format: Integer[a]

For: Number of Aqueous Species

Name of Aqueous Species[a], Charge[b], Hard Core Diameter[c], Number of Elements[d]
Format: Char[a], Real[b], Real[c], Integer[d]
For: Number of Elements in Aqueous Species
Stoichiometric Coefficient of Element[a], Element Name[b]
Format: Real[a], Char[b],
Endfor: Number of Elements in Aqueous Species

Endfor: Number of Aqueous Species

Endcard:

A.40 Aqueous Species Card Examples

```
~Aqueous Species card
 6,
'H+          ', 1.0000, 9.0000, 1,
 1.0000,' H',
'H2O         ', 0.0000,-4.0000, 2,
 2.0000,' H',
 1.0000,' O',
'OH-         ',-1.0000, 3.0000, 2,
 1.0000,' H',
 1.0000,' O',
'CO2(aq)     ', 0.0000, 0.0000, 2,
 1.0000,' C',
 2.0000,' O',
'HCO3-       ',-1.0000, 4.0000, 3,
 1.0000,' H',
 1.0000,' C',
3.0000,' O',
```

```
'TcO4(1-)    ',-1.0000, 4.0000, 2,
 1.0000,'Tc',
 4.0000,' O',
```

A.41 Gas Species Card

Card Title[a] { ~Gas Species [Card] }
Format: *Char*[a]

Number of Gas Species[a]
Format: Integer[a]

For: Number of Gas Species

Name of Gas Species[a], Name of Equilibrium Aqueous Species[b], Gas Species Concentration Dependency (fixed or transient)[c], Gas Diffusion Coefficient (m^2 s^{-1})[d], Number of Elements in Gaseous Species[e]
Format: Char[a], Char[b], Char[c], Real[d], Integer[e]
For: Number of Elements in Gas Species
Stoichiometric Coefficient of Element[a], Element Name[b]
Format: Real[a], Char[b],
Endfor: Number of Elements in Gas Species
Number of Terms in Henry's Coefficient vs. Temperature Curve Fit[a]
Format: Integer[a]
For: Number of Terms in Henry's Coefficient vs. Temperature Curve Fit
log Henry's Law Equilibrium Coefficient Term (M/atm)[a],
Format: Real[a]
Endfor: Number of Terms in Henry's Coefficient vs. Temperature Curve Fit

Endfor: Number of Gas Species

Endcard:

A.42 Gas Species Card Examples

```
~Gas Species card
   2,
'CO2(g)      ', 'CO2(aq)     ', 'transient',  1.69443E-06, 2,
 1.0000,' C',
 2.0000,' O',
 4,
-1.096100E+00,-1.796793E-02, 1.321931E-04,-3.982381E-07,
'O2(g)       ', 'O2(aq)      ', 'fixed',  2.40000E-06, 1,
 2.0000,' O',
 1,
```

```
-2.656700E+00,
```

A.43 Components Card

Card Title[a] { ~Components [Card] }
Format: *Char*[a]
Number of Components[a]
Format: Integer[a]

For: Number of Components

Name of Component[a], Molecular Mass (kg kmol^{-1})[b], Number of Aqueous Species[c],
Format: Char[a], Real[b], Integer[c]
For: Number Aqueous Species
Stoichiometric Coefficient of Aqueous Species[a], Aqueous Species Name[b]
Format: Real[a], Char[b],
Endfor: Number of Aqueous Species

Endfor: Number of Aqueous Species

Endcard:

A.44 Components Card Examples

```
~Components card
3,
'B(total)    ',10.8110,  2,
 1.0000,'BO2-        ',
 1.0000,'CaCO3(aq)   ',
'Tc(total)   ',98.0000,  1,
 1.0000,'TcO4(1-)    ',
'CO2(total)  ',44.0100,  3,
 1.0000,'CO2(aq)     ',
 1.0000,'HCO3-       ',
 1.0000,'CO3(2-)     ',
```

A.45 Solid Species Card

Card Title[a] { ~Solid Species [Card] }
Format: *Char*[a]

Number of Solid Species[a]
Format: Integer[a]

For: Number of Solid Species

> Name of Solid Species[a], Mass Density (Mg m^{-3}), Number of Elements[c]
> **Format**: Char[a], Real[b], Real[c], Integer[d]
> **For**: Number of Elements in Solid Species
> Stoichiometric Coefficient of Element[a], Element Name[b]
> Format: Real[a], Char[b],
> **Endfor**: Number of Elements in Solid Species

Endfor: Number of Solid Species

Endcard:

A.46 Solid Species Card Examples

```
~Solid Species card
   4,
'Quartz      ', 2.6480,  2,
 1.0000,'Si',
 2.0000,' O',
'Albiteh     ', 2.6100,  4,
 1.0000,'Al',
 1.0000,'Na',
 3.0000,'Si',
 8.0000,' O',
'K-feldspar  ', 2.5565,  4,
 1.0000,'Al',
 1.0000,' K',
 3.0000,'Si',
 8.0000,' O',
'illite      ', 2.7631,  6,
 0.6000,' K',
 0.2500,'Mg',
 2.3000,'Al',
 3.5000,'Si',
12.0000,' O',
 2.0000,' H',
```

A.47 Fast Reactions Card

Card Title[a] { ~Fast Reactions [Card] }
Format: *Char*[a]

Number of Fast Reactions[a]
Format: Integer[a]

For: Number of Fast Reactions

> Number of Aqueous Species[a]
> **Format**: Integer[a]
> **For**: Number Aqueous Species
> Stoichiometric Coefficient of Aqueous Species[a], Aqueous Species Name[b]
> Format: Real[a], Char[b],
> **Endfor**: Number of Aqueous Species
>
> Number of Coefficients in Equilibrium Constant vs. temperature polynomial function[a], Exponential Factor of Equilibrium Reaction[b]
> **Format**: Integer[a], Real[b]
> **For**: Number of Coefficients in Equilibrium Constant vs. temperature polynomial function
> Coefficient in Equilibrium Constant vs. temperature polynomial function[a]
> Format: Real[a], Real[a], Real[a], ...
> **Endfor**:

Endfor: Number of Fast Reactions

Endcard:

A.48 Fast Reactions Card Examples

```
~Fast Reactions card
   3,
   3,
-1.0000,'H2O         ',
 1.0000,'H+          ',
 1.0000,'OH-         ',
   5,    1.00000,
-1.49400E+01, 4.17100E-02,-1.91700E-04, 4.95000E-07,-6.15900E-10,
   4,
-1.0000,'H2O         ',
-1.0000,'CO2(aq)     ',
 1.0000,'H+          ',
 1.0000,'HCO3-       ',
   5,    1.00000,
-6.57600E+00, 1.19800E-02,-1.36200E-04, 4.13100E-07,-5.48300E-10,
```

```
   3,
-1.0000,'HCO3-       ',
 1.0000,'H+          ',

 1.0000,'CO3(2-)     ',
   5,    1.00000,
-1.06200E+01, 1.39700E-02,-1.14300E-04, 3.35200E-07,-4.68700E-10,
```

A.49 Kinetic Aqueous Reactions Card

Card Title[a] { ~Kinetic Aqueous Reactions [Card] }
Format: *Char*[a]
Number of Kinetic Aqueous Reactions[a]
Format: Integer[a]

For: Number of Kinetic Aqueous Reactions
Endfor:

Endcard:

A.50 Kinetic Aqueous Reactions Card Examples

```
~Kinetic Aqueous Reactions card
   0,
```

A.51 Slow Reactions Card

Card Title[a] { ~Slow Reactions [Card] }
Format: *Char*[a]

Number of Slow Reactions[a]
Format: Integer[a]

For: Number of Slow Reactions

Mass Action Law Type[a] {Full = 1} {Reduced = -1} {Glass = 0},
Number of Solid Species in Slow Reaction[b] {1 or 2}
Format: Integer[a], Integer[b]
For: Number of Solid Species in Slow Reaction
Stoichiometric Coefficient of Solid Species in Slow Reaction[a], Name of Solid Species[b]

Format: Real[a], Character[b]
EndFor: Number of Solid Species in Slow Reaction
Number Aqueous Species[a]
Format: Integer[a]
For: Number Aqueous Species
Stoichiometric Coefficient of Aqueous Species[a], Aqueous Species Name[b],
Species Participation in Reduced Mass Action Reaction Rate Calculation[c],
{ -1 = Forward Rate Only}, { 0 = Neither }, { 1 = Equilibrium Only }
Stoichiometric Coefficient of Aqueous Species Used in Equilibrium Calculations[d]
Format: Real[a], Char[b], Real[c], Real[d],
Endfor: Number of Aqueous Species
Rate Constant of Solid Reaction[a], Activation Energy of Solid Reaction[b], Exponential Factor of Solid Reaction[c], Exponential Factor of pH dependence of dissolution Reaction[d], Number of Coefficients in Equilibrium Constant vs. temperature polynomial Function[e],
Format: Real[a], Real[b], Real[c], Real[d], Integer[e]
For: Number of Coefficients in Equilibrium Constant vs. temperature polynomial function
Coefficient in Equilibrium Constant vs. temperature polynomial function[a]
Format: Real[a], Real[a], Real[a], ...
Endfor:
Endfor: Number of Slow Reactions

Endcard:

A.52 Slow Reactions Card Examples

```
~Slow Reactions card
    2,
  0,1,
-1.0000,'glass       ',
    8,
-4.50000E-01,'H+          ', 0.0000, 0.0000,
 2.02000E-02,'K+          ', 0.0000, 0.0000,
 4.20800E-01,'Na+         ', 0.0000, 0.0000,
 4.60000E-02,'Ca2+        ', 0.0000, 0.0000,
 1.54000E-01,'Al(OH)3(aq) ', 0.0000, 0.0000,
 6.06000E-01,'SiO2(aq)    ', 1.0000, 1.0000,
 9.40000E-02,'BO2-        ', 0.0000, 0.0000,
 1.61720E-06,'TcO4(1-)    ', 0.0000, 0.0000,
   0.5594027,  74.8,    1.00000, -0.4, 1,
-3.72810E+00,
  1,1,
-1.0000,'Quartz      ',
   2,
-1.00000E+00,'OH-         ', 1.0000,-1.0000,
 1.00000E+00,'HSiO3(1-)   ', 1.0000, 1.0000,
    -17.0052,  0.,    1.00000,  0.0, 1,
 4.82000E-02,
```

A.53 Fluid Decay Card

Card Title[a] { ~Fluid Decay [Card] }
Format: *Char*[a]

Number of Fluid Decay Reactions[a]
Format: Integer[a]

For: Number of Fluid Decay Reactions
Endfor:

Endcard:

A.54 Fluid Decay Card Examples

```
~Fluid Decay card
   0,
```

A.55 Solid Decay Card

Card Title[a] { ~Solid Decay [Card] }
Format: *Char*[a]

Number of Solid Decay Reactions[a]
Format: Integer[a]

For: Number of Solid Decay Reactions
Endfor:

Endcard:

A.56 Solid Decay Card Examples

```
~Solid Decay card
   0,
```

A.57 Lithology Card

Card Title[a] { ~Lithology [Card] }
Format: *Char*[a]

For: Number of Rock/Soil Types

> Rock/Soil Name[a], Number of Solid Species[b],
> **Format**: Char[a], Integer[b],
> **For**: Number of Solid Species
> Name of Solid Species[a], Relative Solid Volume[b], Radius[c]
> Format: Char[a], Real[b], Real[c]
> **Endfor**:

Endfor:

Endcard:

A.58 Lithology Card Examples

```
~Lithology card
'Backfill Soil',  9,
'glass       ', 0.00000E+00, 0.50000E-02,
'Quartz      ', 0.39474E+00, 0.10000E-03,
'Albiteh     ', 0.39474E+00, 0.10000E-03,
'K-feldspar  ', 0.98684E-01, 0.10000E-03,
'illite      ', 0.98684E-01, 0.50000E-05,
'analcime    ', 0.32895E-02,-0.20000E-03,
'calcite     ', 0.32895E-02,-0.20000E-03,
'chalcedony  ', 0.32895E-02,-0.20000E-03,
'NaAlSi2O6.6H', 0.32895E-02,-0.20000E-03,
'Glass Waste ',  9,
'glass       ', 0.98870E+00, 0.50000E-02,
'Quartz      ', 0.00000E+00, 0.10000E-03,
'Albiteh     ', 0.00000E+00, 0.10000E-03,
'K-feldspar  ', 0.00000E+00, 0.10000E-03,
'illite      ', 0.00000E+00, 0.50000E-05,
'analcime    ', 0.28249E-02,-0.20000E-03,
'calcite     ', 0.28249E-02,-0.20000E-03,
'chalcedony  ', 0.28249E-02,-0.20000E-03,
'NaAlSi2O6.6H', 0.28249E-02,-0.20000E-03,
```

A.59 Reaction BC Card

Card Title[a] { ~Reaction BC [Card] }
Format: *Char*[a]

Number of Boundary Segments[a]
Format: Integer[a]

For: Number of Boundary Segments
Boundary Segment Number[a], Boundary Condition Type[b] { 1 = Diriclet }
Format: Integer[a], Integer[b]

Number of Solids in Equilibrium with Solution[a],
Format: Integer[a],
For: Number of Solids in Equilibrium with Solution,
Reaction Number of Solid Reaction[a]
Format: Integer[a],
Endfor:

Number of Kinetic Reactions in Equilibrium with Solution[a],
Format: Integer[a],
For: Number of Kinetic Reactions in Equilibrium with Solution,
Reaction Number of Kinetic Reaction[a]
Format: Integer[a],
Endfor:

Number of Specified Aqueous Species Concentrations[a]
Format: Integer[a],
For: Number of Specified Aqueous Species Concentrations,
Specifiec Total Concentration[a], Number of Aqueous Species[b]
Format: Real[a], Integer[b]
Stoichiometric Coefficient of Aquous Species[a], Name of Aqueous Species[b]
Format: Real[a], Char[a],
Endfor:
Endfor:

Endcard:

A.60 Reaction BC Card Examples

```
~Reaction BC card
   1,
1,1,
   0,
   0,
   12,
  0.10000E+01,  1,
 1.0000,'H2O          ',
  0.10000E-06,  1,
 1.0000,'H+           ',
  0.15900E-03,  1,
 1.0000,'CO2(aq)      ',
  0.10000E-05,  2,
 1.0000,'Al(OH)3(aq) ',
 1.0000,'Al(OH)4-     ',
  0.10000E-04,  1,
 1.0000,'SiO2(aq)     ',
  0.10000E-05,  1,
 1.0000,'K+           ',
  0.10000E-04,  1,
 1.0000,'Na+          ',
  0.10000E-06,  1,
 1.0000,'Ca2+         ',
  0.10000E-08,  1,
 1.0000,'BO2-         ',
  0.32000E-03,  1,
 1.0000,'O2(aq)       ',
  0.10000E-08,  1,
 1.0000,'Mg(2+)       ',
  0.10000E-11,  1,
 1.0000,'TcO4(1-)     ',
```

A.61 Reaction IC card

Card Title[a] { ~Reaction IC [Card] }
Format: *Char*[a]

Number of Reaction Initial Conditions[a]
Format: Integer[a]

For: Number of Reaction Initial Conditions
Endfor:

Endcard:

A.62 Reaction IC Card Examples

```
~Reaction IC card
   0,
```

Note: the default is for the initial conditions to be equal to the inlet boundary conditions.

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This document was too large to scan as a single document. It has been divided into smaller sections.

Section 2 of 5

Document Information			
Document #	**HNF-5636**	**Revision**	**0**
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Projects			
Other Information			

APPENDIX E

Combined Review Comments:

Recommendations for Computer Code Selection of a Flow and Transport Code to be used in Undisturbed Vadose Zone Calculations For TWRS Immobilized Wastes Environmental Analyses

J. A. Voogd
Lockheed Martin Hanford Corporation

Frederick M. Mann
Fluor Daniel Northwest Company

A. J. Knepp
Bechtel Hanford, Inc.

September 11, 1998

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I. INTRODUCTION

The Tank Waste Remediation System (TWRS) is responsible for the safe storage, retrieval, and disposal of waste currently being held in 177 underground tanks at the Hanford Site. In order to successfully carry out its mission, TWRS must perform environmental analyses describing the consequences of immobilized low-activity tank waste contaminants leaving disposal facilities.

Because of the large size of the facilities and the great depth of the dry zone (known as the vadose zone) underneath the facilities, sophisticated computer codes are needed to model the transport of the contaminants. Code selection criteria were established (Mann 1998) based on the information from the low-level waste programs of the U.S. Department of Energy [DOE] (Case 1988) and of the U.S. Nuclear Regulatory Commission (Kozak 1989a) as well as experience gained in the DOE Complex [Mann 1995, WSRC 1992] in applying these criteria.

This document analyzes each of the requirements and desirable features of the three codes that were submitted for consideration, PORFLOW (ACRi 1998, Runchal 1998a), STOMP (White 1996, Nichols 1997, White 1997, Freshley 1998), and VAM3D-CG (HG (1994), Puigh 1998). This version of the recommendation includes information received after April 30, 1998, from Runchal (1998b,c) and from Connelley (1998). This document follows the format of the code selection criteria document and judges how well each of these codes meet the criteria.

- Chapter II - Mandatory Administrative Criteria: those criteria dealing with how the code is created, maintained, and used;

- Chapter III - Mandatory Technical Criteria: the technical features which the code must have; and

- Chapter IV - Desirable Features: those feature which the code should have, but the absence of which will not disqualify a code.

The proposals from each of the code proponents was reviewed and evaluated against the criteria. The results of the review are organized by the code selection criteria (Mann 1998). Also attached are results from an independent review conducted by Bechtel, San Francisco, for the Groundwater/Vadose Zone Integration Project.

The TWRS Decision Management Procedure (LMHC 1998) was followed.

II. SUMMARY AND ANALYSIS

The code selection review process recommends that ILAW proceed with the use of VAM3D-CG as the basis for vadose zone modeling efforts leading to completion of the 2001 performance assessment. This recommendation evolves from the findings described in this document. While each code presented an impressive set of features for vadose zone modeling, each code represented a unique mix of features important to the ILAW disposal program.

In summary the key features that became discriminating factors for the recommendation included:

- Acceptance by the regulatory and technical community.
- The ability to utilize the investment in staff knowledge and working relationships.

A very knowledgeable and capable staff at PNNL supports the STOMP code. The staff supporting the geotechnical data collection for the performance assessment is closely tied to staff proposing use of the STOMP code. However, the ILAW program would be taking on a significant avoidable risk by using a code that has not been formally accepted by WDOE or EPA for use in an application like the TWRS Immobilized Low-Activity Waste Disposal effort. The proposal for the STOMP code indicated a path forward for resolving this issue but the ILAW Disposal Program would be taking on additional unnecessary risk.

The PORFLOW code is well accepted by both the technical and regulatory community. In fact, PORFLOW has been used by the ILAW Performance Assessment for vadose zone calculations. However, the previous modeler is not available due to illness. Analytical and Computational Research, Inc. has indicated a willingness to establish a local capability and work with the program on modeler assignment and training. However, the need to develop new working relationships and develop understandings of the project technical and programmatic issues was a risk the project would be taking on.

The VAM3D-CG code has been accepted by the regulatory community for applications similar to ILAW disposal. Fluor Daniel Northwest, Inc. and GeoHydraulic staff are knowledgeable and available to begin working on the performance assessment. There is a concern that the current version of the code does not adequately handle radioactive decay, however, this appears to be a risk that could be quantified (approximately $10,000) and controllable by the ILAW program.

Each proposal was reviewed independently and evaluated against the specific criteria established in Mann 1998. The proposals were largely reviewed as written with some credit given based upon the experience and judgment of the reviewer. Criteria for the Mandatory Administrative features and Mandatory Technical features were evaluated on a met/not met basis. The Desirable Features were presented on a percentage basis. For two of the reviewers this percentage was based upon judgment, for the third reviewer the value represents the percentage of desirable feature attributes met by the code. Input from three independent reviewers was combined as shown in Table 1. The review data collection, analysis and final recommendation was performed by the ILAW Program Office.

Table 1.

SUMMARY OF RECOMMENDATIONS

Section	Description	PORFLOW	STOMP	VAM3D-CG
Administrative Criteria				
II-A	Technical Documentation	Met/Met/Met	Met/Met/Met	Met/Met/Met
II-B	Code Availability	Met/Met/Met	Met/Met/Met	Met/Met/Met
II-C	Configuration Control	Met/Met/Met	Met/Met/Met	Met/Met/Met
II-D	Input Flexibility	Met/Met/Met	Met/Met/Met	Met/Met/Met
II-E	Real-Time Monitoring/Restart capabilities	Met/Met/Met	Met/Met/Met	Met/Met/Met
Technical Criteria				
III-A	Moisture Flow	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-B	Contaminant Transport	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-C	Boundary Conditions	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-D	Source Term	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-E	Hydrologic Properties	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-F	Geochemical Model	Met/Met/Met	Met/Met/Not	Met/Met/Met
III-G	Time-Dependent Hydraulic and Geochemical Values	Met/Met/Met	Met/Met/Not	Met/Met/Met
III-H	Layering	Met/Met/Met	Met/Met/Met	Met/Met/Met
III-I	Output	Met/Met/Met	Not/Not/Not	Met/Met/Met
III-J	Interface Between Moisture Flow and Contaminant Transport	Met/Met/Met	Met/Met/Met	Met/Met/Met
Desirable Features				
IV-A	Ease of use	40% 60% 100%	50% 30% 100%	50% 60% 00%
IV-B	Certification – Verification – Benchmarking	80% 80% 100%	100% 80% 100%	100% 100% 100%
IV-C	Reputation Among User Community	60% 90% 60%	25% 50% 60%	95% 90% 80%
IV-D	Additional Contaminant Transport Capabilities	80% 80% 100%	60% 60% 30%	75% 80% 30%
IV-E	Additional Moisture Flow Capabilities	35% 70% 66%	100% 70% 66%	100% 70% 66%
IV-F	Decay Products	90% 100% 100%	90% 100% 100%	40% 50% 0%
IV-G	User Support	50% 75% 100%	80% 75% 100%	90% 90% 100%
IV-H	Speed of Execution	N/A	N/A	N/A
IV-I	Proprietary Codes	50% 50% 100%	75% 75% 100%	50% 50% 100%
IV-J	Version	75% 75% 100%	90% 75% 100%	100% 90% 100%

The recommendation for the code was made after assuring that a code could meet all of the mandatory criteria then establishing a preferred code from comparison of the desirable features. All three codes were able to meet all of the Mandatory Administrative Criteria. The Mandatory Technical Criteria provided some discrimination between codes with one code failing to meet all of the Mandatory Technical Criteria. Discrimination between the codes became more apparent in the Desirable Features and the presentation of the proposals from each of the potential code suppliers.

Evaluation of the Mandatory Technical Criteria lead to the following:

1. PORFLOW was judged to meet all of the Mandatory Technical Criteria.

2. STOMP was judged unable to meet the Mandatory Technical Criteria for output. The specific technical criteria identified a need to provide mass balance and mass balance errors at each time step. The proposal states "The current released version of the STOMP simulator does not provide mass balance information after time step . . ." In addition, one reviewer judged that STOMP was unable to meet criteria for III-F Geochemical Models. A basis for this judgment was not provided by the reviewer and, therefore, was not a factor in the recommendation. STOMP was judged not to meet criteria III-G Time-Dependent Hydraulic and Geochemical Values by one reviewer. No basis for this judgment was provided by the reviewer, however, the STOMP submittal states "The current released version of the STOMP simulator can only accommodate time-dependent hydraulic and geochemical values through modification of rock/soil properties through the restart function."

3. VAM3D-CG was judged to meet all of the mandatory Technical Criteria.

The Desirable Features were evaluated on a comparative basis:

1. PORFLOW was distinguished by its ability provide Additional Contaminant Transport Capabilities and Decay Products. The factor that significantly affected the scoring for Ease of Use and User Support is lack of experienced PORFLOW users onsite that are also familiar with the ILAW disposal effort and the ILAW Performance Assessment in particular.

2. STOMP was distinguished by its ability to provide Decay Products and the absence of a fully proprietary Code. The factor that significantly affected scoring for Reputation among User Community was absence of regulatory acceptance and wide commercial use of the code.

3. VAM3D-CG was distinguished by its Certification-Verification-Benchmarking and Reputation among the User Community. VAM3D-CG scored poorly for its handling of decay products. The proposal indicated that this deficiency in VAM3D-CG could be remedied through several different methods for approximately $10,000.
Based upon the factors noted, VAM3D-CG is recommended for use leading to completion of the 2001 ILAW Performance Assessment.

III. MANDATORY ADMINISTRATIVE CRITERIA

These criteria deal with how the code is created, maintained, and used.

A. Technical Documentation

1. **Requirements.** The proponent of the code shall submit the documentation that describes
   - model theory, governing equations, and assumptions,
   - computational techniques and algorithms,
   - code verification,
   - user input, and
   - example applications

   The items listed above to the cognizant engineer along with a notation describing the location of each required item.

   It is recognized that the current version of the code may not have all the documentation at the time of code selection. If this is the case, the proponent shall supply documentation for the latest version of the code for which documentation exists along with a schedule of the expected availability of documentation for the current code version.

   General note: Verification documentation deals mainly with benchmarking tests (analytical and other codes) rather than code verification in computer science.

2. **PORFLOW.** Met/Met. Proposal (1998a) states that two documents exist, but do not reference them. However, ACRi 1998 does describe governing equations (Chapter 2), numerical basis (Chapter 4), and user input (Chapters 5, 6, and 7). Validation manual on web site could not be downloaded. Verification and benchmarking manual that was to be sent has not been received. Revised proposal (Runchal 1998b) references the documents, which were sent by E-mail.

   The online manual describes Version 3.5, while Version 4.0 is being proposed. There is no indication when documentation for Version 4.0 would be available. The revised proposal sent the Version 4.0 manual, which is substantially the same as the Version 3.5.

   An electronic copy of the Manual containing all the above items was sent as an attachment. In addition, a verification and benchmarking manual was mailed. (unable to open)

3. **STOMP.** Met/Met. Model theory, governing equations and assumptions, and computational techniques and algorithms are described in White 1996. User input is described in White (1997). Code verification and example applications are presented in Nichols (1997). Documents are cited by proponents, which is adequate since each document deals with specified component.

   Code is "continuously being upgraded and modified" (proponents' submittal for this requirement). Updated documentation is available on web site (which was checked) and will be incorporated in revisions.

   Pg. 2, A. The STOMP simulator is documented through three published guide manuals: application, theory, and users. Technical documentation descriptions of the code's governing equations, constitutive relations (secondary equations), primary assumptions, and numerical solutions techniques are provided in the STOMP Theory Guide (White and Oostrom 1996).

4. **VAM3D-CG.** Met/Met. Model theory, computational techniques and algorithms, code verification, user input, and example applications are given in HG (1994). The proponents described the location for each item. The version being proposed (3.1) is the one for which documentation was submitted.

   Technical documentation is included in Appendix A (Documentation and User's Guide):

   - Model theory, governing equations and assumptions: pg. 2-1 through 2-26
   - Computational techniques and algorithms: pg. 3-1 through 3-30
   - Code verification: pg. 4-1 through 4-67
   - User input: pg. 8-1 through 8-49
   - Example applications: pg. 4-1 through 4-67

B. Code Availability

1. **Requirements.** The proponent of the code shall document the availability of the executable version of the code and list those computers (and operating systems) on which it will run.

   Satisfactory computer hardware are Intel-compatible processors using the Windows or NT operating system or Sun/SGI/HP computers using the UNIX operating system. Large parallel systems (having more than four processors) will not be considered.

2. **PORFLOW.** Met/Met. Claim installations on UNIX and Intel PCS under Windows.

   PORFLOW Simulation Tool is available for practically any computer and operating systems; the installations have included:

1. Intel x-86 and Pentium processors
2. IBM RISC
3. Sun
4. HP
5. SGI
6-9. Others

Among the current installations are those on:

1. Windows 95
2. Windows NT
4. UNIX (including variations from IBM, HP, SUM, SGI, DEC)

3. **STOMP.** Met/Met. Code has been compiled on a number of UNIX computers without warning messages. However, code proponents do not state on which the code has been shown to run. A subsequent E-mail indicates that the code runs on various UNIX machines and INTEL PCS.

   Pg. 3, B, The U.S. Department of Energy has granted copyright for the software to Battelle Memorial Institute (Battelle), with the stipulation that the simulator be made available to Federal and State agencies through the Energy and Science Technology Software Center or alternate route without royalties to Battelle. . . . The code has previously been compiled on NIX base operating systems around the world and currently compiles free of warning messages.

4. **VAM3D-CG.** Met/Met. Code is available on SGI UNIX and Intel PC computers.

   The executable version of VAM3D-CG Version 3.1 is available for use by on site on the Silicon Graphics, Inc. workstation operating under the UNIX system. Appendices B & C provide the verification and benchmarking information for VAM3D-CG installed on the SGI workstation.

   VAM3D-CG version is also available for use by FDNW on an INTEL PC operating under Windows NT4.0. The code has been verified and benchmarked for the INTEL platform for use in the 200 Areas low-level solid waste performance assessment maintenance activities.

C. Configuration Control

1. **Requirement.** The proponent of the code must submit the software quality management program plan for the code.

2. **PORFLOW.** Met/Met. Original proposal (Runchal 1998a) stated that code is designed to meet "ASME Software QA criteria," but no reference given. Revised proposal (Runchal 1998b) provides a QA procedure which is acceptable.

3. **STOMP.** Met/Met. Submitted acceptable configuration management plan based on IEEE standards.

   Pg. 4, C. The STOMP Configuration Management Plan is a version of the IEEE Std. 828-1990, "Software Configuration management Plans." . . . In brief, version control for the STOMP simulator was initiated on June 19, 1997, using the Revision Control System (RCS) utility on the "muse" cluster of IBM RISC 6000s at the PNNL. RCS is a conventional UNIX utility, which is designed to keep track of multiple file revisions.

4. **VAM3D-CG.** Met/Met. Plans are consistent with Fluor Daniel Hanford requirements, to which Lockheed Martin Hanford Corporation is a subcontractor.

   Configuration control for VAM3D-CG Version 3.1 is maintained per . . . FDNW practice 134.200.0960, "Control of Engineering Software," . . . and assures that the control is consistent with Fluor Daniel Hanford "Configuration Management Plan," HNF-MP-013, Rev. 0, and "Quality Assurance Plan," HNF-MP-014, Rev.1.

D. Input Flexibility

1. **Requirements.** The proponent of the code must show that the code can accept input that is site- and facility-specific.

2. **PORFLOW.** Met/Met. Proposal not responsive. However, online manual (ACRi 1998) indicates that input is site- and facility-specific (MATE card in Chapter 7 of ACRi 1998).

   "PORFLOW provides the most comprehensive set of input options and flexibility of any such code currently available. Among these are:

   1. Over 20 options for soil-moisture and conductivity's

   2. Built-in functions (space, time, or phase variable) for:

      - Boundary conditions
      - Initial conditions
      - Field conditions
      - Sources
      - Properties (fluid density, fluid viscosity, storativity, diffusivity, specific heat).

3. **STOMP.** Met/Met. Input manual (White 1996) indicates that all parameters can be submitted. An example is cited where each grid cell had different parameter set. Pg. 4, D, A primary assumption associated with this numerical scheme is that all physical properties within each grid cell are represented by their values at the cell centroid. In respect, each grid cell is identified with a rock/soil type, which relates geohydrologic properties to the grid cell. Table 1, pg. 5 lists the User Defined Rock/Soil properties.

3. **VAM3D-CG.** Met/Met. Input manual (Section 8 Input Data Preparation of HG 1944) indicates that all parameters can be submitted. Examples are provided where site- and facility-specific data are used.

4. VAM3D-CG does not use any generic data as input for either the site or the facility. The code can use Hanford site-specific data and vadose zone parameters.

E. Real-Time Monitoring/Restart Capabilities

1. **Requirements.** The proponent of the code shall document the real-time diagnostic and restart capability of the code. The monitoring activity can be satisfied by time stamps written to a file.

2. **PORFLOW.** Met. See ACRi 1998, particularly Section 6.4.

PORFLOW provides extensive real-time monitoring and restart capabilities. Among its monitoring capabilities are:

1. Step number and time
2. Any of the phase variables
3. The change in any variable
4. The residual of any of the equations
5. The flux balance for any of the equations.

Any combination of any of these can be monitored at any given time or with any given equency.

PORFLOW provides two types of files, which can be used, for restarting.

3. **STOMP.** Met/Met. Real-time monitoring performed by writing a user-chosen subset of cells to special files (documented in Section 7.2 of White 1977). Restart files are created in every run and can be generated at user selected times (documented in Section 7.5 of White 1997). Restart runs are denoted on Solution Control Card (Appendix A.2).

Pg. 6, E, For real-time monitoring the user can specify particular grid cells within the computational domain as reference nodes. Reference node output is written to

standard output (e.g., typically the screen) and an output file called "output." Every STOMP simulation concludes with the creation of a restart file . . . For example, the restart file entitled "restart.342" would have been created at the conclusion of time step number 342.

4. **VAM3D-CG.** Met/Met. Capabilities involve use of special history files (Section 8.4 Special History Files). Restart capabilities are stated in Section 6.5, "Restart Procedures."

   The real-time monitoring capability is controlled via input data preparation and is described in pg. 8-44 and 8-45 (Appendix A). A restart option is provided in the code for continuation of solution to time-dependent problems.

IV. MANDATORY TECHNICAL CRITERIA

These criteria are the technical features, which the code must have. In general, the theoretical framework of the code shall be based on appropriate scientific principles (e.g., conservation of mass, momentum, and energy) and well established engineering equations (e.g., Darcy's law, lick's law).

A. Moisture Flow

1. **Requirements.** The proponent of the code shall document that the code can perform two- and three-dimensional modeling of unsaturated, constant density moisture flow in an isothermal setting, both under steady state and transient conditions. The code proponent shall supply the authors, titles, and document identifiers of some published papers or reports that document use of the code to model moisture flow.

2. **PORFLOW.** Met/Met. See online manual, particularly Chapter 1. A partial list of publication reports was sent with proposal, including Hanford Site applications. PORFLOW has been used widely to perform simulation under conditions of:

   - 2D & 3D Geometry
   - Steady and transient flow
   - Unsaturated and saturated flow
   - Constant and varying density
   - Isothermal and non-isothermal conditions.
   - A partial list of publications is included (por_pub.doc).

3. **STOMP.** Met/Met. The code can model moisture flow (see White 1996). Two/three dimensional is determined by grid card (A3 of White 1997). All calculations are transient, thus making steady-state calculations a special case.

   Examples are provided.

   Pg. 7, A, . . . the STOMP simulator operates on Cartesian and vertically oriented cylindrical grid domains of either one, two, or three dimensions. The STOMP simulator has robust capabilities for modeling multiple-, pseudo multiple- and single-phase fluid flow through subsurface environments. All STOMP simulations are technically transient where the time step is controlled by user specified limitations or by the nonlineartities of the particular problem. Steady-state solutions are obtained by simulating from an initial condition through a transient solution until steady conditions are achieved.

   References Las Cruces Trench Site - Rockhold, Yucca Mountain - Eslinger, Edwards AFB - White and Gilmore, SX-109 - Ward, water through vadose zone of low-level radioactive waste disposal sites - Meyer.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation) and from examples of HG (1994) (Example Verification and Application Problems). Hanford Site applications show capability.

   VAM3D-CG is capable of simulating two- and three-dimensional unsaturated flow of water of a constant density in an isothermal setting under both steady state and transient flow-field conditions, particularly under conditions expected at the Hanford Site. . . . The ability to model moisture flow under both steady state and transient flowfield conditions at the Hanford Site is documented in 200E Burial Grounds PA (Wood, et al. 1996), 200W Burial Grounds PA (Wood, et al. 1995b), ERDF PA (Wood, et al. 1995a) and TWRS EIS (DOE 1996).

B. Contaminant Transport

1. **Requirements.** The proponent of the code shall document that the code can simulate contaminant transport in two- and three-dimensions as a function of hydrologic conditions established by the moisture flow subsystem and by advection, hydrodynamic dispersion, molecular diffusion, or adsorption. The code proponent shall supply the authors, titles, and document numbers of some published papers or reports that document use of the code to model contaminant transport.

2. **PORFLOW.** Met/Met. See online manual, particularly Chapter 1. A partial list of publication reports was sent with proposal, including Hanford Site applications. "PORFLOW provides for a very comprehensive set of options for transport of contaminants." List provided.

3. **STOMP.** Met/Met. The code can model contaminant transport (see White 1996). Two/three dimensional is determined by grid card (A3 of White 1997).

   Two-dimensional examples are provided.

   - Per the STOMP Application, Theory, and User's Guides, the STOMP simulator solves the governing equation for solute transport over multiple phases. Solutes are assumed to be transported via advection, hydrodynamic dispersion, and molecular diffusion.

   - Las Cruces Trench Site, those of strontium transport at the 100-N Area, Hanford Site, and the investigations of soluted-transport solution scheme are three pertinent examples of STOP generate solution to two dimensional solute transport problems.

   (Note 3D not discussed).

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation) and from examples of HG (1994) (Example Verification and Application Problems). Hanford Site applications show capability.

   VAM3D-CG is capable of simulating two-/three-dimensional contaminant transport (including advection, hydrodynamic dispersion, molecular diffusion, decay, and adsorption). The ability to model contaminant transport at the Hanford Site is documented in 200E Burial Grounds PA (Wood, et al. 1996), 200W Burial Grounds PA (Wood, et. al 1995b), ERDF PA (Wood, et al. 1995a) and TWRS EIS (DOE 1996).

C. Boundary Conditions

1. **Requirements.** The proponent of the code shall document the code's ability to simulate moisture flow for an infiltration rate which varies with time. The proponent shall also document that the code is capable of simulating homogeneous and non-homogeneous Dirichlet and Neumann boundary conditions. It shall be possible to configure the boundary conditions to simulate either upward or downward migration and fate of contaminants.

2. **PORFLOW.** Met/Met. See discussion of BOUN card in Chapter 7 of ACRi 1998.

   Dirichlet type, Neumann, Mixed Radiation, Open boundary, and switching between the Dirilicht & Neumann.

   Boundary conditions can vary as arbitrary functions of time, space phase variables, user defined variables. Boundary conditions can be imposed in any manner and combination, such as:

   - element by element
   - material type
   - block elements
   - whole boundary directed by direction cosines.

3. **STOMP.** Met/Met. Boundary conditions are defined on Boundary Conditions card (Section A.20 of White 1997).

   Pg 8, C. 1) All surfaces on the exterior boundaries of the computational domain require boundary conditions; 4) Boundary conditions variables can be defined as time dependent or constant . . . Beyond these basic rules, the user is free to specify boundary conditions as needed.

   . . . if a user created a one-dimensional simulation and attempted to declare inward flow boundaries (Neumann-type boundary conditions) on both ends of the domain,

STOMP would attempt to find an aqueous pressure solution to the problem. . . . The 'Initial Condition' type boundary condition is a special form of the Dirichlet boundary condition, where the value of the boundary surface variable is set equal to the initial value of the field variable at the node adjacent to the boundary surface.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation) and from examples of HG (1994) (Example Verification and Application Problems). Hanford Site applications show capability.

   A time-dependent boundary condition is handled via Group 17 input data (pg. 8-2, 8-32, 8-33, Appendix A), "Transient flux boundary condition." Other boundary conditions including Dirichlet and Neumann, boundary conditions, are handled via Groups 15 and 16 (pg. 8-2, 8-29, through 8-31; Appendix A) input data.

D. Source Term

1. **Requirements.** The proponent of the code shall document the code can accept a specified time-dependent release rate from one or more volume sources and from disconnected surface sources and then simulate the release until the inventory is depleted.

2. **PORFLOW.** Met/Met. The original proposal (Runchal 1998a) was not responsive. The capabilities are probably contained in SOUR card (Chapter 7 of ACRi 1998), but proposal provides only generalities. The revised proposal (Runchal 1998b) confirmed that the SOUR card does contain information.

   "The SOURce command with TABLe and TIME modifier meets the requirements as stated. In fact, any functional relationship can be specified by the SOURce command or in combination with ALLOCate, SET, and SOURce commands."

3. **STOMP.** Met/Met. Source terms conditions are defined on Source Conditions card (Section A.21 of White 1997). Disconnected surface sources must be modeled at the boundary between active and inactive cells. User inputs explicit time history.

   "As documented in the STOMP User's Guide, source can be specified as time dependent with unique start and stop times. Unlike boundary conditions, multiple sources can be specified for a single grid cell and most source types offer two specification options, volume dependent, and independent."

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation) and from examples of HG (1994) (Example Verification and Application Problems). User inputs explicit source history.

   VAM3D-CG is capable of simulating specified time-dependent release rates from one or more volume sources and from disconnected surface sources. Such

capability is handled via Group 18I input data input data and prescribing variables NDCSRC (number of sources to be considered) and TLDCS contaminant release time duration (pg. 8-33; Appendix A).

E. Hydrologic Properties

1. **Requirements.** The proponent of the code shall document that the code has the capability to use the van Genutchen - Mualem relationships to represent moisture retention and unsaturated conductivity functions in the simulation of moisture movement and that the code has the ability to have different values in each user chosen zone.

2. **PORFLOW.** Met/Met. The original proposal (Runchal 1998a) indicates that PORFLOW has van Genutchen/Mualem relationships and past Hanford Site applications have used this feature. Chapter 3.3 and 3.5 of ACRi 1998 indicate that van Genuchten and Mualem relationships, respectively, are supported by the code. However, the proposal does not indicate where in the manual nor is it obvious which input card contains information. The revised proposed (Runchal 1998b) Providees that the option is available with the MULTphase command using the VAN and MUALem modifiers.

   "The MULTiphase command with VAN and MUALem modifiers meets the requirements as stated."

3. **STOMP.** Met/Met. Van-Genutchen/Mualem representations can be specified by proper choices on Saturation Function Card (Section 1.9 of White 1997) and on Aqueous Relative Permeability Card (Section A.10). Each grid could have a different property.

   Hydrologic properties are specified for rock/soil types, which in turn are specified across domains of grid cells. Table 3 identifies Saturation-Capillary Pressure (s-P) function options. Table 4 identifies Aqueous Relative permeability-Saturation (k-s) function options.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation). Hanford Site applications show capability.

   VAM3D-CG can use either table lookup or van Genuchten-Mualem relationships to represent moisture retention and unsaturated hydraulic conductivity functions. VAM3D-CG has the capability to assign van Genuchten-Mualem parameters by different material types.

F. Geochemical Model

1. **Requirements.** The proponent of the code shall document that the code can simulate geochemical retardation using the linear sorption isotherm model where K_d only depends on the contaminant and the spatial position.

2. **PORFLOW.** Met/Met. The original proposal (Runchal 1998a) indicates that PORFLOW can use the linear sorption isotherm model and past Hanford Site applications have used this feature. However, the proposal does not indicate where in the manual nor is it obvious which input card contains information. The revised proposal (Runchal 1998b) states that ability is present using TRANsport, PROPerty, DISTribution, and RETArdation commands.

   "The linear sorption isotherm model is invoked by an appropriate selection of TRANsport (constant kd or Rd for each material type), PROPerty (to interpret input as kd or Rd), ISTribution (kd as a function), RETArdation (Rd as function) commands. In addition, non-linear isotherm can be specified by a combination of DISTribution, RETArdation, and REACtion commands."

3. **STOMP.** Met/Met. Kd values can be specified on Solute/Porous Media Interaction Card (Section A.18 of White 1997) for each rock type.
   As referenced in the STOMP User's and Theory Guide, the STOMP simulator transports solutes as a function of the solute and rock/soil type according to a linear adsorption isotherm model. . . . additionally allow solute transport via the Freundlich and Langmuir adsorption models.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation). Hanford Site applications show capability. Note RPROG(I,2) specifies Kd.

   "VAM3D-CG can simulate geochemical retardation using the linear sorption isotherm or Kd model where the value of Kd depends on the contaminant and on the spatial location. Such a capability is handled via Group 11 input data and prescribing data for PROP(J,4) for each contaminant species being modeled (pg. 8-18; Appendix A). VAM3D-CG has the capability to assign Kds by material types."

G. Time-Dependent Hydraulic and Geochemical Values

1. **Requirements.** The proponent of the code shall document the ability of the code to simulate changes in hydrogeologic and geochemical properties which are an explicit function of time.

2. **PORFLOW.** Met/Met. The original proposal (Runchal 1998a) indicates that PORFLOW can use time-dependent variables. Past Hanford Site applications have used the restart feature instead. However, proposal does not indicate place in manual nor is it obvious which input card contains information. The revised proposal (Runchal 1998b) states that ability is present using STORativity, DISTribution, RETArdation, and VISCOsity commands.

   See assessment above. "In addition, RESTart feature and MATEreal type designation can be used to assign step-wise changes in properties with time."

3. **STOMP.** Met/Met. Uses restart capability.

"The current released version of the STOMP simulator can only accommodate time-dependent hydraulic and geochemical values through modification of rock/soil properties through the restart function. . . . requires the user to use the restart function . . . Drastic changes in rock/soil properties could result in convergence problems upon restart . . ."

"An alternative would be to modify the simulator to accept time-dependent input for the rock/soil properties. . . . This modification would eliminate the need to halt and restart the simulation as all the rock/soil property transitions could be specified within the input file. A modification of this nature would require approximately one to two man-weeks to implement . . ."

4. **VAM3D-CG.** Met/Met. Uses restart capability.

"VAM3D-CG can simulate time-dependence of hydraulic and geochemical parameters for the engineered facility. Such a capability is accomplished by controlling Group 6 "Temporal discretization data" (pg. 8-12; Appendix A) and invoking the restart option."

H. Layering

1. **Requirements.** The proponent of the code shall document that the code can readily simulate:

   - geologic or engineered layering (including structures),
   - heterogenous features, and
   - anisotropic conditions that would affect moisture flow or contaminant transport.

   The layering shall not be restricted to a horizontal representation.

2. **PORFLOW.** Met/Met. No reference was given in the original proposal (Runchal 1998a) to check that capabilities presence. The revised proposal (Runchal 1998b) documents such capabilities.

   Each material type is assigned with a MATEreal command. Each type may be arbitrarily located and may be contiguous or non-contiguous in any geometric shapes. Multiple commands with the same material type may be used to handle spatial non-uniformity.

   Properties can be assigned to each material type in a heterogenoeus manner.

   For each material type anisotropic properties can be assigned with HYDRaulic, THERmal, and TRANsport commands.

Additional complexity can also be accommodated with STOR, DIST, RETA, and VISC commands.

3. **STOMP.** Met/Met. Uses orthogonal grid systems to define geometry. Nonuniform spacing allowed (Section 4.5.3 of White 1997). Heterogeneous features can be specified as each cell can have different properties. Anisotropic moisture conditions specified by hydraulic properties card (Section A.7 of White 1997).

   All geologic features and engineered structures below the ground surface can be incorporated into a geohydrologic conceptual model for the STOMP simulator with the restriction that the shape of such structures are approximated by grid cells defined by the computational grid.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation). Savannah River Site application shows layering capability.

   VAM3D-CG uses curvilinear grid and transition elements to represent inclined geologic formations and complex geometries such as the engineered system. Unlike finite-difference and integrated finite difference models (e.g., PORFLO), use of finite-element discretization and curvilinear grids in VAM3D-CG avoids "stair-stepping" to represent inclined boundaries.

   The use of curvilinear grid and transition elements is invoked via Group 3 ICURVL input parameter and Group curvilinear mesh data.

   The heterogeneities in geologic formations are modeled in VAM3D-CG via variable NMAT. The anisotropic behavior in saturated media flow and transport properties is modeled in VAM3D-CG via Group 9 input data for the principal components of saturated hydrualic conductivity tensor and Group 11 transport parameters.

I. Output

1. **Requirements.** The proponent of the code shall document that the code can provide moisture content throughout model domain and contaminant concentration and flux at user chosen points, internal surfaces, and/or along boundary segments; all as functions of time as well as be able to calculate flow lines for user chosen source points. The code shall be able to report mass balance and mass balance errors at each time step.

2. **PORFLOW.** Met/Met. No reference was given in the original proposal (Runchal 1998a) to check that capabilities presence. No indication in proposal mass balance is outputted, but past Hanford applications indicate that this is done. The revised proposal (Runchal 1998b) does document capabilities.

3. **STOMP.** Potentially not met/Not. Most output options allowed (see exceptions below). Mass balance errors are a user-specified value (however, where value is specified could not be found). Flowlines would have to be calculated using external software, but is discouraged.

   Two principal output mechanisms for the simulator are reference nodes and plot files. Reference nodes allow the user to specify that a collection of variables are printed or displayed for a number of grid cells after an interval of converged time step.

   The current released version of the STOMP simulator does not provide mass balance information after each time step and does not provide flow-line calculations from selected points.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation). Output at user chosen points, internal surfaces, and/or along boundary segments is handled by VAM3D-CG. TECPLOT (document not supplied) creates flowlines as demonstrated in Hanford Site application. Mass balance input defined in Section 8.

   VAM3D-CG outputs on moisture contents through model domain, contaminant concentrations, and fluxes at user-chosen points (specified nodes), internal surfaces and/or along boundary segments, all as functions of time, are controlled via Group 5 input variables . . . .

   Via TECPLOT, the code is able to draw flow lines for user chosen source points. TECPLOT is a commercial graphical package . . . VAM3D-CG is able to report mass balance errors at each time step for both flow and transport; the option is invoked by setting IMBAL=1 on Group 5 input data.

J. Interface Between Moisture Flow and Contaminant Transport

1. **Requirements.** The proponent of the code shall document that the code is able to perform a moisture flow simulation only, a steady-state contaminant transport simulation based on a previously run moisture flow calculation, and a combined moisture flow/contaminant transport simulation performs. The proponent shall also document that redundant information is not needed for a combined moisture flow/contaminant transport simulation.

2. **PORFLOW.** Met/Met. The original proposal (Runchal 1998a) indicates that requirement met and past Hanford Site applications also indicate that requirement is met. The revised proposal (Runchal 1998b) documents use of SOLVE, SAVE, and RESTART commands.

3. **STOMP.** Met/Met. Solution Control Card (Section A.2 of White 1997).
As referenced in the STOMP User's Guide, the STOMP simulator has options for executing a flow only simulation, a transport only simulation, or a combined flow and transport simulation. . . . Sequencing the solute transport equation solutions allow for first order chemical reactions and radioactive chain decay, but does not allow for complex chemical systems to be resolved. . . .Converting between the three different simulation types only requires single word modification to the input file; no duplication of input file variables is required.

4. **VAM3D-CG.** Met/Met. From Section 8 of HG (1994) (Input Data Preparation).
VAM3D-CG can perform a moisture flow simulation only, a steady-state contaminant transport simulation based on a previously run moisture flow simulation and a combined moisture flow/contaminant transport simulation. Note that for a combined VAM3D-CG moisture flow/contaminant transport simulation, only one set of input file is required; no redundant input files is required.

V. DESIRABLE FEATURES

These items are features which the code should have, but the absence of which will not disqualify a code. However, code selection will depend on the applicability of these desired features. Notably poor performance on a desired feature (such as excessive cost) can be reason for code disqualification. The following sections are listed in order of priority.

A. Ease of Use

1. **Criteria.** The proponent of the code shall document the pre- and post-processing modules that aid user's use of the code and the user's understanding of the output of the code. In particular, the capability to graphically display the numerical grid discretization along with zone identifiers, the contaminant, and moisture fluxes across selected boundaries and/or regions in the modeling domain and contours, spatial cross sections, and time histories of contaminant concentrations is highly desired. The pre- and post-processing systems can be commercial or public domain products not developed by those responsible for the vadose zone code.

   (General note: responses poorly documented ease of use.)

2. **PORFLOW.** 40%/60%. A GUI (undescribed and undocumented) is available for Windows 95 and NT operating systems and is under development for UNIX. A post-processor is available, but is not described or documented. Because of output format, third party software can be used. The validation documentation could not be downloaded from the website. Because of illness, there is no experienced user of PORFLOW in the Hanford Site community and the proposal was submitted by the code developer. Based on proposal's lack of responsiveness, the difficulty of interface with nonlocal users and lack of providing helpful information, ranking is downrated.

   PORFLOW provides on-line manual for problem setup and an acrSHELL work environment. The acr PLOT post processor provides for XY, Vector, Contour, Raster, 3D Surface, and Profile plots. In addition, PORFLOW provides an open file format which has been integrated with powerful post-processing packages such as TECPLOT, SURFER, PLOT3D, etc.

   The code developer has indicated a willingness to establish a local office and provide a senior knowledgeable staff should PORFLOW be chosen.

3. **STOMP.** 50%/60%. Input format is flexible and is checked by code. A graphical interface is available for Macintosh (which is not hardware under consideration). A link between GIS and input is under development. Several undocumented post-processing utilities are available. However, calculation of flowlines (a mandatory requirement) is difficult and is discouraged. Property changes require restarting

the run rather than a smooth transition during a run. Downrated because of lack of specificity and comparison to other codes.

The simulator contains a considerable amount of error check utilities and will provide the user with information about the type of error that was discovered.

This utility (GEOSTOMP) will provide an interface between geologic data contained in GIS or Earth vision, geohydrologic descriptions of the rock/soil types . . . .

Several undocumented post process utilities have been written for the STOMP simulator, that are primarily used to convert output in the "output" and "plot" files to formats required for plotting or visualizing.

PNNL has a local staff knowledgeable of the program, however, code is the least developed of the alternatives.

4. **VAM3D-CG.** 50%/70%. Undocumented pre- and post-processors are available. The use of curvilinear coordinates is a significant feature given that structural components and geologic layers will not be parallel to surface or to each other. However, property changes require restarting the run rather than a smooth transition during a run. Downrated because of lack of specificity and comparison to other codes.

   RETC is a code that provides best fit curve to measured data on soil hydraulic properties . . . . VAMGEN is a customized pre-processor which generates a geometry of the numerical grid discretization along with zone identifiers. VAM2TEC is a post-processor that reads the output files . . . and formats the data for use with the graphical package TECPLOT to display . . . .In addition, at HGL, VAM3D-CG is fully integrated with ARGUS MESH MAKER . . . to generate finite-element mesh with GIS interface.

   Some local staff is available through FDNW and teaming with Hydro Geologic, Inc.

B. Certification/Verification/Benchmarking

1. **Criteria.** The proponent of the code shall supply documentation of such testing. The experimental data need not be from the Hanford Site, but should reflect similar environmental conditions (dryness, geochemistry). The proponent shall also supply any information concerning verification/benchmarking simulations against other codes which are relevant for Hanford Site vadose zone-like conditions.

2. **PORFLOW.** 80%/80%. Validation document could not be downloaded from web site. Alternate website could not be contacted. The proposal states a large number of users of the code, but provides no references to documents providing

certification, verification, and benchmarking data in this section. List of publications does provide some (including Hanford Site) references. Because of its use in 98 ILAW PA, PORFLOW is known to have a well documented testing base. Downrated because of poorness of response. Even revised proposal (Runchal 1998c) does not provide references.

3. **STOMP.** 100%/80%. The proposal referenced and supplied good documentation on benchmarking. Documents are cited for Hanford Site-relevant conditions including the relevant simulation of the Sisson-Lu experiment.

   Although the verification process has been formally documented in the STOMP Application Guide, the simulator continues to be compared against analytic solutions, numerical solutions, and experimental data.

   With respect to benchmarking against field experiments at the Hanford Site, the simulator was applied against the injection experiment of Sisson and Lu. There is implied benchmarking against Las Cruces Trench Site.

4. **VAM3D-CG.** 100%/100%. The proposal referenced and supplied good document action on benchmarking. Documents are cited for Hanford Site-relevant conditions including the relevant simulation of the Sisson-Lu experiment.

   Detailed information on VAM3D-CG certification, verification, and benchmarking for the Hanford Site is provided in Appendices B and C. Additional testing of VAM3D-CG using data from a field experiment (Sisson and Lu 1984) in 200 East Area is described by Lu and Khaleel (1993). Additional benchmarking and testing identified . . . .

C. Reputation Among User Community

1. **Criteria.** The proponent of the code shall document examples of use of the code beyond the developing organization. The proponent shall document whether the code has been accepted by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) for environmental analyses for the Hanford Site. If the code has not been accepted, then the proponent shall indicate plans for achieving such acceptance. The code proponent shall supply the authors, title, and document identifiers of some of the reports which have used the code to model moisture flow and contaminant transport in the Hanford Site vadose zone. The proponent shall indicate for each report cited the type of external review that was conducted. Such external reviews shall be provided if requested.

2. **PORFLOW.** 60%/100%. The proposal notes that PORFLOW has been used by a wide variety of users. Although unstated by the proposal, but of significant importance, is the use of PORFLOW in the 98 ILAW PA (Mann 1998) as well as performance assessments at other DOE sites. The proposal makes no acknowledgment of acceptance of the code by the EPA or Ecology for use at the

Hanford Site, although a earlier version has been accepted for Hanford Site use by the two agencies. The proposal does not "indicate for each report cited the type of external review that was conducted." Even though PORFLOW has an extremely high reputation among the user community, the proposal was downrated because of lack of responsiveness.

The proposal included a long list of users and references including the U.S. Nuclear Regulatory Commission (NRC) and numerous DOE contractors.

3. **STOMP.** 25/50%. As noted by the proposal, because of the newness of the code, STOMP has not yet developed a large user reputation. However, it was used by the Hanford Site Environmental Remediation Contractor (although not for 200E Area analyses) and by a member of the NRC staff. Significant concerns are that the output files contain the disclaimer "Results from this version of STOMP should not be used for license related applications." The analyses to be performed, if not "license related applications," are at the same level as they will be reviewed as part of a regulatory decision making process by the DOE, the NRC, and Ecology. The proposal notes discussion has been held with EPA concerning the use of STOMP on Hanford Site analyses, but makes no indication whether conversations have been held with Ecology (the lead agency for most of our activities). Downrated because of lack of acceptance in user community, "license-related" remark, and because of lack of discussions with Ecology.

   The simulator has gained recognition among the Hanford Site community through the application by M. Connelley at CH2M Hill Incorporated.

   Extensive academic usage: Oklahoma Christian University has used the simulator as part of the curriculum for an engineering design class. Ed Hill at the University of North Carolina used the simulator to investigate the behavior of DNAPL pools during enhanced remediation by surfactant and co-solvent flushing.

   Stomp has yet to be formally accepted by EPA or Ecology.

4. **VAM3D-CG.** 95%/90%. The proposal notes that EPA and Ecology have accepted VAM for Hanford Site uses in 1990; however, this was for earlier version of code. The proposal notes that code has been used in Hanford Site performance assessments approved by DOE. The proposal also notes approval of analyses by NRC using code. Proposal slightly downrated because of much earlier version approved by EPA and Ecology not recent version, but this probably reflects more on agencies than on code.

   Under TPA milestone M-29-01 "Description of Codes and Models to be Used in Risk Assessment," a committee was established in 1990 comprised of personnel from RL, contractors, and regulators. The committee recommended that VAM2D, a predecessor of VAM3D-CG, be selected as one of the vadose zone codes at Hanford. A series of peer-reviewed articles (Huyakorn, et al. 1986, 1985, 1984;

McCord, et al. 1991) on VAM3D-CG and its predecessors have appeared in Water Resource Research, a journal that is ranked number one in impact factor in the water resource category by the ISI Journal Citation Reports.

Use by other DOE, U.S. Department of Defense (DOD), Superfund, Resource Conservation and Recovery Act of 1976 (RCRA), and commercial sites.

NRC funding of HG to develop VAM3D-CG.

D. Additional Contaminant Transport Capabilities

1. **Criteria.** The proponent of the code shall document whether the code has the ability to modify the K_d value and/or the diffusion parameter based on moisture content and whether the code can model sorption-enhanced dispersivity. The code proponent may submit additional capabilities that may be advantageous to TWRS.

2. **PORFLOW.** 80%/80%. The proposal claims that criteria are satisfied, but does not provide references to the user's manual and it is not obvious where in user's manual such capabilities are described. Note has been made of proposed added capabilities. The revised proposal (Runchal 1998c) repeats the claims, but does not provide significantly more information.

   In response to Mandatory Criteria G above: Time-Dependent Hydraulic and Geochemical Values; distribution and retardation co-efficients are stated to be arbitrary functions of time, space, phase variables, and user defined variables.

3. **STOMP.** 60%/60%. The proposal claims that the first two criteria are satisfied, but does not provide references to the user's manual. A modification of code to allow sorption-enhanced dispersion and to allow a single run of time dependent Kd would be easy.

   "The simulator also offers two models for the effective diffusion co-efficient as a function of aqueous saturation. The conventional model reduces the molecular diffusion co-efficient by the tortuosity and aqueous saturation . . . The current released version of the STOMP simulator does not address sorption-enhanced dispersivity."

4. **VAM3D-CG.** 75%/80%. The code handles moisture-dependent diffusion co-efficients and sorption-enhanced dispersivities and provides references to their collection in the user's manual. It does not handle moisture-dependent Kds but the capacity can be added. Note has been made of proposed added capabilities.

   VAM3D-CG does not accept Kd as a function of saturation, however, in computing the retardation factor, the variability in saturation is included. The code can be modified to account for variation in Kd due to saturation.

Additional capabilities that may be advantageous:

- molecular diffusion co-efficient
- sorption-enhanced dispersivity
- upstream weighting and uncertainty analysis
- flow and transport predictions with quantified uncertainty.

E. Additional Moisture Flow Capabilities

1. **Criteria.** The proponent of the code shall document the functional representations available in the code to represent hydraulic conductivity and moisture retention as well as the ability to treat saturation-dependent anistropy. The proponent shall document how the code treats moisture hysteresis. The code proponent may submit additional capabilities that may be advantageous to TWRS.

2. **PORFLOW.** 35%/70%. The proposal states a number of representations are available in the code, but does not point to reference in user's manual. No mention is made of hysteresis. Moisture-dependent anistrophy is available in an earlier version and could be easily added to current version. The revised proposal (Runchal 1998c) again makes claims, but does not add significantly more information.

   Options include Van Genuchten with Mualem and Burdine, Brooks and Corey with Mualem and Burdine, Exponential Characteristic, 4th Order Polynomial Characteristic, Logarithmic Characteristic, Power (and Inverse) Law Characteristic, Arbitrary Tabulated Values.

   In PORFLOW the user flexibility is further increased by the fact that the characteristic for saturation characteristic can be different than that for relative conductivity.

3. **STOMP.** 100%/70%. Criteria are in code and adequately presented in proposal. Added capabilities were noted.

   "Constitutive functions for relative permeability, saturation, and capillary pressure currently recognized by the STOMP simulator are shown in Tables 3 and 4. The hysteretic k-s-p model applied in the STOMP simulator for the Water Operational Mode follows the theory of Kaluarachchi and Parker . . ."

4. **VAM3D-CG.** 100%/70%. Criteria are in code and adequately presented in proposal. Added capabilities were noted.

   VAM3D-CG can use Brooks-Carey relationships for representing soil moisture characteristics data. Saturation-dependent anistropy option is invoked by . . . . This is a significant field-scale phenomenon for the dry, heterogenous sediments such as those expected beneath the ILAW disposal facility. VAM3D-CG can include soil moisture retention data for both main drainage and main wetting curves and can model hysteresis phenomena in flow calculations. Additional

VAM3D-CG capabilities of interest include mass lumping and Newton-Raphson technique and upstream weighting.

F. Decay Products

1. **Criteria.** The proponent of the code shall document those features of the code which allow different contaminant transport properties to be assigned automatically to progeny by the code based on position in the radioactive decay chain.

2. **PORFLOW.** 90%/100%. Proposal claims ability. Documented in ACRi 1998 using DECA line. Downrated because location not provided. The revised proposal (Runchal 1998c) again makes claim, but does not provide information.

3. **STOMP.** 90%/100%. Proposal claims ability, although how implemented could not be found in user's manual in a quick search. Proposal provides method of solution, a bonus.

   "As referenced in the STOMP User's Guide, the simulator can address multiple solutes with radioactive decay and complex decay chains."

4. **VAM3D-CG.** 40%/50%. Capability not available in submitted version, but could be added based on capability of alternate version.

   To model decay chain, VAM3D-CG uses RESTART option. VAM2D and VAM3DF model the chanted decay transport with much more ease. Benchmarking and certification of VAM3DF decay chain option $10K.

G. User Support

1. **Criteria.** The proponent of the code shall document available user support (including applicable costs). The code proponent shall also document relevant instances of user support.

2. **PORFLOW.** 50%/75%. Schedule of 1998 charges supplied. Proposal does not contain relevant instances of user support. Analytic and Computational Research, Inc. is a well established and well thought of company. However, based on responsiveness of proposal, user support may not be adequate.

   Telephone conversation indicates that ACRi would set up office in the Tri-Cities, if necessary, to support ILAW. The issue is dedicated knowledgeable staff tied to ILAW and it's needs. There would be several months learning for ACRi and devotion of project staff to support learning estimate $20 – $30K.

3. **STOMP.** 80%/75%. Applicable costs not supplied. However, proposal does provide instance of Hanford Site support. Major concern is that the code is still considered by developers as a scientific tool rather than as a tool used for license-type applications.

   "For private clients, government agencies, and government contractors, the policy has been to provide user support through a cost recovery basis. Because the original development team continues to apply and modify the simulator, the laboratory can offer full user support for STOMP, including application consulting, code modifications, and output interpretation. An example of user support for the stomp simulator being extended to a Hanford Site contractor is the investigative project of 90-Sr migration by M. Connelley at CH2M Hill."

4. **VAM3D-CG.** 90%/90%. Applicable costs not supplied. However, proposal does contain instances of Hanford Site support. More significantly, proposal contains teaming letter with commercial firm which developed VAM. A phone call from Connelley (1998) indicated that as of July 1, 1998, HydroGeologic, Inc. has opened a Northwest Office in Richland. However, rating was not changed.

   Five knowledgeable VAM3D-CG users are with Fluor Daniel Northwest, Inc. (FDNW) and its consultants. In addition to the code developer, a total of 25 VAM3D-CG modelers are with HydroGeologic, Inc. A teaming arrangement has been worked out with the code developer for ILAW modeling support.

H. Speed of Execution

1. **Criteria.** The proponent of the code shall provide evidence of the relative speed of the code.

   General Note: No comparison figures were provided.

2. **PORFLOW.** Not rated because of lack of information. However, code does provide a number of solvers. Past experience indicates that execution speed of PORFLOW is not a basis for elimination. The revised proposal (Runchal 1998c) is silent.

   To handle a variety of applications, it provides for a number of efficient matrix solvers. In addition, an interface is provided so that any external matrix solver can be used without any code modification.

   Typical execution time for a vadose flow problem on an Intel Pentium II 400MHz system is on the order of 0.02 millisecond per element per step per equation. This means that a flow and transport problem with 10,000 elements and 1,000 time steps can be completed in less than seven minutes.

3. **STOMP.** Not rated because of lack of information. However, according to the proposal, the predecessor to STOMP was slower than other codes because of use of multiple-phase calculations. As this application will be mainly single-phase application, STOMP is expected to be slower than other codes, but not to a significant extent.

   "The current release version of the STOMP simulator has not been subjected to a formal comparison for execution speed against comparable software. (The predecessor MSTS) - MSTS was executed against the multi-phase and single-phase codes for two isothermal, unsaturated flow problems. With respect to execution speed, MSTS was comparable to the other multi-phase simulators, but slower than the dedicated single-phase simulators. The STOMP simulator currently offers a variety of options to decrease execution time ..."

4. **VAM3D-CG.** Not rated because of lack of information. Past experience indicates that execution speed of VAM3D-CG is not a basis for elimination.

   A comparison of PORFLO and VAM3D-CG run times for a PA production run shows the processing times for the two codes are comparable and runs can be completed overnight.

I. Non-Proprietary Codes

1. **Criteria.** The proponent of the code shall document whether the code is proprietary. If the code is proprietary, then the code proponent must document that the source code will be made available by lease or purchase to the U.S. Department of Energy, Richland Operations Office (RL) and its contractors (including LMHC and its agents. The proponent shall also supply the licensing cost (and any other mandatory fees for the use of the code).

2. **PORFLOW.** 50%/50%. PORFLOW is a proprietary code. The source code is available by lease. License cost was provided. Downrated because code is proprietary.

   "We have reason to believe that PORFLOW can handle all current and future needs of the Hanford Site with minimal, if any, additional development costs." Any cost savings of a public domain code will be more than offset by the future development costs."

3. **STOMP.** 75%/75%. STOMP is a mixture of proprietary code and code developed under DOE support. The source code is available and there is no license cost. The parts that are proprietary will probably not be used by TWRS. Downrated because the code is not fully in public domain.

   Battelle maintains copyright on all versions, revisions, and operational modes of STOMP simulator as granted by the DOE with stipulation that Versions 1.x of the STOMP simulator be made available to Federal and State agencies. RL and its

contractors under Battelle's copyright stipulations will be provided a royalty-free copy of the STOMP software source coding for use on the TWRS environmental analysis program.

4. **VAM3D-CG.** 50%/50%. VAM3D is a proprietary code. The source code is at FDNW and is available from the code developer for inspection by other parties. License costs have already been paid by FDNW. Downrated because code is proprietary.

   Although proprietary, VAM3D-CG, Version 3.1, including the source code, is already available for FDNW use. The required licensing fees have been paid and no other mandatory fees are required. If needed, the source code for VAM3D-CG can be made available, via HGL, to a third party without additional fees for inspection and verification.

J. Version

1. **Criteria.** The proponent of the code shall document the history of code versions and shall indicate where the particular version submitted falls in this history.

2. **PORFLOW.** 75%/75%. PORFLOW, Version 4.0 is the latest version in a long line. However, no mention of the previous history is given in the proposal.

   PORFLOW, Version 4.0 is fully tested. The release of each version of PORFLOW is tested against a suite of 42 test problems. A beta version was released in mid-1997. The current version was released in December 1997. As such, it has already been in use by our clients for a few months.

3. **STOMP.** 90%/75%. The current version in Version 1, Revision 1. The proposal does not give indication of sub-versions (e.g., revision is 12). Information is obtainable from configuration management file.

   "The current release version of the simulator is Version 1, with various revision numbers depending on the particular library file. . . . currently carries the revision number 12 . . . . The RCS revision log which documents the modifications made to this file is shown in Figure 1."

4. **VAM3D-CG.** 100%/90%. History of versions provided.

   A timeline for different versions of VAM3D-CG is provided below:

   1988 - VAM2D
   1991 - VAM2D v 5.0
   1993 - VAM3D v 2.4b
   1994 - VAM3D v 3.1
   1995 - VAM3DF

VI. REFERENCES

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APPENDIX F

Verification and Validation for VAM3DF, Version 1.00 (FFS version 1.00)

Prepared by

Scott H. Finfrock
Fluor Federal Services

January 2000

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1.0 INTRODUCTION

VAM3DF (typically called VAM) is a vadose zone/groundwater modeling code. The code and supporting documentation are provided by HydroGeoLogic (HGL). Earlier versions of VAM have been in use at the Hanford Site since the 1980's. Fluor Federal Services (FFS) has acquired this new version to support the 2001 ILAW PA. Prior to using this new version for production calculations, it is necessary to demonstrate that the code is adequately verified and validated. This report serves to document the verification and validation of VAM3DF.

VAM3DF has been verified and validated by HGL (Huyakorn and Panday 1999, and Appendix A). Earlier versions of VAM (e.g., VAM3DCG) have been verified and validated (Lu and Langford 1995 and Puigh, 1998) for use at Hanford. The new version, VAM3DF (Huyakorn and Panday 1999), is substantially the same as version VAM3DCG but with the addition of some significant new features. This new version provides an integration technique called 'data fusion' (which will not be used in the ILAW analyses), and provides for decay chain nuclide analysis. In addition, a variable anisotropy feature has been added. In order to qualify VAM3DF for use, it is necessary to complete an installation test of the code and show that the test cases produce the same results as published by HGL (which has validated the code). In addition, VAM3DF will be tested with Hanford specific cases, which were run on version VAM3DCG, to show that any differences in the calculational results (between this version and the previous) are within acceptable limits.

2.0 FFS NT COMPUTER SYSTEM

2.1 Hardware

VAM3DF will be run on the FFS Advanced Computing Center (ACC). This system is composed of a network of Intergraph PC type computers. Each computer is based on an Intel Pentium II Xeon processor. The individual computers have some variations (such as clock speed and amount of RAM) but are generally similar. The minimum configuration is a 400 MHz cpu, 256 MB RAM, and 9.1 GB hard disk (partitioned into smaller drives).

The installation and detailed testing were conducted on one specific computer, id# NW30032274 (currently located in 1200 Jadwin, Room 448).

2.2 Operating System

All of the computers (that will be used for running VAM) in the ACC are running the Microsoft Windows NT operating system, version 4.0, service pack 3.0 or higher.

3.0 VAM INSTALLATION

VAM3DF was provided by HGL as an NT executable and a dynamic link library (dll) file. Installation of the VAM3DF code only required placing the two files in the desired directory on the host machine.

4.0 VERIFICATION TESTING

Verification testing is intended to assure that the code is calculating results correctly. This can be done by running test cases and demonstrating that the code produces essentially the same results with the new installation as it did with the previous installation. Verification can also be accomplished by comparing results to hand calculations or other data sources. Both of these methods were employed in verifying VAM3DF.

4.1 Test Cases

A suite of cases has been identified for testing the VAM installation. This suite consists of three cases provided by HGL, two cases from a previous Hanford modeling effort (using VAM3DCG), and a variation of one of the Hanford cases to test the new decay chain feature. In addition, three cases were constructed to demonstrate new features (decay chain with variable Kd, and variable anisotropy) that are not amenable to formal validation. These cases were not compared to previous calculations but the results were reviewed qualitatively and will serve as comparisons for new code versions that may be installed in the future. A copy of each of the input files is included in Appendix B. The cases are described below:

1) 2-D Transient Unsaturated Flow in a Rectangular Slab

2) 2-D Transient Solute Transport in a Rectangular Slab

3) 2-D Concurrent Flow and Transport in a Rectangular Slab

4) Vadose and Groundwater Flow Beneath a Solid Waste Trench

5) Solute Transport Beneath a Solid Waste Trench

6) Solute Transport Beneath a Solid Waste Trench with Uranium Decay

7) Solute Transport Beneath a Solid Waste Trench with Decay and Variable Kd.

8) Isotropic Vadose Flow.

9) Anisotropic Vadose Flow.

Case 2 uses the results from case 1 as an input, and case 3 is equivalent to the combination of case 1 and case 2. Cases 5, 6, and 7 use the results of case 4. Case 8 is used as a comparison for case 9.

4.2 Verification Test Results

All of the cases were run on the ACC. For the first five cases, the output files from the benchmark runs were copied to the ACC and the equivalent files from each case were compared. For the sixth case, the results were compared to hand calculations.

4.2.1 HGL Test Cases

The three installation test cases (cases 1-3) were compared to the HGL output files using a 'diff' utility. This comparison indicated that the output files were identical.

4.2.2 Hanford Benchmark Cases

The two Hanford cases (cases 4-5) produced very similar but not identical results when run with VAM3DF and compared to VAM3DCG calculations. This is expected due to the changes in the modeling methods employed in VAM3DCG. The flow runs were compared by using a visualization program (Tecplot) to view the flow field. The overall fields were compared visually and a selection of specific points were compared numerically. The results of the VAM3DF calculation were vertical velocity values of 0.0500 cm/yr throughout the vadose zone (this is equal to the recharge rate and is therefore the 'correct' solution). The results of the VAM3DCG calculation were vertical velocity values of 0.0499 cm/yr. This difference of less than 1% is considered acceptable. The transport cases were evaluated using the mass reaching the 100 m well (one of the primary results of the modeling effort). This value was plotted against time for both cases and found to be nearly identical, with a time offset and magnitude change of less than 2 %. This level of agreement is considered acceptable.

4.2.3 Decay Chain

The Hanford transport benchmark case (case 5) was also set up as a decay chain problem (case 6), using an abbreviated uranium decay chain and a Kd of 100 L/mg for all species (the Kd was set to a large value to facilitate the verification effort). The mass percentage in each daughter nuclide was calculated by summing the nodal results produced by the code. As a check, the expected values were calculated using the Bateman equations (Lapp and Andrews 1972) shown below. The results of these calculations are shown in Table 4.1. As can be seen, the differences are small (<1% for the worst case).

$$A_1(t)=A_1(0)e^{-\lambda_1 t}$$

$$A_2(t)=A_1(0)*(\lambda_2/(\lambda_2-\lambda_1))*(e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

$$A3(t)= A_1(0)*(\lambda_1\lambda_2)*(a*e^{-\lambda_1 t} + b*e^{-\lambda_2 t} + c*e^{-\lambda_3 t})$$
$$a=(1/((\lambda_2-\lambda_1)*(\lambda_3-\lambda_1))$$
$$b=(1/((\lambda_1-\lambda_2)*(\lambda_3-\lambda_2))$$
$$c=(1/((\lambda_1-\lambda_3)*(\lambda_2-\lambda_3))$$

$$A4(t)= A_1(0)*(\lambda_1\lambda_2\lambda_3)*(a*e^{-\lambda_1 t} + b*e^{-\lambda_2 t} + c*e^{-\lambda_3 t} + d*e^{-\lambda_4 t})$$
$$a=(1/((\lambda_2-\lambda_1)*(\lambda_3-\lambda_1)*(\lambda_4-\lambda_1))$$

$b=(1/((\lambda_1-\lambda_2)*(\lambda_3-\lambda_2)*(\lambda_4-\lambda_2))$
$c=(1/((\lambda_1-\lambda_3)*(\lambda_2-\lambda_3)*(\lambda_4-\lambda_3))$
$d=(1/((\lambda_1-\lambda_4)*(\lambda_2-\lambda_4)*(\lambda_3-\lambda_4))$

Table 4.1

Nuclide Id	Initial Activity (Ci)	Decay Constant (yr^{-1})	Activity at t=100,000 yr (Bateman Eqns.)	Activity at t=100,000 yr (VAM3DF Calculations)
U235	1	1.55e-10	9.9998E-01	9.9998E-01
Th230	0	9.19e-6	1.0144E-05	1.0143E-05
Bi210	0	2.31e-7	5.3272E-06	5.3407E-06
Pb206	0	0.0	4.4102E-08	4.4361E-08

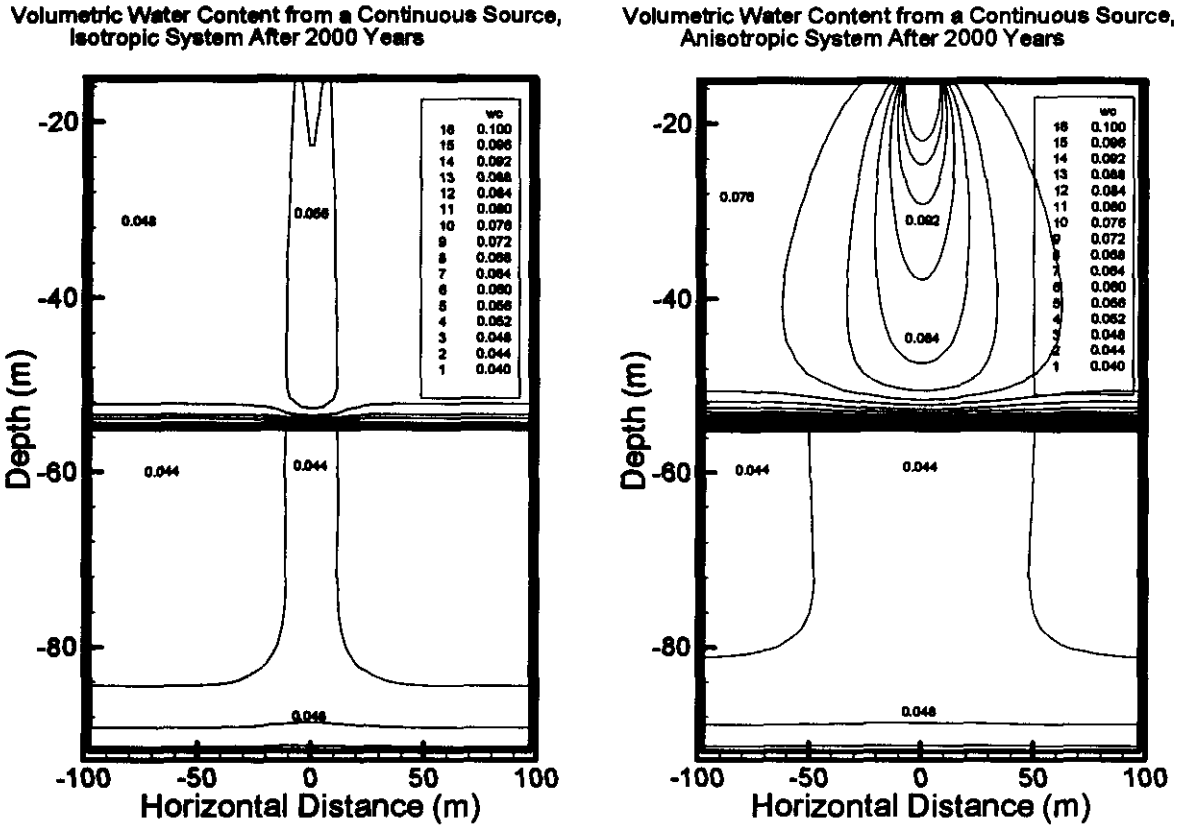
4.2.4 Decay Chain with Variable Kd

The decay chain case (case 6) was also run with variable Kd's (case 7) to test the effect of this option. It is not practical to check the results of this calculation with a hand calculation but the results can be evaluated qualitatively to ascertain that the results are reasonable. In this case the four isotopes modeled in the decay chain case described in section 4.2.3 were each given a different Kd. The relative formation and transport of each of the different isotopes were then compared and found to be consistant with their relative decay coefficients and Kd values.

4.2.5 Variable Anisotropy

Two numerical simulations were run, one using an anisotropy option (case 9) within VAM3DF and the other for an isotropic case (case 8). There are three anisotropy options included in version 2.0 of the VAM3DF code (Huyakorn and Panday 1999). The anisotropy simulation presented here uses the third option based on the work of Polmann (1990). The results of the simulations are shown in Figure 4.1. This figure shows that the moisture distribution in the upper sand layer is much higher for the anisotropic case than for the isotropic case. In the lower gravel there is more spread in the anisotropic case but the water content ranges are much closer for both isotropic and anisotropic systems. This suggests that the upper sand absorbs much of the water and dominates the system. These results are qualitatively what would be expected for the inclusion of an anisotropic condition.

Figure 4.1. Simulated Water Contents For The Isotropic And The Variably Anisotropic Conditions



5.0 CONFIGURATION MANAGEMENT

All files associated with the installation and testing of VAM3DF on the ACC were placed on the hard disk of cpu NW30032274. A directory was created, e:\data\vam\vam3df\benchmark, for storing all of the files.

The executable file is named vam3df100.exe, and is identified as VAM3DF version 1.00, FFS installation version 1.00. The executable file and the library file, tecutil.dll is stored on cpu fdnweng02, in subdirectory \\applications\vam\bin.

6.0 AUTHORIZED USERS

Authorized users of the VAM3DF code:

Scott Finfrock*
Gene Freeman
Raz Khaleel
Allen Lu
Mel Piepho

* Code Custodian

7.0 CONCLUSION

VAM3DF has been verified for use on the ACC. The code was installed, and the test cases were run and produced identical results to the previous (HGL) installation. Test cases using Hanford site models were run and compared to the same models run with the previous version of Vam (VAM3DCG). These cases produced results that had differences in the results that were within acceptable limits. This gives confidence that cases run with the old version of Vam are still valid.

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9.0 TECHNICAL PEER REVIEW CHECKLIST

Practice 134 290 1112
Publication Date 22Nov99
Attachment #2 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:	HNF-5769 Rev. 0
Title:	Verification and Validation for VAM3DF, Version 1.00 (FFS version 1.00)
Author:	Scott H. Finfrock
Date:	January 24, 2000
Scope of Review:	Full Document

Yes	No*	NA	
[ ]	[ ]	[X]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[X]	Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]	Computer codes and data files documented.
[ ]	[ ]	[X]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[ ]	[ ]	[X]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[X]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[X]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[ ]	[ ]	[X]	Software output consistent with input and with results reported in document reviewed.
[X]	[ ]	[ ]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[X]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[X]	[ ]	[ ]	Format consistent with applicable guides or other standards.
[ ]		[X]**	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]	Document approved (for example., the reviewer affirms the technical accuracy of the document).

Eugene J. Freeman
Reviewer: (Printed and Signed)

1/24/00
Date

* All "NO" responses must be explained below or on an additional page.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

NUCLEAR ENGINEERING

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APPENDIX A

LETTER OF CERTIFICATION

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HYDRO GeoLogic INC.

JAN 04 RECD.

Letter of Certification.

This is to certify that I have checked the decay chain option and the Polmann variable anisotropy option that have been programmed in the latest version of VAM3DF by Dr. Kim, and that they have been correctly implemented and verified.

Please call me at 703-736-4567 if you have any questions.

Sincerely

Sorab Panday

Dr. Sorab Panday
Senior Director, Research and Development.

HydroGeoLogic, Inc.
1155 Herndon Parkway • Suite 900 • Herndon, VA 20170 • USA
(703) 478-5186 • Fax (703) 471-4180 • http://www.hgl.com

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APPENDIX B

VAM3DF INPUT FILES

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```
    1                                                                                                  GROUP 1
2-D FLOW IN RECTANGULAR SLAB.                                                                          GROUP 2
    1   -1    0    0    1   10  352  150    0    0    1    0    0    0                                GROUP 3
    1    1   10    0    1      0.01        1.    0    0    0                                         GROUP 4
    0    1    0    0    1    5    0    5    0    1    0    0                                         GROUP 5
        0.      0.01       1.2      0.05                                                              GROUP 6A
   -90.00                                                                                              GROUP 7
      1.E0      1.E0      1.E0      0.E0    0.45E0      0.E0      0.E0                               GROUP 9
  0.333E0      1.E0    -1.E-2      1.E0     -1.E0                                                     GROUP 10
   11   16    2    0       1.0       1.0      10.0    0                                               GROUP 12
       1.0       1.0       15.       10.        1.        1.        0.        0.                      GROUP 14
      10.0       10.        1.        0.                                                              --------
   32    0    0    0    0                                                                             GROUP 15A
  166    1      -90.                                                                                   GROUP 15B
  167    1      -90.                                                                                   ---------
  168    1      -90.                                                                                   ---------
  169    1      -90.                                                                                   ---------
  170    1      -90.                                                                                   ---------
  171    1      -90.                                                                                   ---------
  172    1      -90.                                                                                   ---------
  173    1      -90.                                                                                   ---------
  174    1      -90.                                                                                   ---------
  175    1      -90.                                                                                   ---------
  176    1      -90.                                                                                   ---------
  342    1      -90.                                                                                   ---------
  343    1      -90.                                                                                   ---------
  344    1      -90.                                                                                   ---------
  345    1      -90.                                                                                   ---------
  346    1      -90.                                                                                   ---------
  347    1      -90.                                                                                   ---------
  348    1      -90.                                                                                   ---------
  349    1      -90.                                                                                   ---------
  350    1      -90.                                                                                   ---------
  351    1      -90.                                                                                   ---------
  352    1      -90.                                                                                   ---------
    7    1        0.                                                                                   ---------
    8    1       -1.                                                                                   ---------
    9    1       -2.                                                                                   ---------
   10    1       -3.                                                                                   ---------
   11    1       -4.                                                                                   ---------
  183    1        0.                                                                                   ---------
  184    1       -1.                                                                                   ---------
  185    1       -2.                                                                                   ---------
  186    1       -3.                                                                                   ---------
  187    1       -4.                                                                                   ---------
   14                                                                                                  GROUP 22A
    7    8    9   10   11  183  184  185  186  187  166  176  342  352                                  GROUP 22B
```

```
   1                                                                                                  GROUP 1
TRANSPORT IN TRANSIENT FLOW FIELD.                                                                    GROUP 2
   0    0    0    0    1   10  352  150    0    0    1    0    0    0                                GROUP 3
   0    0   10    0    1      0.00        1.    0    0    0      0.01                               GROUP 4
   2    1    0    3    0    0    0    5    0    1    0    0                                         GROUP 5
       0.      0.01       1.2      0.05                                                              GROUP 6
     0.00        0.                                                                                   GROUP 7
     1.E0      0.E0     1.E-2      1.E0    0.45E0    1.46E0                                          GROUP 11A
    1.E-3     0.308                                                                                   GROUP 11B
  11   16    2    0        1.        1.        1.    0                                               GROUP 12
       1.        1.       15.       10.        1.        1.        0.        0.                      GROUP 14
      10.       10.        1.        0.                                                              --------
  10    0    0    0    0                                                                             GROUP 15A
   7    1        1.                                                                                   ---------
 183    1        1.                                                                                   ---------
   8    1        1.                                                                                   ---------
 184    1        1.                                                                                   ---------
   9    1        1.                                                                                   ---------
 185    1        1.                                                                                   ---------
  10    1        1.                                                                                   ---------
 186    1        1.                                                                                   ---------
  11    1        1.                                                                                   ---------
 187    1        1.                                                                                   ---------
       0.        0.        0.        1.        1.        1.        0.    0                           GROUP 19
  14                                                                                                  GROUP 22A
   7    8    9   10   11  183  184  185  186  187  166  176  342  352                                 GROUP 22B
```

```
   1                                                                                                  GROUP 1
TRANSIENT FLOW AND TRANSPORT IN 2-DIMENSIONS                                                          GROUP 2
   2   -1    0    0    1   10  352  150    0    0    1    0    0    0                                GROUP 3
   0    1   10    0    1      0.05        1.    0    0    0      0.01                                GROUP 4
   0    1    0    3    0    5    0    5    0    1    0    0                                         GROUP 5
       0.      0.01       1.2      0.05                                                              GROUP 6
   -90.00        0.                                                                                   GROUP 7
     1.E0      1.E0      1.E0      0.E0    0.45E0      0.E0      0.E0                                GROUP 9
  0.333E0      1.E0    -1.E-2      1.E0     -1.E0                                                    GROUP 10
     1.E0      0.E0     1.E-2      1.E0    0.45E0    1.46E0                                         GROUP 11A
    1.E-3     0.308                                                                                   GROUP 11B
  11   16    2    1        1.        1.        1.    0                                               GROUP 12
       1.        1.       15.       10.        1.        1.        0.        0.                      GROUP 14
      10.       10.        1.        0.                                                              --------
  21    0    0    0    0                                                                             GROUP 15A
   7    1        0.                                                                                   GROUP 15B
   7    2        1.                                                                                   ---------
   8    1       -1.                                                                                   ---------
   8    2        1.                                                                                   ---------
   9    1       -2.                                                                                   ---------
   9    2        1.                                                                                   ---------
  10    1       -3.                                                                                   ---------
  10    2        1.                                                                                   ---------
  11    1       -4.                                                                                   ---------
  11    2        1.                                                                                   ---------
 166    1    -90.00                                                                                   ---------
 167    1    -90.00                                                                                   ---------
 168    1    -90.00                                                                                   ---------
 169    1    -90.00                                                                                   ---------
 170    1    -90.00                                                                                   ---------
 171    1    -90.00                                                                                   ---------
 172    1    -90.00                                                                                   ---------
 173    1    -90.00                                                                                   ---------
 174    1    -90.00                                                                                   ---------
 175    1    -90.00                                                                                   ---------
 176    1    -90.00                                                                                   ---------
       0.        0.        0.        1.        1.        1.        0.    0                           GROUP 19
   7                                                                                                  GROUP 22A
   7    8    9   10   11  166  176                                                                    GROUP 22B
```

```
    1    1    0                                                                                                                  G-1
200E, E-12 mats, flow, .05m/yr, deact. nodes for trench, 2d curvilinear, tot head, vam3df
    1   -1   -1    0    3  400 1856  868    1    0    4    1    0    0    1    1     G-3
    1    1   30    3    2 0.500E-01 0.000E+00    1    0    0 0.000E+00    1    0     G-4
    0    1  928    0    2   10  -10   10    0    1    1    0    0    0    0    1     G-5
 0.000E+00 0.100E-02 0.140E+01 0.100E+02 0.100E-03 0.200E+04 0.200E+01                 G-6a
-3.330E-01 0.000E+00                                                                  G-7a
    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4     G-8
    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
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    0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
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    0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4     2nd plane
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```

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 0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1
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 0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0
 0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1
3.780E+00 3.780E+00 0.000E+00 1.000E-04 1.450E-01 0.000E+00 0.000E+00                    G-9a
6.840E+02 6.840E+02 0.000E+00 1.000E-04 3.526E-01 0.000E+00 0.000E+00
8.600E+01 8.600E+01 0.000E+00 1.000E-04 1.477E-01 0.000E+00 0.000E+00
3.000E+04 3.000E+04 0.000E+00 1.000E-04 2.500E-01 0.000E+00 0.000E+00
0.000E+00-1.000E+00 2.060E+00 1.278E+00                                              G-10a
1.361E-01-1.000E+00 8.100E-01 2.379E+00
8.800E-02-1.000E+00 2.050E+00 1.559E+00
0.000E+00-1.000E+00 2.050E+00 1.559E+00
   2    2    1    1    1    0    1                                                   G-14A
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000     G-14Bai
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
```

-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
30.0000	40.0000	50.0000	60.0000	70.0000	80.0000	90.0000	100.0000
-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
-35.0000	-30.0000	-25.0000	-22.0000	-20.0000	-18.0000	-15.0000	-10.0000
-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
30.0000	40.0000	50.0000	60.0000	70.0000	80.0000	90.0000	100.0000
-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
-35.0000	-30.0000	-25.0000	-22.0000	-20.0000	-18.0000	-15.0000	-10.0000
-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
30.0000	40.0000	50.0000	60.0000	70.0000	80.0000	90.0000	100.0000
-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
-35.0000	-30.0000	-25.0000	-22.0000	-20.0000	-18.0000	-15.0000	-10.0000
-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
30.0000	40.0000	50.0000	60.0000	70.0000	80.0000	90.0000	100.0000
-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
-35.0000	-30.0000	-25.0000	-22.0000	-20.0000	-18.0000	-15.0000	-10.0000
-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
30.0000	40.0000	50.0000	60.0000	70.0000	80.0000	90.0000	100.0000
-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
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 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01
 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01
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 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
-0.400E+01-0.400E+01-0.400E+01-0.400E+01-0.400E+01-0.400E+01-0.400E+01-0.400E+01
```

```
-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01
-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01-0.500E+01
-0.600E+01-0.600E+01-0.600E+01-0.600E+01-0.600E+01-0.600E+01-0.600E+01-0.600
```

```
   1    1    0                                                                                                  G-1
200E, E-12 mats, trans, .05m/yr, deact. nodes for trench, 2d curvilinear, vam3df
   0   -1    0    0    1  800 1856  868    1    0    4    0    0    0    1    1   G-3
   1    0    1    3    0 0.000E+00 0.000E+00    1    0    0 1.000E-02    1    0   G-4
   2    1    0    0    0   10  -10   10    1    1    1    0    0    1    0    1   G-5
 0.000E+00 0.200E+00 0.100E+01 0.200E+00 0.000E+00 0.000E+00 0.000E+00              G-6a
 0.000E+00 0.000E+00                                                               G-7a
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4   G-8
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   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
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1.000E+00 1.000E-01 2.400E-03 1.000E+00 1.450E-01 2.250E+00 1.000E+00                    G-11a
1.000E+00 1.000E-01 7.860E-03 1.000E+00 3.526E-01 1.710E+00 1.000E+00
1.000E+00 1.000E-01 2.460E-03 1.000E+00 1.477E-01 2.160E+00 1.000E+00
1.000E+00 1.000E-01 4.970E-03 1.000E+00 2.500E-01 1.990E+00 1.000E+00
0.000E+00 0.000E+00                                                                     G-11b
0.000E+00 0.000E+00
0.000E+00 0.000E+00
0.000E+00 0.000E+00
   2    2    1    1    1    0    1                                                     G-14A
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-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
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-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
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-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
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-100.0000	-90.0000	-80.0000	-70.0000	-60.0000	-50.0000	-45.0000	-40.0000
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-35.0000	-30.0000	-25.0000	-22.0000	-20.0000	-18.0000	-15.0000	-10.0000
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-5.0000	-2.0000	0.0000	2.0000	5.0000	10.0000	15.0000	20.0000
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G-14Ba11

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-55.0000	-55.0000	-55.0000	-55.0000	-55.0000	-55.0000	-55.0000	-55.0000
-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000
-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000
-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000
-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000	-50.0000
-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000
-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000
-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000
-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000	-40.0000
-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000
-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000
-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000
-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000	-30.0000
-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000
-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000
-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000
-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000	-25.0000
-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000
-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000
-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000
-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000	-20.0000
-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000
-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000
-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000
-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000	-18.0000
-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000
-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000
-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000
-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000	-17.0000
-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000
-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000
-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000
-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000	-16.0000
-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000
-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000
-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000
-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000	-15.0000
-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000
-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000
-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000
-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000	-14.0000
-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000
-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000
-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000
-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000	-12.0000
-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000
-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000
-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000
-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000	-11.0000
-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000
-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000
-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000
-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000	-10.0000
-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000
-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000	-9.0000

```
 -9.0000   -9.0000   -9.0000   -9.0000   -9.0000   -9.0000   -9.0000   -9.0000
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 -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000
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 -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000   -8.0000
 -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000
 -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000
 -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000
 -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000   -7.0000
 -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000
 -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000
 -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000
 -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000   -6.0000
 -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000
 -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000
 -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000
 -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000   -4.0000
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 -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000
 -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000   -2.0000
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 -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000
 -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000
 -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000
 -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000   -1.0000
  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000   -1.0000                                                              G-14Baiii
 29   32                                                                        G-14C
  4   25    0    7    0                                                        G-15a
  1    1    0.0000    0.0000                                                              G-15b
 33    1    0.0000    0.0000
 65    1    0.0000    0.0000
 97    1    0.0000    0.0000
897    1    0.0000    0.2500                                                              G-15c
898    1    0.0000    0.5000
899    1    0.0000    0.5000
900    1    0.0000    0.5000
901    1    0.0000    0.5000
902    1    0.0000    0.3750
903    1    0.0000    0.2500
904    1    0.0000    0.2500
905    1    0.0000    0.2500
906    1    0.0000    0.2500
907    1    0.0000    0.2000
908    1    0.0000    0.1250
916    1    0.0000    0.1250
917    1    0.0000    0.2000
918    1    0.0000    0.2500
919    1    0.0000    0.2500
920    1    0.0000    0.3750
921    1    0.0000    0.5000
922    1    0.0000    0.5000
923    1    0.0000    0.5000
924    1    0.0000    0.5000
925    1    0.0000    0.5000
926    1    0.0000    0.5000
927    1    0.0000    0.5000
928    1    0.0000    0.2500
749    1   48    0                                                  G-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
```

```
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.42738E-2 .42734E-2 .42615E-2 .41166E-2 .36178E-2 .27644E-2 .18218E-2 .10487E-2
.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
.19000E-6 .60000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 750    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .39500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 751    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
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.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 752    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.21368E-1 .21367E-1 .21307E-1 .20583E-1 .18089E-1 .13822E-1 .91087E-2 .52434E-2
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.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
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.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
 753    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 754    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .39500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 755    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.42735E-2 .42734E-2 .42615E-2 .41166E-2 .36178E-2 .27644E-2 .18218E-2 .10487E-2
.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
.19000E-6 .60000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 0.000000  0.000000  0.000000  1.000000  1.000000  1.000000         1          6-20
 118    1                                                                     6-23a
 897  898  899  900  901  902  903  904  905  906  907  908  726  727  728  729
 730  731  732  916  917  918  919  920  921  922  923  924  925  926  927  928
   1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
  17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
  33   65   97  129  161  193  225  257  289  321  353  385  417  449  481  513
```

```
 545  577  609  641  673  705  737  769  801  833  865   64   96  128  160  192
 224  256  288  320  352  384  416  448  480  512  544  576  608  640  672  704
 736  768  800  832  864  896
   4   32   64   96  128
   0.0000 2000.0000    1    1                                                    G-28
   1                                                                            G-29a
2000.0000                                                                       G-29b
```

```
   1    1    0                                                                                                  G-1
v2et001; with decay chain, u238
   0   -1    0    0    2 1500 1856  868    1    0    4    0    0    0    1    1    1 G-3
   1    0    1    3    0 0.000E+00 0.000E+00    1    0    0 1.000E-02    2    0      G-4
   2    1    0    0    0   10  -10   10    1    1    1    0    0    1    0    1      G-5
0.000E+00 0.200E+00 0.100E+01 0.200E+00 0.000E+00 0.000E+00 0.000E+00                  G-6a
0.000E+00 1.000E+02 2.000E-01    0                                                     G-6c
1.000E+02 1.000E+06 1.000E+02    1                                                     G-6c
0.000E+00 0.000E+00                                                                    G-7a
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4      G-8
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
```

```
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4    2nd plane
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4
 4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
 0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
 0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
 0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
 0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   1
 1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
 0   0   0   1   1   1   1   1   1   1   1   1   1   1   1   1
1.000E+00 1.000E-01 2.400E-03 1.000E+00 1.450E-01 2.250E+00 1.000E+00          G-11a
1.000E+00 1.000E-01 7.860E-03 1.000E+00 3.526E-01 1.710E+00 1.000E+00
1.000E+00 1.000E-01 2.460E-03 1.000E+00 1.477E-01 2.160E+00 1.000E+00
1.000E+00 1.000E-01 4.970E-03 1.000E+00 2.500E-01 1.990E+00 1.000E+00
 4   0                                                                     G-11ci
 1   0                                                                     G-11ciii
 2   1
 1       1.
 3   1
```

```
  2        1.
  4    1
  3        1.
  1    0                                                                    G-11c1v
1.55e-10  9.19e-06  2.31e-07  1.00e-20
    100.      100.      100.      100.
  2    1
  3    1
  4    1
  2    2    1    1    1    0    1                                          G-14A
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000  G-14Ba1
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
```

```
-35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
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-35.0000   -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
 -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
 30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
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  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  0.0000   -1.0000                                                          G-14Baiii
 29   32                                                                    G-14C
 16  121    0    7    0    0    0    0    0                                          G-15a
  1    1    0.0000    0.0000                                                          G-15b
 33    1    0.0000    0.0000
 65    1    0.0000    0.0000
 97    1    0.0000    0.0000
  1    2    0.0000    0.0000
 33    2    0.0000    0.0000
 65    2    0.0000    0.0000
 97    2    0.0000    0.0000
  1    3    0.0000    0.0000
 33    3    0.0000    0.0000
 65    3    0.0000    0.0000
 97    3    0.0000    0.0000
  1    4    0.0000    0.0000
 33    4    0.0000    0.0000
 65    4    0.0000    0.0000
 97    4    0.0000    0.0000
897    1    0.0000    0.2500                                                          G-15c
898    1    0.0000    0.5000
899    1    0.0000    0.5000
900    1    0.0000    0.5000
901    1    0.0000    0.5000
902    1    0.0000    0.3750
903    1    0.0000    0.2500
```

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905	1	0.0000	0.2500
906	1	0.0000	0.2500
907	1	0.0000	0.2000
908	1	0.0000	0.1250
916	1	0.0000	0.1250
917	1	0.0000	0.2000
918	1	0.0000	0.2500
919	1	0.0000	0.2500
920	1	0.0000	0.3750
921	1	0.0000	0.5000
922	1	0.0000	0.5000
923	1	0.0000	0.5000
924	1	0.0000	0.5000
925	1	0.0000	0.5000
926	1	0.0000	0.5000
927	1	0.0000	0.5000
928	1	0.0000	0.2500
897	2	0.0000	0.2500
898	2	0.0000	0.5000
899	2	0.0000	0.5000
900	2	0.0000	0.5000
901	2	0.0000	0.5000
902	2	0.0000	0.3750
903	2	0.0000	0.2500
904	2	0.0000	0.2500
905	2	0.0000	0.2500
906	2	0.0000	0.2500
907	2	0.0000	0.2000
908	2	0.0000	0.1250
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917	2	0.0000	0.2000
918	2	0.0000	0.2500
919	2	0.0000	0.2500
920	2	0.0000	0.3750
921	2	0.0000	0.5000
922	2	0.0000	0.5000
923	2	0.0000	0.5000
924	2	0.0000	0.5000
925	2	0.0000	0.5000
926	2	0.0000	0.5000
927	2	0.0000	0.5000
928	2	0.0000	0.2500
897	3	0.0000	0.2500
898	3	0.0000	0.5000
899	3	0.0000	0.5000
900	3	0.0000	0.5000
901	3	0.0000	0.5000
902	3	0.0000	0.3750
903	3	0.0000	0.2500
904	3	0.0000	0.2500
905	3	0.0000	0.2500
906	3	0.0000	0.2500
907	3	0.0000	0.2000
908	3	0.0000	0.1250
916	3	0.0000	0.1250
917	3	0.0000	0.2000
918	3	0.0000	0.2500
919	3	0.0000	0.2500
920	3	0.0000	0.3750
921	3	0.0000	0.5000
922	3	0.0000	0.5000
923	3	0.0000	0.5000
924	3	0.0000	0.5000
925	3	0.0000	0.5000
926	3	0.0000	0.5000
927	3	0.0000	0.5000

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 897    4    0.0000    0.2500
 898    4    0.0000    0.5000
 899    4    0.0000    0.5000
 900    4    0.0000    0.5000
 901    4    0.0000    0.5000
 902    4    0.0000    0.3750
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 904    4    0.0000    0.2500
 905    4    0.0000    0.2500
 906    4    0.0000    0.2500
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 926    4    0.0000    0.5000
 927    4    0.0000    0.5000
 928    4    0.0000    0.2500
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 749    3    0.0000    0.1000
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 751    3    0.0000    0.2000
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 753    3    0.0000    0.2000
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 749    4    0.0000    0.1000
 750    4    0.0000    0.1250
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.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
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.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
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.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 750    1   48    0                                                  0-17
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.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .38500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 751    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 752    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.21368E-1 .21367E-1 .21307E-1 .20583E-1 .18089E-1 .13822E-1 .91087E-2 .52434E-2
.26857E-2 .12460E-2 .53163E-3 .21127E-3 .79000E-4 .28030E-4 .95000E-5 .30900E-5
.97000E-6 .30000E-6 .90000E-7 .30000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
 753    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
```

```
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 754    1   48    0                                                  G-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .39500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 755    1   48    0                                                  G-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.42735E-2 .42734E-2 .42615E-2 .41166E-2 .36178E-2 .27644E-2 .18218E-2 .10487E-2
.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
.19000E-6 .60000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 0.000000  0.000000  0.000000  1.000000  1.000000  1.000000         1          G-20
 118    1                                                                     G-23a
 897  898  899  900  901  902  903  904  905  906  907  908  726  727  728  729
 730  731  732  916  917  918  919  920  921  922  923  924  925  926  927  928
   1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
  17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
  33   65   97  129  161  193  225  257  289  321  353  385  417  449  481  513
 545  577  609  641  673  705  737  769  801  833  865   64   96  128  160  192
 224  256  288  320  352  384  416  448  480  512  544  576  608  640  672  704
 736  768  800  832  864  896
   0.0000 2000.0000    1    1                                              G-28
   1                                                                       G-29a
2000.0000                                                                  G-29b
```

```
1    1    0                                                
```

```
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    2nd plane
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   4    4    4    4    4    4    4    4    4    4    4    4    4    4    4    4
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0
   0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0
   0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0
   0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0
   0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    0    0    0    0
   0    0    0    1    1    1    1    1    1    1    1    1    1    1    1    1
1.000E+00 1.000E-01 2.400E-03 1.000E+00 1.450E-01 2.250E+00 1.000E+00          G-11a
1.000E+00 1.000E-01 7.860E-03 1.000E+00 3.526E-01 1.710E+00 1.000E+00
1.000E+00 1.000E-01 2.460E-03 1.000E+00 1.477E-01 2.160E+00 1.000E+00
1.000E+00 1.000E-01 4.970E-03 1.000E+00 2.500E-01 1.990E+00 1.000E+00
   4    0                                                               G-11ci
   1    0                                                               G-11ciii
   2    1
   1        1.
   3    1
```

```
  2        1.
  4    1
  3        1.
  1    0                                                                  G-11civ
1.55e-10  9.19e-06  2.31e-07  1.00e-20
    200.       100.       50.       10.
  2    1
  3    1
  4    1
  2    2    1    1    1    0    1                                         G-14A
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000  G-14Ba1
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
-100.0000  -90.0000  -80.0000  -70.0000  -60.0000  -50.0000  -45.0000  -40.0000
 -35.0000  -30.0000  -25.0000  -22.0000  -20.0000  -18.0000  -15.0000  -10.0000
  -5.0000   -2.0000    0.0000    2.0000    5.0000   10.0000   15.0000   20.0000
  30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000  100.0000
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  0.0000   -1.0000                                                              G-14Baiii
 29  32                                                                        G-14C
 16 121    0   7    0   0    0   0   0                                                    G-15a
  1   1    0.0000    0.0000                                                             G-15b
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 65   1    0.0000    0.0000
 97   1    0.0000    0.0000
  1   2    0.0000    0.0000
 33   2    0.0000    0.0000
 65   2    0.0000    0.0000
 97   2    0.0000    0.0000
  1   3    0.0000    0.0000
 33   3    0.0000    0.0000
 65   3    0.0000    0.0000
 97   3    0.0000    0.0000
  1   4    0.0000    0.0000
 33   4    0.0000    0.0000
 65   4    0.0000    0.0000
 97   4    0.0000    0.0000
897   1    0.0000    0.2500                                                             G-15c
898   1    0.0000    0.5000
899   1    0.0000    0.5000
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902   1    0.0000    0.3750
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919	1	0.0000	0.2500
920	1	0.0000	0.3750
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924	1	0.0000	0.5000
925	1	0.0000	0.5000
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897	2	0.0000	0.2500
898	2	0.0000	0.5000
899	2	0.0000	0.5000
900	2	0.0000	0.5000
901	2	0.0000	0.5000
902	2	0.0000	0.3750
903	2	0.0000	0.2500
904	2	0.0000	0.2500
905	2	0.0000	0.2500
906	2	0.0000	0.2500
907	2	0.0000	0.2000
908	2	0.0000	0.1250
916	2	0.0000	0.1250
917	2	0.0000	0.2000
918	2	0.0000	0.2500
919	2	0.0000	0.2500
920	2	0.0000	0.3750
921	2	0.0000	0.5000
922	2	0.0000	0.5000
923	2	0.0000	0.5000
924	2	0.0000	0.5000
925	2	0.0000	0.5000
926	2	0.0000	0.5000
927	2	0.0000	0.5000
928	2	0.0000	0.2500
897	3	0.0000	0.2500
898	3	0.0000	0.5000
899	3	0.0000	0.5000
900	3	0.0000	0.5000
901	3	0.0000	0.5000
902	3	0.0000	0.3750
903	3	0.0000	0.2500
904	3	0.0000	0.2500
905	3	0.0000	0.2500
906	3	0.0000	0.2500
907	3	0.0000	0.2000
908	3	0.0000	0.1250
916	3	0.0000	0.1250
917	3	0.0000	0.2000
918	3	0.0000	0.2500
919	3	0.0000	0.2500
920	3	0.0000	0.3750
921	3	0.0000	0.5000
922	3	0.0000	0.5000
923	3	0.0000	0.5000
924	3	0.0000	0.5000
925	3	0.0000	0.5000
926	3	0.0000	0.5000
927	3	0.0000	0.5000

```
 928    3    0.0000    0.2500
 897    4    0.0000    0.2500
 898    4    0.0000    0.5000
 899    4    0.0000    0.5000
 900    4    0.0000    0.5000
 901    4    0.0000    0.5000
 902    4    0.0000    0.3750
 903    4    0.0000    0.2500
 904    4    0.0000    0.2500
 905    4    0.0000    0.2500
 906    4    0.0000    0.2500
 907    4    0.0000    0.2000
 908    4    0.0000    0.1250
 916    4    0.0000    0.1250
 917    4    0.0000    0.2000
 918    4    0.0000    0.2500
 919    4    0.0000    0.2500
 920    4    0.0000    0.3750
 921    4    0.0000    0.5000
 922    4    0.0000    0.5000
 923    4    0.0000    0.5000
 924    4    0.0000    0.5000
 925    4    0.0000    0.5000
 926    4    0.0000    0.5000
 927    4    0.0000    0.5000
 928    4    0.0000    0.2500
 749    2    0.0000    0.1000
 750    2    0.0000    0.1250
 751    2    0.0000    0.2000
 752    2    0.0000    0.2500
 753    2    0.0000    0.2000
 754    2    0.0000    0.1250
 755    2    0.0000    0.1000
 749    3    0.0000    0.1000
 750    3    0.0000    0.1250
 751    3    0.0000    0.2000
 752    3    0.0000    0.2500
 753    3    0.0000    0.2000
 754    3    0.0000    0.1250
 755    3    0.0000    0.1000
 749    4    0.0000    0.1000
 750    4    0.0000    0.1250
 751    4    0.0000    0.2000
 752    4    0.0000    0.2500
 753    4    0.0000    0.2000
 754    4    0.0000    0.1250
 755    4    0.0000    0.1000
 749    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.42735E-2 .42734E-2 .42615E-2 .41166E-2 .36178E-2 .27644E-2 .18218E-2 .10487E-2
.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
.19000E-6 .60000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 750    1   48    0                                                  6-17
```

```
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .39500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 751    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 752    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.21368E-1 .21367E-1 .21307E-1 .20583E-1 .18089E-1 .13822E-1 .91087E-2 .52434E-2
.26857E-2 .12460E-2 .53163E-3 .21127E-3 .79000E-4 .28030E-4 .95000E-5 .30900E-5
.97000E-6 .30000E-6 .90000E-7 .30000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
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.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
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.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
.25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0 .25000E+0
 753    1   48    0                                              6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.17094E-1 .17094E-1 .17046E-1 .16466E-1 .14471E-1 .11057E-1 .72870E-2 .41947E-2
.21485E-2 .99678E-3 .42531E-3 .16901E-3 .63200E-4 .22420E-4 .76000E-5 .24700E-5
.78000E-6 .24000E-6 .70000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
```

```
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
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.20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0 .20000E+0
 754    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.10684E-1 .10684E-1 .10654E-1 .10291E-1 .90446E-2 .69109E-2 .45544E-2 .26217E-2
.13428E-2 .62299E-3 .26582E-3 .10563E-3 .39500E-4 .14010E-4 .47500E-5 .15500E-5
.49000E-6 .15000E-6 .40000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
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.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
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.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
.12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0 .12500E+0
 755    1   48    0                                                  6-17
.00000E+0 .20000E+1 .40000E+1 .60000E+1 .80000E+1 .10000E+2 .12000E+2 .14000E+2
.16000E+2 .18000E+2 .20000E+2 .22000E+2 .24000E+2 .26000E+2 .28000E+2 .30000E+2
.32000E+2 .34000E+2 .36000E+2 .38000E+2 .40000E+2 .42000E+2 .44000E+2 .46000E+2
.48000E+2 .50000E+2 .52000E+2 .54000E+2 .56000E+2 .58000E+2 .60000E+2 .62000E+2
.64000E+2 .66000E+2 .68000E+2 .70000E+2 .72000E+2 .74000E+2 .76000E+2 .78000E+2
.80000E+2 .82000E+2 .84000E+2 .86000E+2 .88000E+2 .90000E+2 .90090E+2 .90000E+3
.42735E-2 .42734E-2 .42615E-2 .41166E-2 .36178E-2 .27644E-2 .18218E-2 .10487E-2
.53714E-3 .24919E-3 .10633E-3 .42250E-4 .15800E-4 .56100E-5 .19000E-5 .62000E-6
.19000E-6 .60000E-7 .20000E-7 .10000E-7 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0 .00000E+0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
.10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0 .10000E-0
 0.000000  0.000000  0.000000  1.000000  1.000000  1.000000          1          6-20
 118    1                                                                      6-23a
 897  898  899  900  901  902  903  904  905  906  907  908  726  727  728  729
 730  731  732  916  917  918  919  920  921  922  923  924  925  926  927  928
   1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
  17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
  33   65   97  129  161  193  225  257  289  321  353  385  417  449  481  513
 545  577  609  641  673  705  737  769  801  833  865   64   96  128  160  192
 224  256  288  320  352  384  416  448  480  512  544  576  608  640  672  704
 736  768  800  832  864  896
   0.0000 2000.0000    1    1                                                  6-28
   1                                                                          6-29a
2000.0000                                                                     6-29b
```

```
                                                                    1
two-dimensional model for ILAW (9/23/99) VAM3DF 1.0 (m/y/g)
    1   -1   -1    0    3 3000 6890 3328    1    0    2    0    0    0    1    0    GRP3
    1    1   20    3    2      0.02        0.0    0    0    0      0.0    2    0    2GRP4
    0    1    0    0    2    0  -50    0    0    1   -1    0    0    0    0    1    GRP5
    0.0E+0  2.73E-6       1.1    1.0E+1   2.73E-4   2.00E+3                        GRP6a
   -5.0E+0                                                                        GRP7
    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
```

2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2

```
1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
```

```
   18    1-0.980E+02
   19    1-0.980E+02
   20    1-0.980E+02
   21    1-0.980E+02
   22    1-0.980E+02
   23    1-0.980E+02
   24    1-0.980E+02
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    0    1    0    0    2    0  -50    0    0    1   -1    0    0    0    0    1    GRP5
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-8.000E+00-8.000E+00-8.000E+00-8.000E+00-8.000E+00-8.000E+00-8.000E+00-8.000E+00-8.000E+00

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APPENDIX G

Geologic Data Package for 2001 Immobilized Low-Activity Waste Performance Assessment

S. P. Reidel
D. G. Horton

December 1999

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352

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Summary

This database is a compilation of existing geologic data from both the existing and new immobilized low-activity waste disposal sites for use in the 2001 Performance Assessment. Data were compiled from both surface and subsurface geologic sources. Large-scale surface geologic maps, previously published, cover the entire 200-East Area and the disposal sites. Subsurface information consists of drilling and geophysical logs from nearby boreholes and stored sediment samples. Numerous published geological reports are available that describe the subsurface geology of the area. Site-specific subsurface data are summarized in tables and profiles in this document.

Uncertainty in data is mainly restricted to borehole information. Variations in sampling and drilling techniques present some correlation uncertainties across the sites. A greater degree of uncertainty exists on the new site because of restricted borehole coverage. There is some uncertainty to the location and orientation of clastic dikes across the sites.

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1.0 INTRODUCTION

The Office of River Protection at the Hanford Site is responsible for safe underground storage of liquid waste from previous Hanford Site operations, storage and disposal of immobilized tank waste, and closure of underground tanks. The current plan is to place immobilized low-activity tank waste (ILAW) in four existing vaults along the east side of 200-East Area and in new facilities in the south-central part of 200-East Area (Figure 1.1) (Mann et al. 1998).

This report is a compilation of geologic information for the existing disposal site and the new ILAW disposal site. This data package is being assembled for the 2001 ILAW Performance Assessment (PA). Basic requirements for the ILAW Performance Assessment are defined in Mann et al. (1998). Specific scenarios that will be considered in the 2001 PA are discussed in Mann (1999). These scenarios assume that the main pathway for exposure from the ILAW sites involves water movement into and through the disposal facilities with dissolution of waste followed by transport of contaminants through the vadose zone to the unconfined aquifer and transport in the aquifer to a water supply well. Estimates of possible exposure will be made from predictions of subsurface flow and contaminant transport using numerical simulations. The geologic framework for the numerical model will be developed from this report.

1.1 SCOPE

Data for the 2001 performance assessment will be derived from the following sources:

- **Geology**. Geologic Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment (this report).
- **Near-Field Hydrology**. Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment (Meyer and Serne 1999).
- **Far-Field Hydrology**. Far-Field Hydrology Data Package for the Immobilized Low-Activity Tank Waste Performance Assessment (Khaleel 1999).
- **Recharge**. Recharge Data Package for the Immobilized Low-Activity Waste 20001 Performance Assessment (Fayer et al. 1999).
- **Geochemistry**. Geochemical Data Package for the Immobilized Low-Activity Tank Waste Performance Assessment (Kaplan and Serne 1999).
- **Inventory**. Immobilized Low-Activity Waste Inventory Data Package (Wootan 1999).

The geology data provided in this report concentrate principally on stratigraphy and structure of the two areas. The mineralogy of sediments and their geochemistry is presented in the geochemistry data package. The physical, hydraulic, and transport properties of the soils sediments are presented in the far-field data package and the near-field data package.

This geology data package is a compilation of the basic stratigraphic and structural framework of the two sites and a description of the principal sediments. In addition, this report includes a summary on the sources and uncertainties of the data.

It is beyond the scope of this report to integrate the physical, hydraulic, and transport properties reported in the other data packages. An integration of all the physical, hydraulic, and transport properties of the stratigraphic layers from the ILAW sites will be done in preparation for the numerical simulations for the PA.

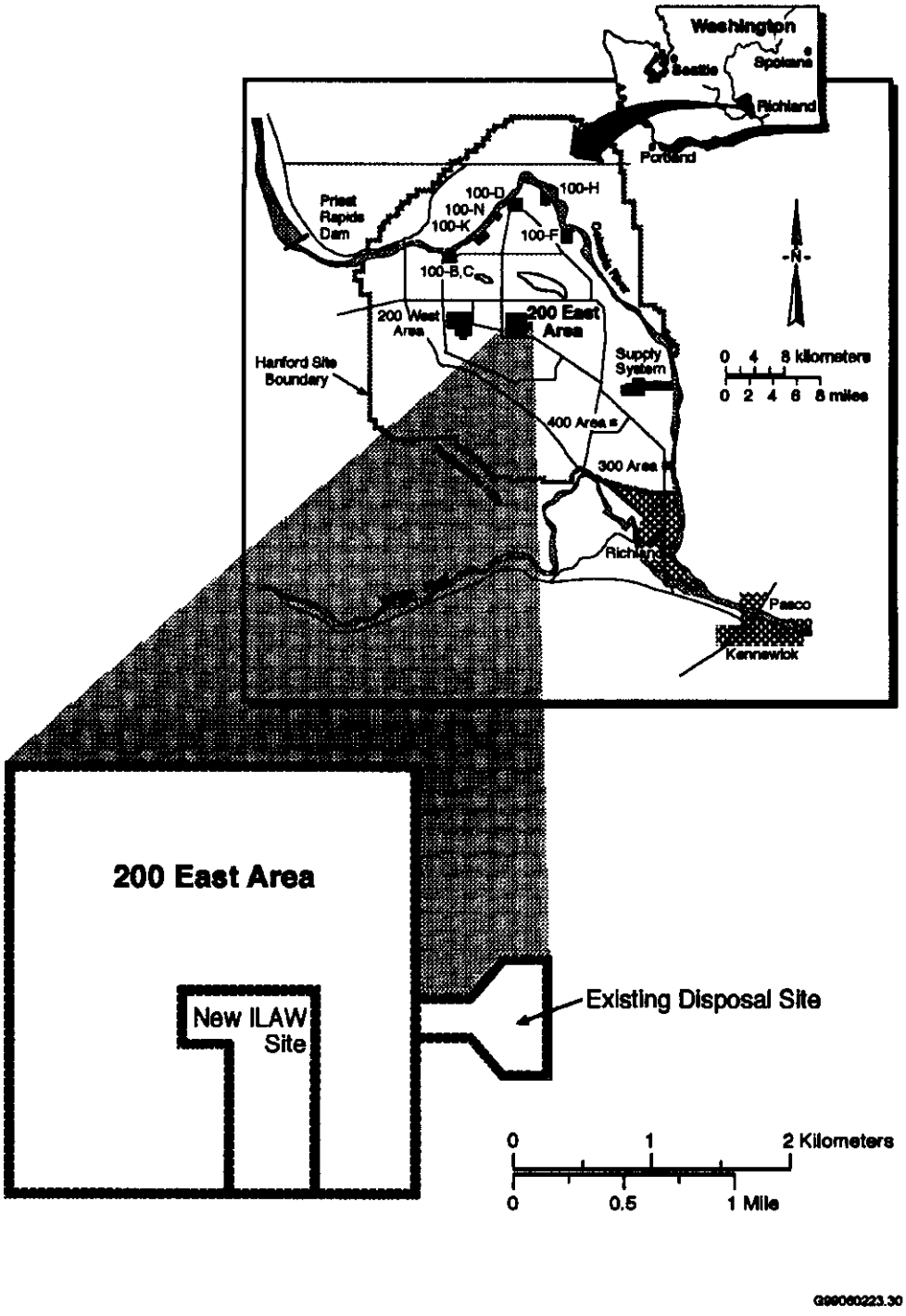

Figure 1.1. Location Map of the Existing Disposal Site and the New ILAW Disposal Site

2.0 SOURCE OF DATA

Data used in this compilation was obtained from surface geologic studies and from borehole data.

2.1 SURFACE DATA

The surface geology and geomorphology of the Hanford Site has been mapped and published by Reidel and Fecht (1994a, 1994b). The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains physiographic region and anticlinal ridges of the Yakima Folds physiographic region. Surface topography has been modified within the past several million years by geomorphic processes related to 1) Pleistocene cataclysmic floods, 2) Holocene eolian activity, and 3) landslides.

Cataclysmic flooding of the Hanford Site occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Anastomosing flood channels, giant current ripples, bergmounds, and giant flood bars are among the landforms created by the floods and are readily seen on Site. Most of the large landslides in the region occurred when these flood waters eroded steep slopes of the anticlinal ridges and along the White Bluffs.

The 200-East Area is located on the Cold Creek bar, one major Pleistocene flood bar. Since the end of the Pleistocene, winds have locally reworked the flood sediments, depositing sand dunes in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Sand dunes have generally been stabilized by anchoring vegetation except where the dunes have been reactivated when vegetation is disturbed.

2.2 BOREHOLE SOURCES

Borehole data consisting of drilling logs, archive samples, and geophysical logs provide the principal data used to interpret the subsurface at the existing disposal site and the new ILAW disposal site. In addition, numerous reports describing the geology of the area and vicinity are available and a valuable source of information (e.g., Tallman et al. 1979; DOE 1988; Connelly et al. 1992; Lindberg et al. 1993; Lindsey et al. 1992, 1994b).

Tables 2.1 and 2.2 summarize information about the wells and boreholes used in this report. The north-south and east-west coordinates listed in Tables 2.1 and 2.2 were obtained from the well completion report for each borehole or, if no well completion report was available, from the well location database maintained by Pacific Northwest National Laboratory (PNNL). If several surveys for the same well were found in the database, the most recent survey was used. The specific survey associated with borehole locations obtained from well completion reports is not known but should not affect significantly the information in this data package.

Table 2.1. Borehole Information for Some Boreholes in and Adjacent to the Existing Disposal Site

Borehole #	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (ft)	Casing Elevation (ft)	NAVD88, TOC[a] (m)	Ground Surface Elevation (ft) (brass plate)	Total Depth (ft)	Type of Log	Drilling Method[b]	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
299-E16-1	Jan. 1961	135219.906/ 575782.65	38505/-46303	696.44		694.3	510	Driller		Yes			Yes		Yes
299-E25-1	Feb. 1955	136031.16/ 575366.21	41165/-47759	690.57	211.56	690.21	322	Driller	Hard tool (nom)	Yes					Yes
299-E25-2	Mar. 1955	136062.15/ 575513.98	41270/-47190	675.45	206.95	673.6	375	Driller	Hard tool (nom)	Yes			Yes		Yes
299-E25-22	Jun. 1983	135609.375/ 575998.483	39776.4/ -45588.8	674.02		671.66	295	Driller	DB 0 - 190; HT 191 - 295.	Yes					Yes
299-E25-25	Apr. 1985	135984.406/ 576388.887	41002.00/ -43648.00	699.42	205.13	~672	288	Geologist	DB 0 - 170; HT 170 - 288	Yes		Yes	Yes	Yes	Yes
299-E25-26	Apr. 1985	135912.861/ 575907.504	40772.82/ -45884.46	668.55	204.85	668.51	290	Geologist	DB 0 - 160; HT 160 - 205	Yes		Yes	Yes		Yes
299-E25-27	May 1985	135633.91/ 576136.46	39855.23/ -45135.71	676.08	207.16	674.06	300	Geologist	DB 0 - 155; HT 155 - 300			Yes	Yes	Yes	Yes
299-E25-28	Mar. 1985	136111.693/ 576011.773	41424.00/ -45541.00	662.44		660.34	348	Geologist	DB 0 - 200; HT 200 - 348	Yes			Yes		Yes
299-E25-29	Sept. 1987	135729.161/ 575953.668	40169.4/ -45734.77	672.84	206.17	672.07	336	Geologist	DB 40 - 205; HT 205 - 336	Yes			Yes	Yes	Yes
299-E25-30	Oct. 1987	135589.913/ 576208.357	39710.36/ -44900.42	678.15	207.78	677.24	330	Geologist	DB 0 -178; HT 178 - 330	Yes			Yes	Yes	Yes
299-E25-31	July 1987	135772.251/ 575948.016	40311.20/ -45752.9	674.64	206.65	671.66	298	Driller	Air rotary	Yes			Yes	Yes	Yes
299-E25-32	Jan. 1988	136044.335/ 576382.422	41199.17/ -44325.6	670.38	205.31	668.07	354	Geologist	DB 0 -180; HT 180 - 354	Yes			Yes	Yes	Yes
299-E25-33	Jan. 1988	135713.014/ 575992.033	40116.4/ -45609.0	674.97	205.3	672	400	Geologist	DB 0 -190; HT 190 - 400						Yes
299-E25-34	Sept. 1988	136100.011/ 576019.038	41385.90/ -45516.85	662.87	203.12	660.62	276	Geologist	DB 0 -160; HT 160 - 276						Yes
299-E25-35	Aug. 1988	135864.687/ 575708.338	40616.66/ -46538.50	674.39	206.64	670.89	285	Geologist	DB 0 - 220; HT 220 - 285				Yes	Yes	Yes
299-E25-37	Sept. 1989	135818.4/ 575949.2	40461.5/ -45749.2	673.29	206.34	670.29	280	Geologist	DB 0 - 198; HT 198 - 280				Yes	Yes	Yes

Table 2.1. (contd)

Borehole #	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (ft)	Casing Elevation (ft)	NAVD88, TOC[a] (m)	Ground Surface Elevation (ft) (brass plate)	Total Depth (ft)	Type of Log	Drilling Method[b]	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
299-E25-38	Sept. 1989	135695.2/ 576034.9	40056.4/ -45469.0	673.52	206.38	670.54	283	Geologist	DB 0 - 202; HT 202 - 283				Yes	Yes	Yes
299-E25-39	Oct. 1990	135837.27/ 576581.88	40518/-43673	671.01	205.65	668.45	282.35	Geologist	DB 0 - 207, 210 - 262; HT 207 - 210, 262 - 282		Yes	Yes	Yes	Yes	Yes
299-E25-40	Sept. 1989	136212.317/ 575464.675	41759.6/ -47334.8	665.71		662.8	274	Geologist	DB 0-274				Yes		Yes
299-E25-41	Sept. 1989	136145.925/ 575466.061	45541.8/ -47330.9	671.26		668.1	279	Geologist	DB 0 - 225; HT 225 - 279				Yes		Yes
299-E25-42	Aug. 1991	135887.6/ 575622.8	40692/-46820.1	683.29	209.33	679.71	294.68	Geologist	DB 0 - 19; HT 191-		Yes	Yes	Yes		Yes
299-E25-43	Aug. 1991	136251.5/ 576132.3	41881.7/ -45144.9	649.89	199.15	646.52	259.7	Geologist	DB 0 - 260		Yes	Yes	Yes		Yes
299-E25-44	Jun. 1992	135656.93/ 576185.55		675.29	206.84	672.9	293.3	Geologist	Air rotary		Yes	Yes	Yes	Yes	Yes
299-E25-45	Aug. 1992	135659.15/ 576185.55		678.45	207.81	675.74	297.65	Geologist	Air rotary		Yes	Yes	Yes	Yes	Yes
299-E25-48	Aug. 1992	135815.16/ 575623.43		682.31	208.98	679.68	297.5	Geologist	Rotary 0 - 265; DB 265 - 297		Yes	Yes	Yes		Yes
299-E25-49	Aug. 1993	135668.325/ 576291.697		678.66	207.88	675.44	293	Geologist	Air rotary		Yes	Yes	Yes	Yes	Yes
299-E25-50	Sept 1993	135681.613/ 576399.049		677.6	207.56	675.32	294.2	Geologist	Air rotary		Yes	Yes	Yes	Yes	Yes
299-E25-234	Sept. 1987		40547.2/ -45618.5			622	141	Geologist	SS 0 - 59 ft; DB 59 - 141	Yes					Yes
299-E25-235	Oct. 1987		40054/-45185				174	Geologist	DB	Yes					Yes
299-E25-1000	Oct. 1993	135737.654/ 576478.436		674.4	206.58	670.96	391.89	Geologist	Air rotary		Yes	Yes	Yes	Yes	Yes

Table 2.1. (contd)

Borehole #	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (ft)	Casing Elevation (ft)	NAVD88, TOC[a] (m)	Ground Surface Elevation (ft) (brass plate)	Total Depth (ft)	Type of Log	Drilling Method[b]	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
299-E26-12	Aug. 1991	136383.2/ 576197.7		630.75	193.31	627.27	242.2	Geologist	DB		Yes	Yes	Yes		Yes
699-41-42	Feb. 1992	136068.17/ 577122.21		643.91		640.32	342.92	Geologist	Rotary		Yes	Yes			Yes
699-42-42B	Oct. 1988	136433.923/ 579998.097	42472.9/ -42301.3	583.23		579.83	250	Geologist	DB 0 - 109, 161 - 180; HT 109 - 160, 181 - 250	Yes			Yes		Yes
699-43-42K	Jan. 1989	136445.203/ 576997.5	42309.0/ -42304.3	581.38		579.03	263	Geologist	DB 0 -111; HT 112 - 263				Yes		Yes

(a) TOC = Top of casing.
(b) Drill Method: DB = Drive Barrel, HT = Hard Tool.

Table 2.2. New ILAW Disposal Site Borehole Database

Borehole #	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (ft)	Casing Elevation (ft)	Quality	Ground Elevation (ft)	Total Depth (ft)	Type of Log	Drilling Method	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
E13-10	1984	134249.07/ 573190.57	33348/-54798	733	Good	NA	346	Geologist	Cable tool						
E17-12	1986	135118.36/ 574902.94	38200/-49180	719	Good	NA	340	Geologist	Cable tool						
E17-13	1986	135164.69/ 574902.94	38352/-49039	719	Good	NA	337	Geologist	Cable tool						
E17-17	1988	135201.57/ 575044.06	38473/-48717	720	Good	717	331	Geologist	Cable tool				Yes		
E17-18	1988	135115.31/ 575109.99	38190/ -48500.7	721	Good	718	332	Geologist	Cable tool				Yes		
E17-20	1988	135407.71/ 574936.49	39149.3/ -49069.9	719	Good	717	324	Geologist	Cable tool				Yes		
E17-21	1998	134894.21/ 574107.02	NA	737	Good	735	480	Geologist	Becker hammer	Yes	Yes	Yes	Yes (spectral gamma)	Yes	Yes
E18-1	1988	135197.30/ 573294.20	38459/-54458	720	Good	716	332	Geologist	Cable tool	Yes	Yes		Yes		Yes
E18-3	1988	135274.42/ 573426.85	38712/ -54022.8	722	Good	718	330	Geologist	Cable tool	Yes	Yes		Yes		Yes
E18-4	1988	135755.82/ 573426.48	38651/-54024	722	Good	718	330	Geologist	Cable tool	Yes	Yes		Yes		Yes
E19-1	1957	135083.31/ 572817.19	38085/-56023	736	Poor	NA	370	Driller's	Cable tool				Yes		
E23-1	1956	136011.73/ 574043.40	41131/-52000	710	Fair	NA	348	Driller's	Cable tool	Yes	Yes		Yes		Yes
E23-2	1961	135667.00/ 573738.60	40000/ -53000	721	Fair		456	Driller's	Cable tool				Yes		
E24-4	1956	136027.24/ 575115.44	41181.9-48482.8	697	Fair	NA	330	Driller's	Cable tool				Yes		
E24-7	1956	135554.38/ 574405.20	39630.5/ -50813	716	Poor	NA	450	Driller's	Cable tool	Yes	Yes				Yes

Table 2.2. (contd)

Borehole #	Completion Date	Lambert Coordinates NS/EW (m)	Hanford Coordinates NS/EW (ft)	Casing Elevation (ft)	Quality	Ground Elevation (ft)	Total Depth (ft)	Type of Log	Drilling Method	Sieve	$CaCO_3$	Moisture	Gross Gamma-Ray Log	Neutron Log	Drill Cuttings
E24-16	1988	135456.54/ 575016.14	39309.5/ -48808.6	718	Good	715	329	Geologist	Cable tool				Yes		
E24-17	1988	135456.32/ 574936.34	39308.8/ -49070.4	719	Good	716	329	Geologist	Cable tool				Yes		
E24-18	1988	135463.0/ 574645.59	39330.7/ -50024.3	719	Good	716	330	Geologist	Cable tool				Yes		
E37-47A	1996	134893.26/ 575556.97	37430.58/ 47044.23	717	Good	715	525	Geologist	Air Rotary	Yes	Yes	Yes	Yes	Yes	Yes

NA = Not available.

Elevation information listed in Tables 2.1 and 2.2 were obtained from well completion reports or as-built diagrams if available, or from Chamness and Merz (1993). Because several different borehole surveys have been used at the Hanford Site over the years, no attempt was made to assure consistency in the elevation survey data. However, differences among surveys are generally small (<3 feet [1 m]) compared to other uncertainties associated with the data (see discussion on uncertainties) and, except for water levels in areas with a relatively flat water table, will not affect significantly the information presented in this database. The well completion dates for the boreholes, the total depths, and the types of boreholes were obtained from well completion reports, as-built diagrams, and Chamness and Merz (1993).

Particle size distribution and calcium carbonate content information are available for some boreholes from the ROCSAN database. The database is no longer maintained but is on file at PNNL. Tables 2.1 and 2.2 indicate the drilling method used for each borehole. ROCSAN data was only considered for intervals in boreholes sampled by drive barrel because hard tool drilling pulverizes the sediments so that results are not representative of actual particle size distribution. The drilling method was obtained from geologists logs, well construction reports, and as-built diagrams for most boreholes. Appropriate particle size distribution data from ROCSAN was used as supplemental textural information but, because of varying data quality, it is not included in this report. The Khaleel (1999) and Fayer et al. (1999) report on particle size data from the two disposal sites are the best compilation of particle size information from the two sites for the ILAW 2001 PA. Meyer and Serne (1999) report similar data on near-field material for the two sites.

Calcium carbonate and moisture contents are available for some boreholes. Available data are in borehole packages on file at PNNL and in the ROCSAN database. The data were obtained from discrete samples collected by the borehole geologist during drilling. Moisture data were used to supplement the geologists log and the gross gamma-ray log in determining lithologic variations. For obvious reasons, moisture data is only valuable for samples collected above the water table. Khaleel (1999) and Fayer et al. (1999) report moisture data from the disposal sites and should be referred to for the best compilation of moisture data from these sites.

Gross gamma-ray logs and neutron moisture logs exist for many of the boreholes used for this report. If at all possible, logs obtained during drilling were used to supplement geologist logs. This is important for moisture measurements because most of the geophysical logs obtained subsequent to borehole completion reflect borehole construction materials more than they do geologic materials. Available logs listed in Tables 2.1 and 2.2 are on file at PNNL.

Finally, drill cuttings are available from most boreholes used for this report. The same precautions pertaining to ROCSAN data pertain to physical samples. That is, drill cuttings obtained from hard tool drilling methods will yield an unrepresentative particle size distribution. Uncertainties in these data are discussed in Section 3.0. All available physical samples are on file in the Hanford Geotechnical Sample Library under custody of PNNL.

2.3 METHODOLOGY

The process of building the data package followed a series of steps designed to ensure data were used properly. First, the main stratigraphic units and contacts were identified in boreholes with geologists logs and geophysical data. Gross gamma-ray logs were examined with respect to geologist logs for geophysical signatures of the stratigraphy. For many boreholes from both sites, chip samples from the Hanford Geotechnical Sample Library were examined to help control the location of contacts and lithologies of stratigraphic units and lateral changes in the percentage of silt, sand, and gravel. Next, boreholes with driller's logs and gross gamma-ray logs were examined and compared to nearby wells and boreholes. Lastly, boreholes with only driller's logs were given the least priority for constructing the geologic models. These data were then used to construct the maps and cross sections in Section 4.0.

3.0 UNCERTAINTY IN DATA

The principal source of uncertainty is in borehole data. Surface mapping is well controlled at Hanford and has been done by geologists with extensive mapping experience at Hanford and in the Columbia Basin. The quality of borehole data is related to drilling technique, logging of the boreholes, and sample collection. Borehole data collection methods (i.e., grab samples) make subtle differences between some stratigraphic units such as silty sandy layers of the Hanford formation and units of the underlying Ringold Formation (e.g., upper Ringold) difficult to identify. The use of geophysical logs is crucial to reducing uncertainty in poor quality driller and geologists logs.

In addition to the uncertainty in borehole data, there is uncertainty in the geometric shape of the sediment body. Lindsey (1996) provides a detailed depositional model for the Ringold Formation but few models are available on the Hanford formation. Borrow pits and excavation sites at Hanford (e.g., FFTF, tank farms, burial grounds, US Ecology) in the Pasco Basin provide information on the geometric shape of a sediment body but boreholes remain the principle means of collecting data to interpret the subsurface.

3.1 DRILLING METHODS

Most boreholes at and near the existing disposal site and the new disposal site have been drilled using cable tool techniques and, less often, air rotary techniques. Only the new ILAW borehole, 299-E17-21, was drilled using the Becker-Hammer technique that allowed high quality core samples to be recovered.

Cable tool drilling has been the standard technique from earliest drilling at Hanford because drilling can be done without adding water; unfortunately, many drillers routinely added water. Drilling techniques include use of drive barrel or hard tool and by driven temporary or permanent casing. The technique generally provides acceptable sample control and has proven successful. More recently, in uncontaminated areas, air rotary has been the preferred technique. Samples obtained from most drilling methods have inherent disadvantages. These disadvantages include:

- **Limited sample size**. The diameter of the borehole and length of the sampling device control the size of the sample.
- **Retention of samples**. Dry sediment samples are difficult to retain in any sampling device. This is especially true in drive barrels but also true of core barrels.
- **Gravel retrieval**. Unconsolidated gravels are not easily retained in drive barrels. Split spoon samples have better success.
- **Depth control**. Except for cored samples, the exact depth of a sample is not well controlled because part of the sample may be lost or sluffing may occur.

- **Cemented gravels.** Cemented gravels or large gravels must be sampled using a "hard tool." All drilling methods requiring hammered drilling and sampling including a split spoon breaks up the sample. Cemented gravels have been successfully cored but some loss is always to be expected.

Most boreholes prior to the 1980s were drilled without a well-site geologist to log samples. Thus, the only records of early drilling are driller's logs that vary in quality of the sample description. Driller's logs reflect lack of geologic knowledge, detailed descriptions, and accuracy of sampling interval. The quality of the geologists logs also varies from borehole to borehole. For example, a geologist new to the site will recognize the major sediment changes in drill cuttings but may not recognize the subtler changes that also represent changes in stratigraphy. Various procedures used to log sediments can result in different descriptions, which may not be directly comparable to other borehole sample descriptions.

Many boreholes at Hanford were completed without the benefit of being geophysically logged. Geophysical logging can be an important tool for determining lithologic changes. Geophysical logs show subtle lithology differences stemming from differing amounts of natural gamma-ray emitters (most commonly ^{40}K). At Hanford, gamma-ray logs typically indicate clay and silt abundance and can provide information on changes in grain size. When geophysical logs are used along with well-site geologist's logs and archived samples, the uncertainty of the depth of lithologic changes is reduced.

3.2 BOREHOLE LOCATION AND COVERAGE

Borehole coverage is usually dictated by factors other than just addressing a geologic problem. Therefore, the coverage of boreholes is generally inadequate to address many geologic problems. For the existing disposal site, there is borehole coverage for most of the area because of siting studies for the Grout Treatment project. Borehole coverage is less than adequate for the new ILAW disposal site because there are no existing waste disposal site studies. Borehole data is particularly poor on the east side of the new ILAW disposal site.

3.3 SAMPLING

Sample retrieval is often difficult and sample quantities are limited. Vadose zone drilling is difficult for sample recovery because the samples are typically dry and are not easily retained in the drive barrel. As indicated above, grain size of the sample can also be affected by drilling techniques such as in "hard tool" drilling or sonic drilling.

In order to perform certain tests, samples from several depths often must be composited. Also, certain tests performed on samples in the past may also have destroyed the integrity of the sample. In the past, particle size testing resulted in loss of fines, which were discarded before samples were returned to the Hanford Geotechnical Sample Library.

4.0 GEOLOGY

4.1 GENERAL HANFORD STRATIGRAPHY

4.1.1 Surface Geology and Geomorphology

Previous studies (DOE 1988) have discussed the general geomorphology of the 200 Areas. These studies describe the 200 Areas as a flood bar (200 Areas plateau) that formed as sediments were deposited by the Missoula floods during Pleistocene. The topographic low area immediately east of 200-East Area is an erosional channel cut by Missoula flood waters that moved south through Gable Gap.

The principal geologic units exposed at the surface are glacial fluvial and eolian sands (Reidel and Fecht 1994a, 1994b) (Figure 4.1). The fluvial sands were deposited by Missoula floods and have since been reworked by westerly winds to form a thin veneer of parabolic dunes.

4.1.2 Subsurface Geology

The existing and new disposal sites are in a sequence of sediments that overlie the Columbia River Basalt Group on the north limb of the Cold Creek syncline. These sediments include the upper Miocene to Pliocene Ringold Formation, Pleistocene cataclysmic flood gravels, sands and silt of the Hanford formation, and Holocene eolian deposits (Figures 4.1 and 4.2).

The main nomenclature employed in this report is consistent with the standardized use for the Hanford Site (i.e., Delaney et al. 1991; Reidel et al. 1992; Lindsey et al. 1994a, 1994b; Lindsey 1996) and the new ILAW disposal site (Reidel et al. 1998). Subdivision of some units is inconsistent across the sites because of the difficulty in correlating beds over great distances. Following geologic convention, the discussion in this report proceeds from oldest to youngest units. In addition, this report will use feet rather than meters following the convention used in borehole data.

Rocks underlying the 200-East Area consists of the Elephant Mountain Member of the Saddle Mountains Basalt, Columbia River Basalt Group overlain by the Ringold Formation and the Hanford formation. The Elephant Mountain Member consists of two lava flows totaling approximately 100 ft (30 m) in thickness and forms the base of the unconfined aquifer at 200-East Area.

The Ringold Formation consists of fluvial and lacustrine sediments deposited by the ancestral Columbia and Clearwater-Salmon river systems between about 3.4 and 8.5 Ma. Lindsey (1996) described the Ringold Formation in terms of three informal members: 1) the member of Wooded Island, 2) the member of Taylor Flat, and 3) the member of Savage Island. Of these, only the member of Wooded Island is present beneath the 200-East Area (Figure 4.2).

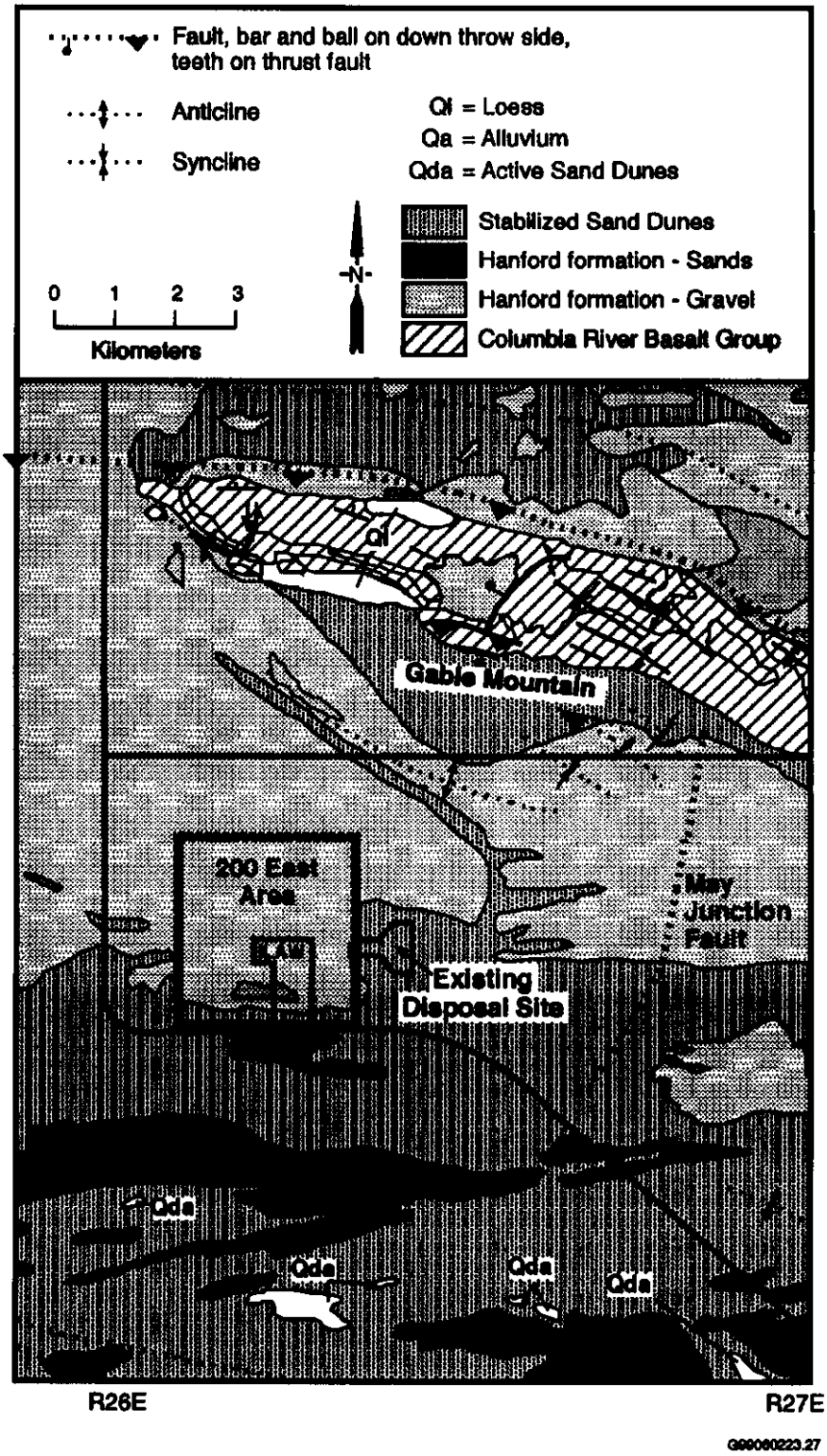

Figure 4.1. Geologic and Geomorphic Map of the 200-East Area (dashed geologic structures indicate they are buried by younger units) (From Reidel and Fecht [1994a, 1994b])

Nomenclature Used in this Report		Equivalent of Lindsey et al. (1994a), Lindsey (1996), and Reidel et al. (1992)	Equivalent of Reidel and Fecht (1994a, 1994b)
Eolian			Qd
Hanford formation		H	Qfs and Qfg
Sandy Sequence	Layer 3	H2	Qfs_3
	Layer 2	H2	Qfs^2
	Layer 1	H2 and HZA	Qfs_1(?)
Basal Gravel Sequence		H3	Qfs_1(?)
Ringold Formation, Member of Wooded Island		Ringold Formation, Member of Wooded Island	P_LM
	Unit E	Unit E	P_LMcg
	Lower Mud	Lower Mud	P_LMc
	Unit A	Lower A	P_LMcg

Figure 4.2. Generalized Stratigraphy of the Hanford Site and New ILAW Disposal Site

The member of Wooded Island consists of five separate units dominated by fluvial gravels (conglomerate). The gravels are designated (from bottom to top) as units A, B/D, C, and E. The gravel units are separated by fine-grained deposits typical of overbank and lacustrine environments. The lowermost of the fine-grained sequences is designated the lower mud unit. Only gravel units A and E are present beneath the 200-East Area and the Ringold Formation is entirely absent beneath the north and northeast parts of the 200-East Area (Lindsey et al. 1992, 1994b).

The Ringold Formation conglomerate is a variably indurated clast- and matrix-supported, pebble to cobble gravels with a fine to coarse sand matrix (Lindsey 1996). The most common lithologies are basalt, quartzite, and intermediate to felsic volcanics. Interbedded lenses of silt and sand are common. Cemented zones within the gravels are discontinuous and of variable thickness. In outcrop, the gravels are massive, planer bedded, or cross-bedded. Lying above the Ringold gravels are silts and sands of the upper Ringold, the member of Taylor Flats, which is not generally present beneath the 200-East Area.

The Hanford formation overlies the Ringold Formation. The Hanford formation consists of glacio-fluvial sediments deposited by cataclysmic floods from Glacial Lake Missoula, Pluvial Lake Bonneville, and ice-margin lakes. Hanford formation sediments resulted from at least four major glacial events and were deposited between about 1 Ma and 13 Ka. The formation consists of pebble- to boulder-gravel, fine- to coarse-grained sand, and silt- to clayey-silt. These deposits are divided into three facies: 1) gravel-dominated facies, 2) sand-dominated facies, and 3) silt-dominated facies (Reidel et al. 1992; Lindsey et al. 1992, 1994a, 1994b). These same facies are referred to as coarse-grained deposits, plane-laminated sand facies, and rhythmite facies, respectively, in Bjornstad et al. (1987) and Baker et al. (1992). The Hanford formation is present throughout the Hanford Site and is as much as 380 ft (116 m) thick (Delaney et al. 1991).

- Gravel-dominated facies - This facies generally consists of coarse-grained basaltic sand and granule to boulder gravel. These deposits display an open framework texture, massive bedding, plane to low-angle bedding, and large-scale planar cross bedding in outcrop. Silt content is variable and local interbedded silt and clay have been observed in outcrop. Clay and silt have been found as coatings on clasts but generally not filling open spaces between clasts. The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channelways.

- Sand-dominated facies - This facies consists of fine- to coarse-grained sand and granule gravel. The sands typically have a high basalt content and are commonly referred to as black, gray, or salt-and-pepper sands (Lindsey et al. 1992). They may contain small pebbles and rip-up clasts, pebble-gravel interbeds, and silty interbeds less than 3 ft (1 m) thick. The silt content of the sands is variable, but where it is low a well-sorted and open framework texture is common. The sand facies was deposited adjacent to main flood channelways during the waning stages of flooding. The facies is transitional between the gravel-dominated facies and the silt-dominated facies.

- Silt-dominated facies - This facies consists of thin bedded, plane-laminated and ripple cross-laminated silt and fine- to coarse-grained sand. Beds are typically a few centimeters to several tens of centimeters thick and commonly display normal grading (Myers et al. 1979; Bjornstad et al. 1987; DOE 1988). Local clay-rich beds occur in the silt-dominated facies and paleosols have been observed in core from the 200-East Area. Sediments of this facies were deposited under slack water conditions and in back flooded areas (DOE 1988).

4.1.3 Clastic Dikes

Clastic dikes are vertical to subvertical sedimentary structures that cross cut normal sedimentary layering and could effect the vertical movement of water and contaminants. Clastic dikes are a common geologic feature of Pleistocene flood deposits of the Hanford formation although they also have been found in the underlying Ringold Formation and in Columbia River Basalt Group and intercalated sedimentary interbeds. Clastic dikes at Hanford have been described in detail by Fecht et al. (1998).

Clastic dikes typically occur in swarms and occur as regular-shaped polygonal-patterns; irregular-shaped polygonal-patterns; pre-existing fissure fillings; and random occurrences. Regular polygonal networks resemble 4- to 8-sided polygons. Dikes in irregular-shaped polygon networks are generally crosscutting in both plan and cross-section resulting in extensive segmentation of the dikes. Where zones of pre-existing weakness occur, clastic dikes often occur in these zones.

Clastic dikes typically show a wide range in widths, depths, and lengths. The vertical extent of clastic dikes has been observed to range from 30 cm to greater than 55 m. Clastic dike widths ranges from about 1 mm to greater than 2 m and their length varies from as little as 0.3 m to more than 100 m.

In general, a clastic dike is composed of an outer skin of clay with coarser infilling material. Clay linings are commonly 0.03 mm to 1.0 mm thick, but linings up to about 10 mm are known. The clay skins may have a great influence on transport both within and adjacent to the clastic dikes. The width of individual infilling layers range from as little as 0.01 mm to more than 30 cm and their length can vary

from about 0.2 m to more than 20 m. Infilling sediments are typically poor to well-sorted sand, but may contain clay, silt, and gravel.

Clastic dikes have been noted in the Hanford formation sand sequence in the existing disposal site (Lindberg et al. 1993) and are suspected to occur but have not been identified at the new disposal site. At the existing disposal site, clastic dikes have not been mapped and their number and distribution are not known. Clastic dikes have been found in numerous locations on the 200 Area plateau where they occur primarily in polygonal networks with dimensions ranging from 30 to 240 m (Fecht et al. 1998). The total depth of the clastic dikes in the existing disposal site is also unknown but they extend below the bottom of the excavations for the former Grout Treatment Facility (Lindberg et al. 1993).

4.2 EXISTING DISPOSAL SITE

4.2.1 Previous Investigations

In 1988, Swanson et al. reported the existing knowledge of the subsurface geology of the existing disposal site area. Their report included geologic cross-sections, available particle size distribution data, chemical analyses of 47 sediment samples from boreholes, and sediment moisture data.

Swanson (1992) published the borehole completion package containing all known data from the then new RCRA borehole 299-E25-39 within the existing disposal facility. A gross gamma-ray borehole log, moisture and $CaCO_3$ contents, and a geologists log are included in that report. Similar reports are available for boreholes 299-E25-37 and 299-E25-38 (Swanson 1993) and boreholes 299-E25-49, -50, and -1000 (Swanson 1994).

Lindberg et al. (1993) updated Swanson's description of the geology and aquifer characteristics of the Grout Disposal site (now the existing disposal facility area). Using geologic logs from approximately 45 groundwater wells in the Grout Facility - B Pond - 241-A, AX area, they produced a set of isopach and structure contour maps for each of the geologic units in their interpretation of the subsurface geology. They also provided two cross-sections through the existing disposal site.

Rockhold et al. (1993) estimated the hydraulic properties of material and sediments that determine the movement of water at the existing disposal facility area. They present particle size, bulk density, and particle density data from selected samples from borehole 299-E25-234 in the existing disposal facility.

In 1998, the TWRS Phase 1 Privatization Site Preconstruction Characterization Report (Mitchell 1998) was issued for the existing disposal site and planned glass melter. That report included ground penetrating radar and electromagnetic induction surveys, and borehole geophysical surveys (spectral gamma-ray and neutron-moisture surveys). Unfortunately, most of the neutron moisture surveys from the existing disposal site are of little use because they reflect borehole construction characteristics rather than geologic characteristics.

Surface geophysical surveys reported by Mitchell (1998) for the existing disposal site interrogated the subsurface to a depth of about 13 ft (4 m). Most of the upper 13 ft (4 m) of the existing disposal facility area consisted of homogeneous sediment interpreted as wind blown Holocene sands and silts. In some areas, however, stratification was observed similar to what is found in inactive sand dunes or possibly the finer sediments of the Hanford formation (Mitchell 1998). In one area, geologically complex stratification was noted where soil stratification was laterally discontinuous possibly, in part, due to clastic dikes (Mitchell 1998). Several clastic dikes were noted in the excavation for the former Grout Treatment Facility.

4.2.2 Site Stratigraphy

Data reported in this document were compiled from 32 boreholes and monitoring wells in and around the existing disposal site. Figure 4.3 shows the location of the boreholes. Table 4.1 is a listing of the boreholes used along with their location, elevation, and construction information pertinent to this report. For this report, boreholes within the existing disposal facility are considered most important. The boreholes outside the existing disposal facility are used to supplement those within the existing disposal facility.

Six lithologic sequences are identified in this data package for performance assessment purposes. These are (from youngest to oldest):

- Recent surface deposits
- Hanford formation sand sequence
- Hanford formation gravel sequence
- Ringold Formation fine-grain sequence at top of Unit A
- Ringold Formation Unit A
- Columbia River Basalt Group.

The vadose zone beneath the existing disposal site is from approximately 250 ft (76 m) to 277 ft (84 m) thick. The vadose zone thins toward the northeast due to a decrease in elevation in that direction and an increase in the elevation of the water table beneath B Pond. With a few exceptions, the water table is in the Ringold Formation fine-grained sequence or just above the sequence in the Hanford formation gravel sequence.

Figure 4.3 shows the locations of the wells in the existing disposal site that were used to interpret the geology and construct the four cross-sections given in Figures 4.4 through 4.7. The cross sections depict the relationships of the lithologic sequences. All data used in constructing the cross sections (and the structure contour maps presented later) are given in Table 4.1. Appendix C provides a more generalized north-south and east-west cross sections depicting the primary features of the area.

The location of cross-section A-A' was chosen to illustrate the geology across the center of the existing disposal site. The exact location was influenced by the locations of existing and newer groundwater wells with the maximum of quality data. The location of cross-section B-B' was chosen to illustrate the geology along the southern portion of the existing disposal site. Likewise, the location of C-C' was

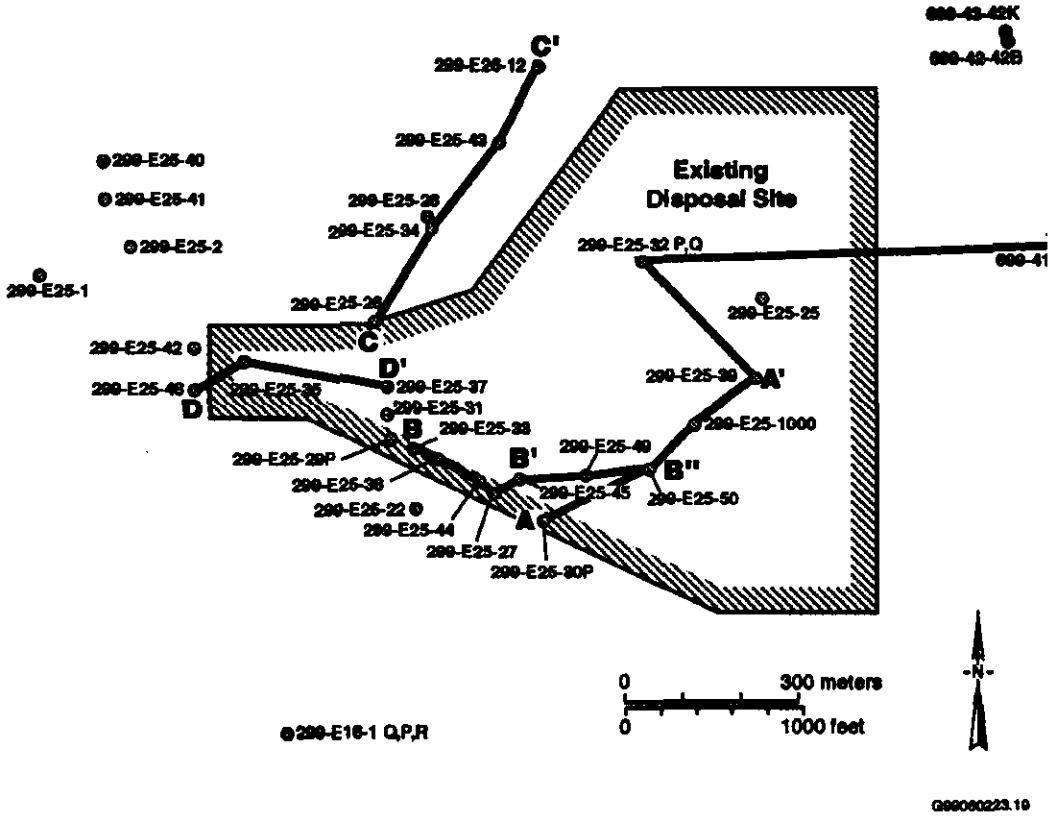

Figure 4.3. Map of the Existing Disposal Site Showing the Location of Boreholes and Cross-Sections

chosen to illustrate the geology along the northwestern edge of the site. The lack of suitable wells along the northern edge precluded extending the cross-section in that direction. Finally, cross-section D-D' is to illustrate the geology through the center of the waste transfer corridor.

4.2.2.1 Columbia River Basalt Group

The Elephant Mountain Member of the Saddle Mountains Basalt, Columbia River Basalt Group underlies the Ringold Formation. The top of the Elephant Mountain Member was penetrated in only 6 boreholes in the existing disposal facility area. A top of basalt map is shown in Figure 4.8.

4.2.2.2 Ringold Formation Unit A

The Ringold Formation Unit A overlies the Columbia River Basalt Group. This unit is equivalent to the Ringold Formation Unit A described in Lindberg et al. (1993).

The Ringold Formation Unit A is described on borehole logs of cuttings and samples as gravel, sandy gravel, and slightly sandy gravel to muddy sandy gravel at the existing disposal site. The gravels are

generally poorly sorted, subangular to rounded, and consist of pebbles and cobbles in a sand and mud matrix. Calcium carbonate is common but not abundant. These sediments are interpreted to represent fluvial gravels and sands.

Based on observations of outcrop and intact core, the Ringold Formation Unit A fluvial gravels consist of clast- and matrix-supported, pebble- to cobble-conglomerate with a fine- to coarse-sand matrix and interbedded fine- to coarse-sand and silt lenses (Lindsey 1996). The cement content ranges from absent to well developed. Cemented Ringold Formation conglomerates are discontinuous zones of variable thickness. The conglomerates exhibit massive, planer, and cross-bedding. Clast imbrication is common in the stratified sediments (Lindsey 1996).

Intercalated in the Ringold conglomerates are laterally discontinuous, fine- to coarse-grained, cross-bedded sand interbeds. Also interbedded in the conglomerates are thin, variably colored silty deposits, typically with disrupted bedding (Lindsey 1966).

The Ringold Formation Unit A is interpreted to represent rapid deposition of fluvial bed-load sediment in shallow channels across a gravelly floodplain.

The total thickness of the Ringold Formation Unit A at the existing disposal site is not known in most boreholes because most boreholes terminate before penetrating the lower contact. The lower contact is known, however, in 6 boreholes in the existing disposal facility area. In these boreholes, the Ringold Formation Unit A ranges from 55 to 100 ft (17 to 30 m) thick with an average thickness of 78 ft (23.7 m).

4.2.2.3 Ringold Formation Fine-Grained Sequence at Top of Unit A

A fine-grained sequence occurs as the uppermost Ringold Formation sediments in the existing disposal facility area. This sequence, along with the underlying gravels, is equivalent to the Ringold Formation Unit A described by Lindberg et al. (1993) and may be equivalent to a portion of the Ringold Formation Lower Mud. However, facies distribution maps shown in Lindberg et al. (1993) indicate that the Lower Mud has been eroded from most of the area beneath the existing disposal facility so that, if the Lower Mud is present, it is found only as erosional remnants.

The fine-grained sequence is described on borehole logs of cuttings and samples as sand and silty sand with minor silt/clay beds. The sequence is unconsolidated and generally lacks significant cement although it commonly has a variable but often strong reaction with HCl. On borehole logs, internal stratification and other internal features generally are not noted; however, the drilling method used to collect the samples has probably destroyed any internal structure that existed. The fine-grained sequence is represented by an increase in activity on the gross gamma-ray log from most but not all boreholes where it is present. The fine-grained sequence is interpreted to be fluvial sand deposits; possibly bedload deposits and/or proximal overbank deposits.

The fine-grained sequence varies in thickness from 0 to 27 ft (0 to 8 m) with an average thickness of 18 ft (5.5 m). The sequence is absent in boreholes 299-E25-25, -28, -31, -37, -42, and -43.

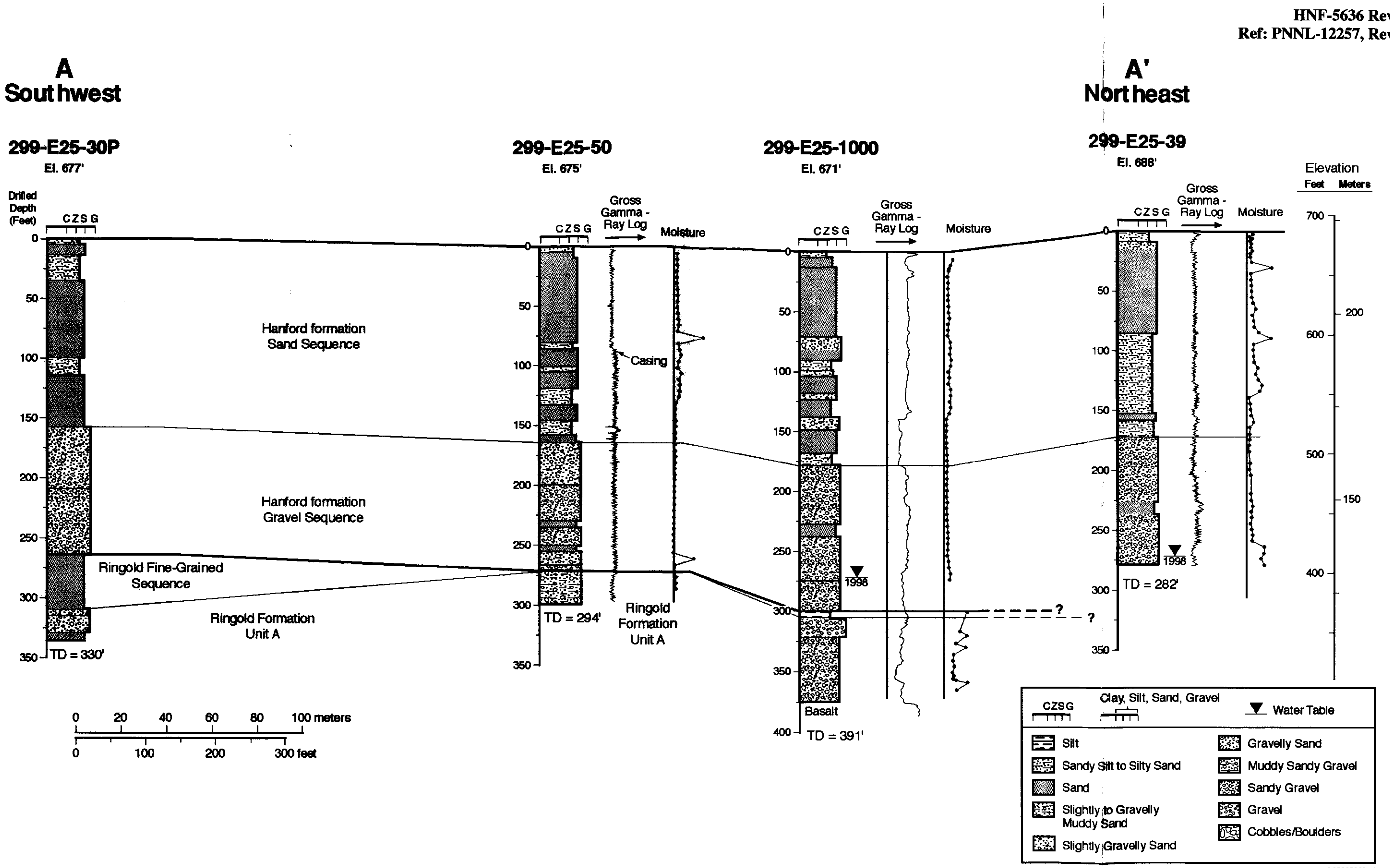

Figure 4.4. Cross-Section A-A" Across the Existing Disposal Site

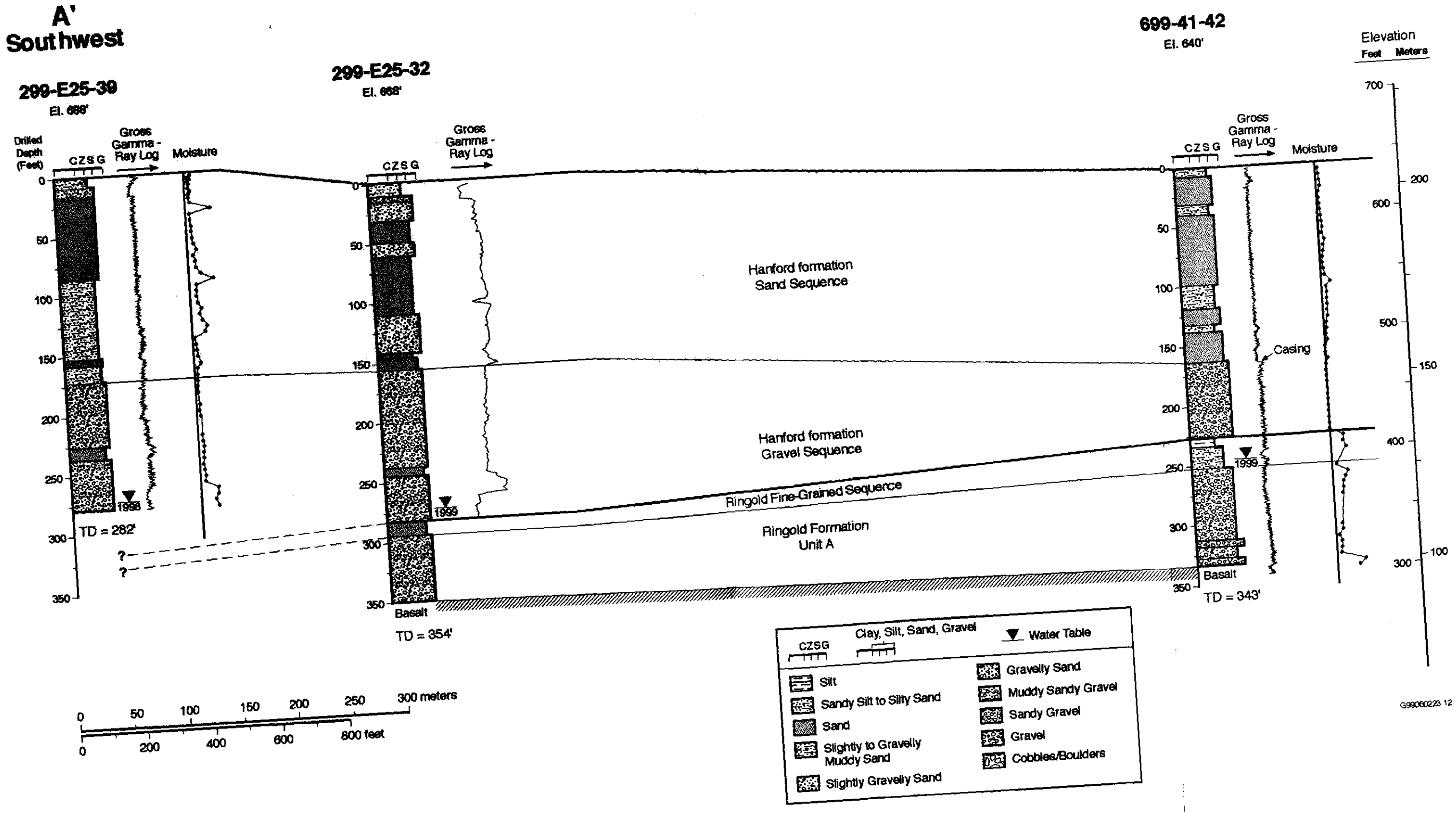

Figure 4.4. (contd)

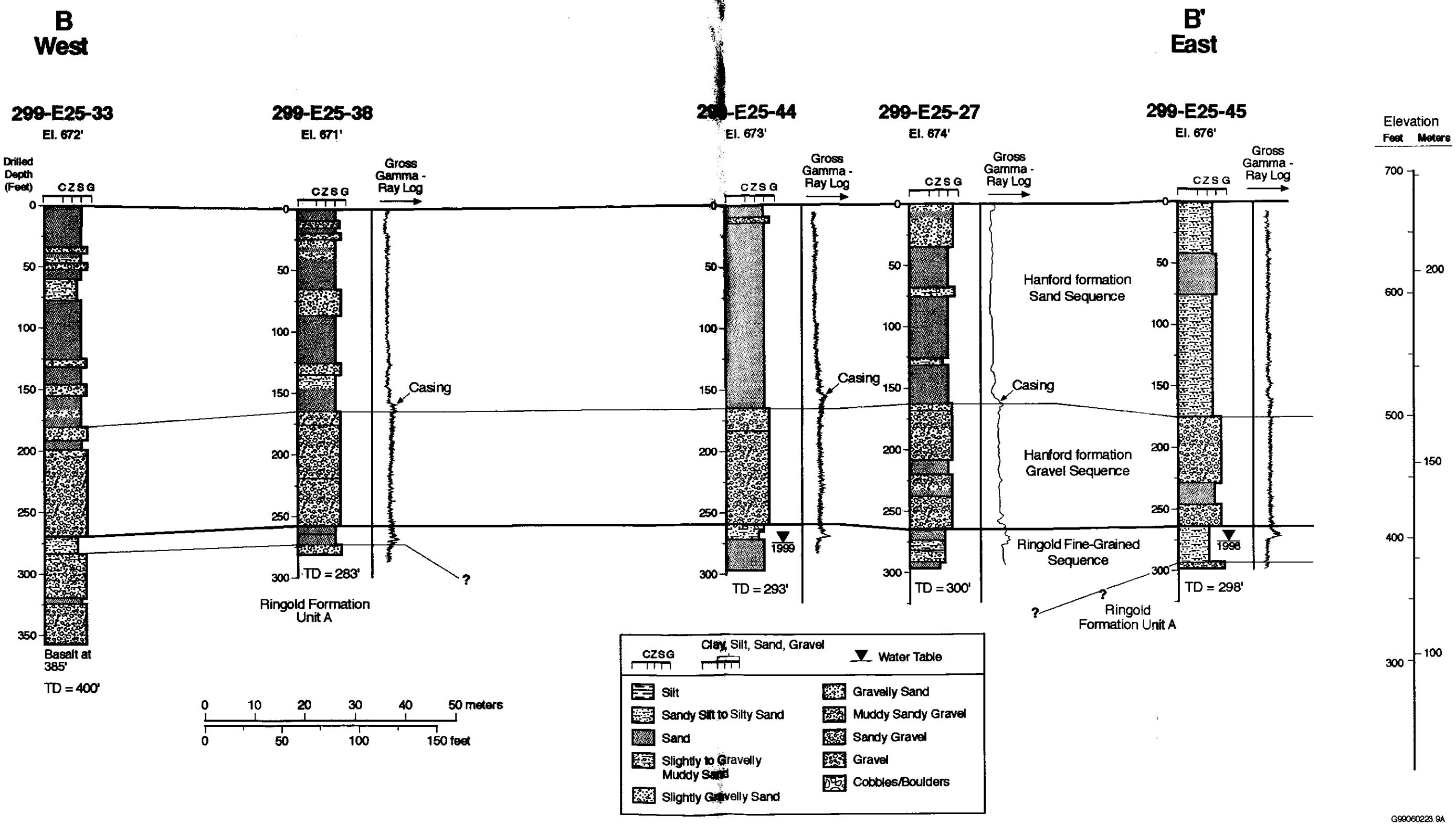

Figure 4.5. Cross-Section B-B" Across the Southern Part of the Existing Disposal Site

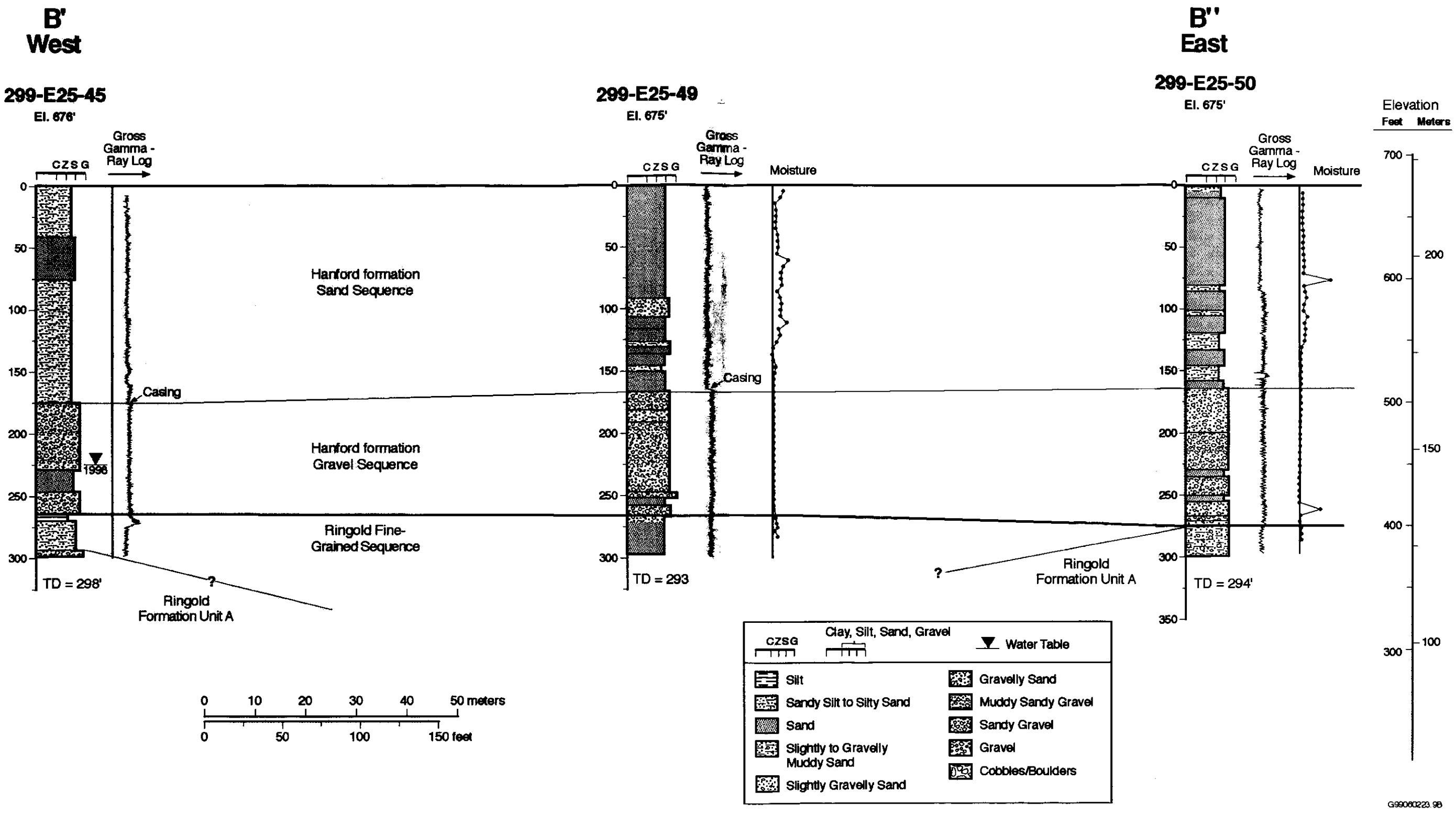

Figure 4.5. (contd)

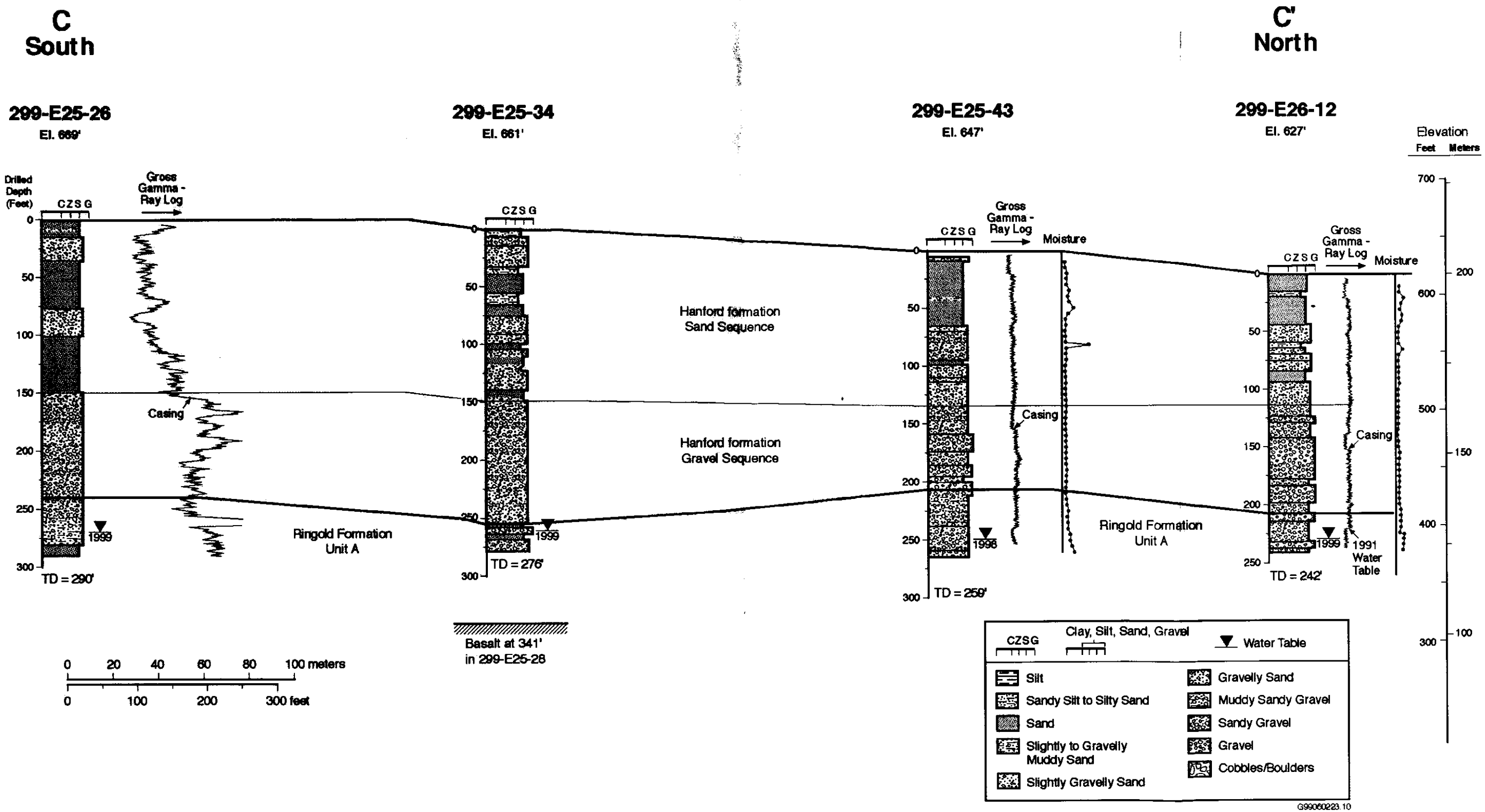

Figure 4.6. Cross-Section C-C' North of the Existing Disposal Site

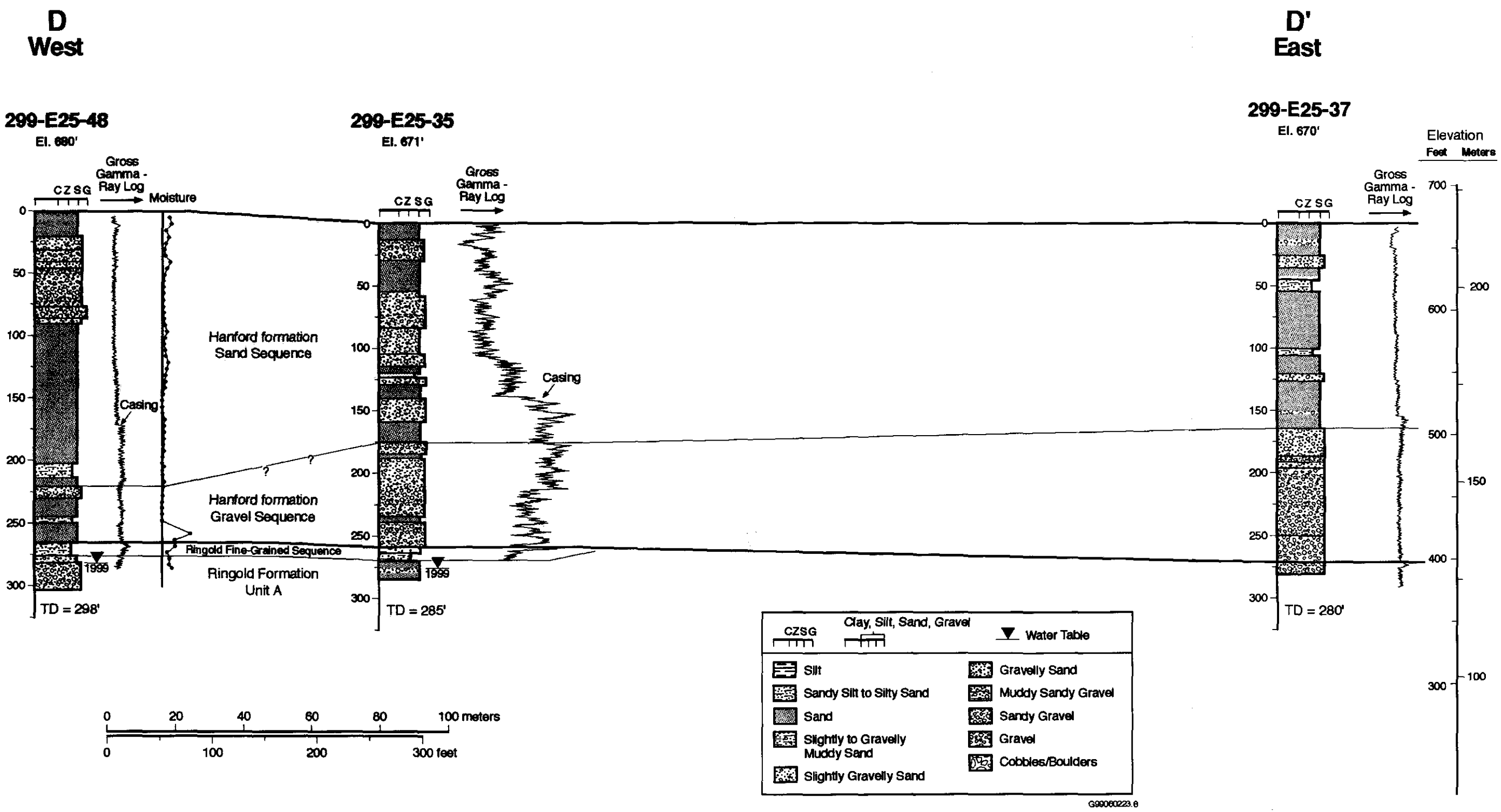

Figure 4.7. Cross-Section D-D' Across the West Part of the Existing Disposal Site

Table 4.1. Existing ILAW Disposal Site Borehole Database

Borehole #	Ground Surface Elevation (ft) (brass plate)	Total Depth (ft)	Elevation of Top of Hanford Formation Sand Sequence (ft)	Thickness of Hanford Formation Sand Sequence (ft)	Elevation of Top of Hanford Formation Gravel Sequence (ft)	Thickness of Hanford Formation Gravel Sequence (ft)	Elevation of Top of Ringold Formation Fine-grained Sequence (ft)	Thickness of Ringold Formation Fine-grained Sequence (ft)	Elevation of Top of Ringold Formation Unit A Gravel Sequence	Thickness of Ringold Formation Unit A Gravel Sequence (ft)	Elevation of Top of Basalt (ft)	Depth to the Water Table (ft)	Date of Water Level Measurement
299-E16-1	694.3	510	694								222	292.37	1999
299-E25-1	690.21	322	655	250	NP?		420	15	405	TD		288.52	Jul-93
299-E25-2	673.6	375	639	170	469	55	414	15	399	90	309	275.99	Mar-99
299-E25-22	671.66	295	672	196	476	58	418	20	398	TD		273.42	1996
299-E25-25	672?	288	672	168	504	82	NP		422	TD		269.64	Jul-98
299-E25-26	668.51	290	668	150	518	105	413	TD				269.7	Mar-99
299-E25-27	674.06	300	674	165	509	95	414	TD				273.64	Jun-93
299-E25-28	660.34	348	660	145	515	99	NP		416	97	319	263.34	Mar-99
299-E25-29	672.07	336	672	203	469	99	370	23	347	TD		272.02	Aug-97
299-E25-30	677.24	330	677	149	518	105	413	46	367	TD		276.8	Jul-96
299-E25-31	671.66	298	672	180	492	79			413	TD		275.01	Mar-99
299-E25-32	668.07	354	668	155	513	130	383	10	373	55	318	271.1	Mar-99
299-E25-33	672	400	672	205	492	90	402	15	387	100	287	268.64	Jun-96
299-E25-34	660.62	276	660	150	510	105	405	15	390	TD		263.94	Mar-99
299-E25-35	670.89	285	671	175	496	85	411	10	401	TD		274.97	Mar-99
299-E25-37	670.29	280	670	165	505	105			400	TD		272.3	Oct-95
299-E25-38	670.54	283	670	165	505	92	413	13	400	TD		271.52	Oct-93
299-E25-39	668.45	282	668	175	493	55	438	10	428	TD		271.07	Jul-98
299-E25-40	662.8	274	663	195	468	60	408	10	398	TD		266.37	Jun-05
299-E25-41	668.1	279	668	220	468	55	413	15	398	TD		271.82	Jun-05
299-E25-42	679.71	295	680	220	460	TD						283.78	Mar-99
299-E25-43	646.52	260	646	134	511	75	NP		436	TD		249.87	Jul-98
299-E25-44	672.9	293	673	165	508	98	410	TD				275.62	Mar-99
299-E25-45	673.74	297	676	175	501	94	407	26	381	TD		277.93	Apr-98
299-E25-48	679.68	298	680	220	460	46	414	18	396	TD		282.64	Mar-99
299-E25-49	675.44	293	675	165	510	100	410	TD					
299-E25-50	675.32	294	675	165	510	110	400	TD					

Table 4.1. (contd)

Borehole #	Ground Surface Elevation (ft) (brass plate)	Total Depth (ft)	Elevation of Top of Hanford Formation Sand Sequence (ft)	Thickness of Hanford Formation Sand Sequence (ft)	Elevation of Top of Hanford Formation Gravel Sequence (ft)	Thickness of Hanford Formation Gravel Sequence (ft)	Elevation of Top of Ringold Formation Fine-grained Sequence (ft)	Thickness of Ringold Formation Fine-grained Sequence (ft)	Elevation of Top of Ringold Formation Unit A Gravel Sequence	Thickness of Ringold Formation Unit A Gravel Sequence (ft)	Elevation of Top of Basalt (ft)	Depth to the Water Table (ft)	Date of Water Level Measurement
299-E25-234	622	141	622	125	497	TD							
299-E25-1000	670.96	392	671	180	481	111	370	10	360	67	293	274.15	Jun-98
299-E26-12	627.27	242	627	115	512	95	NP		417	TD		231.01	Mar-99
699-41-42	640.32	345	634	150	485	73	412	27	385	80	305	240.87	Mar-99
699-42-42B	579.83	250	580	109	471	50	421	23	398	TD		179.64	1999
699-43-43K	579.03	263	579	109	470	49	421	23	398	62	336		
Average				169.16		84.66		18.11		78.71			
Std Dev				33.21		22.72		8.81		17.77			

Elevations are feet above sea level.
NP = Not present.
TD = Total depth of borehole.

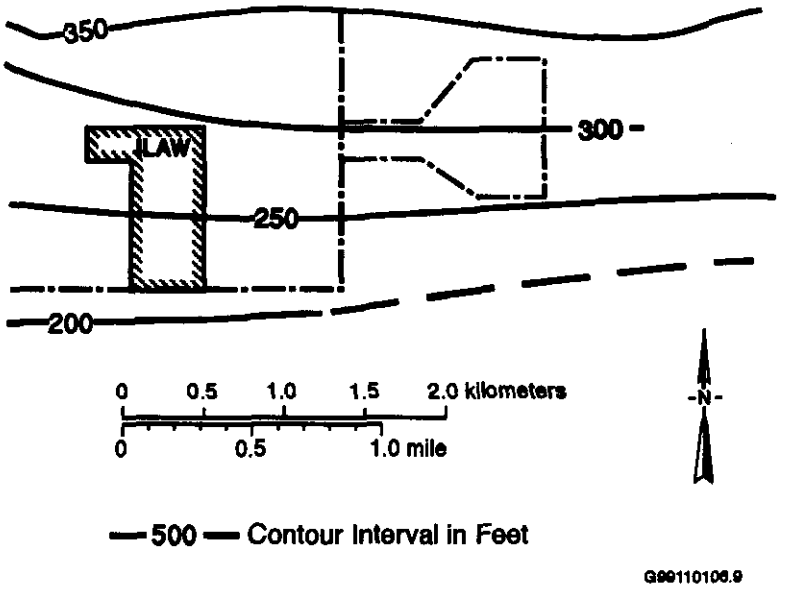

Figure 4.8. Generalized Elevation of the Top of the Columbia River Basalt Group Under the 200-East Area

Figure 4.9 is a structure contour map of the top of the Ringold Formation. The map shows a roughly northwest to southeast trending low across the center of the existing disposal site with about 66 ft (20 m) of relief in the area. The structural low may be due to post-depositional scouring by Pleistocene floods.

4.2.2.4 Hanford Formation Gravel Sequence

A thick sequence of Pleistocene Hanford formation flood gravels overlies the Ringold Formation. This sequence is equivalent, at least in part, to the lower gravel sequence of the Hanford formation of Lindberg et al. (1993) and Lindsey et al. (1992), to the Hanford formation H3 sequence of Lindsey et al. (1994a), and to the Qfg deposits of Reidel and Fecht (1994a, 1994b) (Figure 4.2).

The Hanford formation gravel sequence is described on borehole logs of cuttings and samples as dominantly sandy gravel and gravelly sand in the existing disposal site. Thin beds of sand, generally less than about 10 ft (3 m) in thickness, are common but not abundant. Silt lenses were not noted on the borehole logs of the gravel sequence at the existing disposal site. The gravels are generally poorly sorted, subrounded to subangular and have basalt content up to 80%. Calcium carbonate is common but the gravel sequence is not cemented.

Based on observation of outcrop and intact core, the gravel sequence sediments described on the borehole logs are interpreted to be gravel-dominated facies. This facies is typically open framework or matrix supported framework, granule to boulder gravel with massive bedding, plane to low-angle bedding, and cross-bedding. Lenticular and discontinuous units of sand-dominated facies are interbedded with gravel-dominated facies. The Hanford formation gravel sequence was deposited by high-energy, cataclysmic, Pleistocene floods.

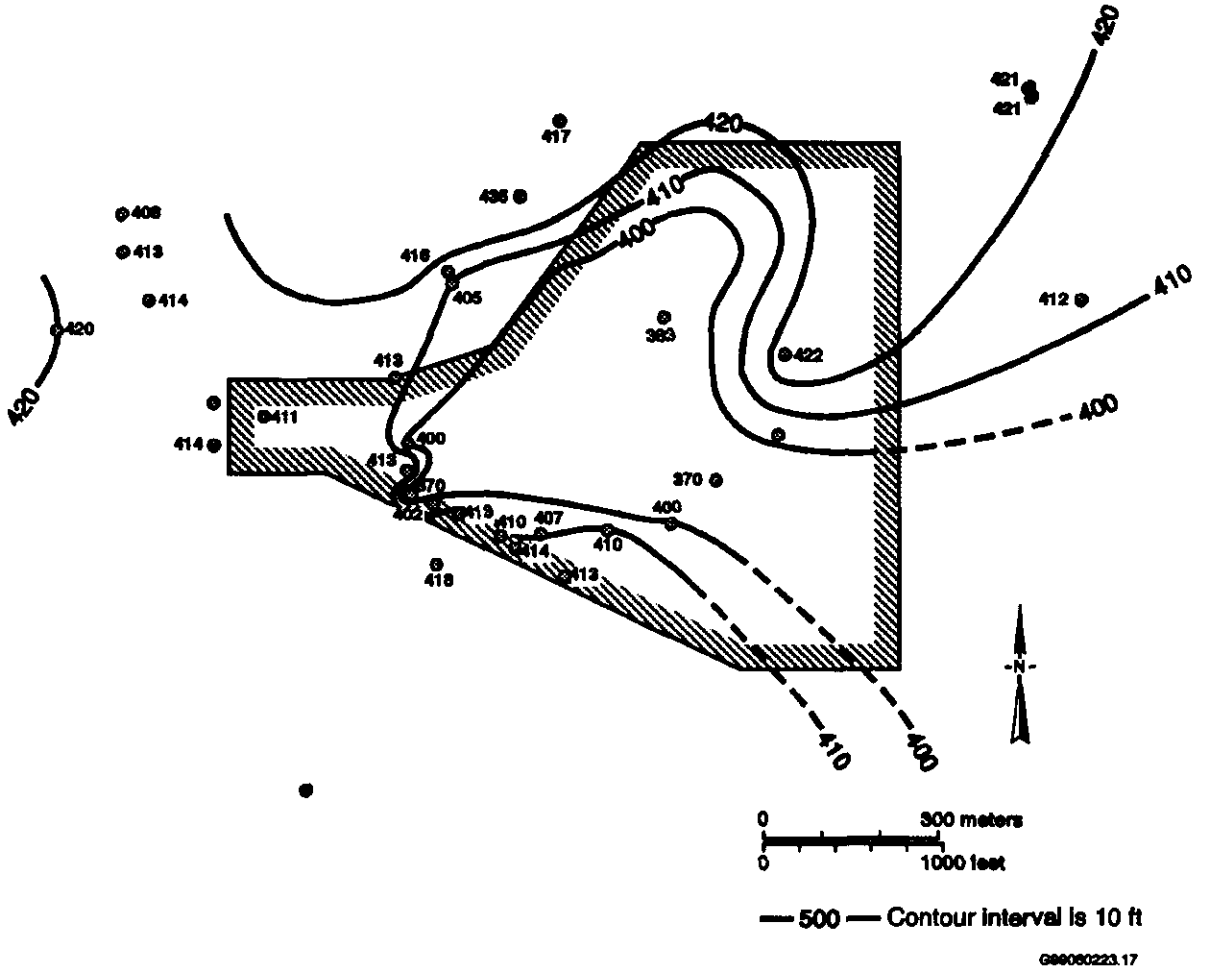

Figure 4.9. Structure Contour Map of the Top of the Ringold Formation in the Existing Disposal Site. Values are Elevations Above Sea Level.

The base of the Hanford formation gravel sequence was picked at the top of the silt, silty sand, or sand defining the top of the Ringold fine-grained sequence. In boreholes where the Ringold fine-grained sequence does not occur, the contact was chosen at a change in the degree of induration and/or change in the basalt content of the gravel. The lithology change was generally fairly dramatic going from about 50% or more basalt in the Hanford formation gravel sequence to about 10 to 15% basalt in the underlying Ringold Formation. In a few boreholes where neither the Ringold fine-grained sequence nor a dramatic change in lithology was evident, the base of the Hanford formation gravel sequence was taken from data in Lindberg et al. (1993).

Figure 4.10 shows a structure contour map on the top surface of the Hanford formation gravel sequence. The map shows that the top of the sequence has about 55 ft (17 m) of relief in the existing disposal site area and is highest through the center of the area in a north to north-northwest trend.

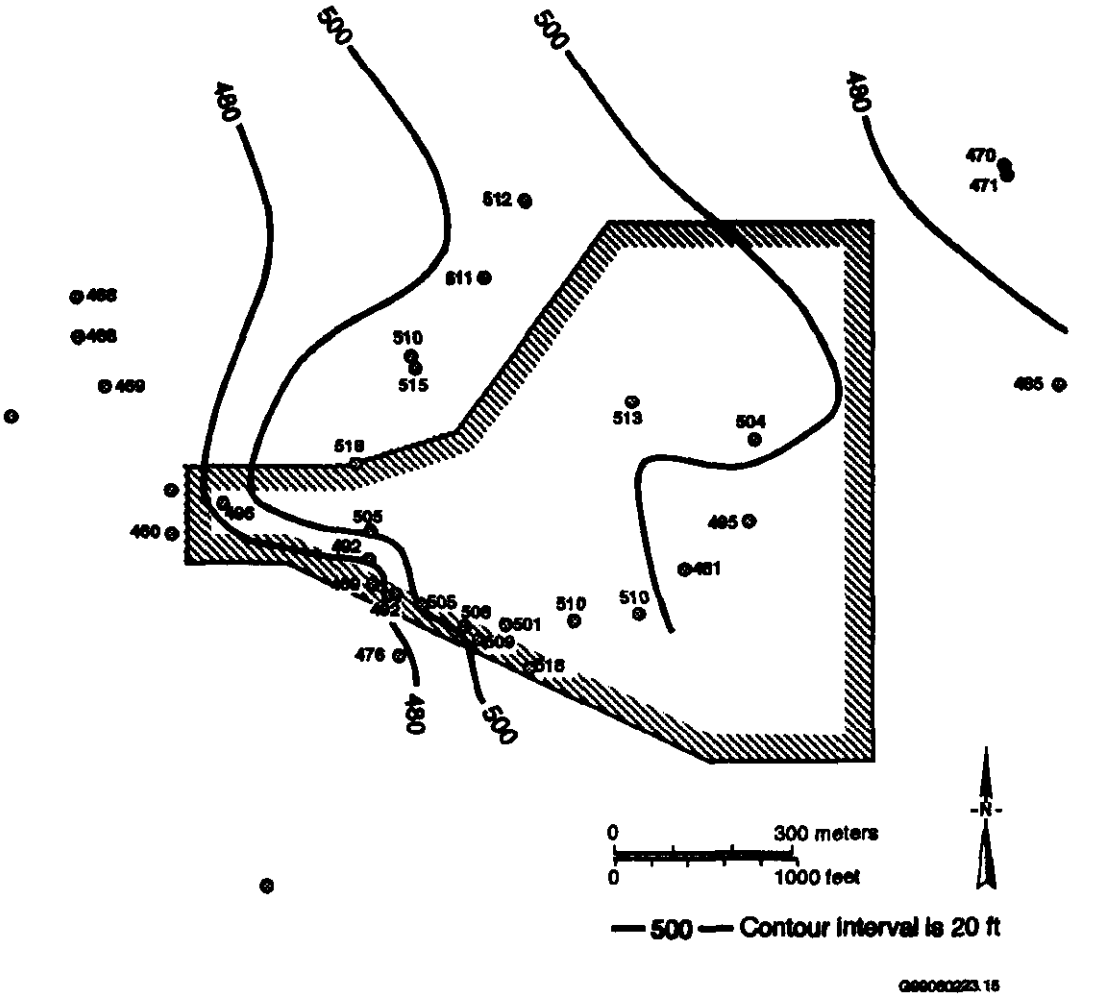

Figure 4.10. Structure Contour Map of the Top of the Hanford Formation Gravel Sequence in the Existing Disposal Site. Values are elevations in feet.

4.2.2.5 Hanford Formation Sand Sequence

The Hanford formation sand sequence overlies the Hanford formation gravel sequence. This sequence is equivalent to the sandy sequence of the Hanford formation of Lindberg et al. (1993) and Lindsey et al. (1992), the Hanford formation H2 sequence of Lindsey et al. (1994a), and to Qfs of Reidel and Fecht (1994a, 1994b) (Figure 4.2).

The Hanford formation sand sequence is described on borehole logs of cuttings as coarse to very fine sand. Beds of silty sand and gravelly sand are common; sandy gravels also exist but are less common. The composition of the sand sequence varies from typically 50 to 70% mafic and 30 to 50% felsic. Minor calcium carbonate is common in the sand sequence as indicated on the geologist's logs. Also, some caliche layers were noted on geologist's logs. The caliche is generally fine to medium pebble-sized cemented clasts.

The sand-sequence sediments are interpreted to consist of typical sand-dominated facies intercalated with beds of the silt-dominated and gravel-dominated facies. The amount of gravel-dominated facies sediment tends to increase toward the northwestern and western parts of the existing disposal site (see Figures 4.4 through 4.7) whereas the sequence is mostly sand-dominated with some silt-dominated beds in the central and eastern parts of the site.

Beds of silt-dominated facies were noted in the Hanford formation sand sequence from many geologist's logs. The beds are generally 6 in. (0.15 m) or less in thickness and in many boreholes were moist to wet relative to adjacent sediment. Silt-dominated units primarily were noted in three depth intervals: 10 to 15 ft (3 to 4.5 m), 20 to about 35 ft (6 to about 11 m), and 100 to 135 ft (30 to 41 m). However, many silt-dominated units were identified outside these depth intervals between 50 and 70 ft (15 and 21 m) and between 87 and 97 ft (26.5 and 29.5 m). Silt intervals were commonly noted as layered or bedded (with sand) by the geologist. In some boreholes, anomalies in gross gamma-ray logs and moisture content data reflect the presence of silt-dominated strata. In other boreholes, similar anomalies probably reflect silt-dominated strata that were not noted on the lithologic logs. Silt-dominated units cannot be correlated among boreholes and are interpreted to be lenticular. However, samples are normally collected every 5 ft (1.5 m) during drilling so most thin silt-dominated units would not get described.

The geologist's logs for two boreholes (299-E25-26 and 299-E25-220) indicate the presence of Mt. St. Helens set "S" ash at 14 to 15 ft (4.3 to 4.6 m) depth. If this horizon is Mt. St. Helens set "S" ash, it indicates an age of 13,000 years for the sediment at this depth.

The Hanford formation sand sequence in the existing disposal site varies from 134 to 220 ft (41 to 67 m) in thickness with an average thickness of 169 ft (51 m). Because of the difficulty in picking a contact between the Hanford formation sand sequence and the overlying surficial sands, both are included in the sand sequence thickness given in Table 4.1.

The bottom of the Hanford formation sand sequence was chosen as the top of the first, thick (>10 ft [3 m]), sandy gravel or gravelly sand underlying at least 25 ft (7.6 m) of sand, silty sand or slightly gravelly sand. Although there are some differences, this change in lithology agrees well with that used by Lindberg et al. (1993), who used the data set from Lindsey et al. (1992), to delineate the Hanford formation sand sequence from the underlying gravel sequence.

4.2.2.6 Recent Surface Deposits

Ground penetrating surveys conducted in 1998 found a variably thick sequence of surficial deposits across most of the existing disposal site. These deposits consist of Holocene wind blown sand and are typically about 10 ft (3 m) thick. Some geologist's logs and driller's logs note a surficial deposit but most do not. In some boreholes, the thickness of the surfical deposits can be established based on lithology where the eolian sands overly sandy gravel or gravelly sand. In those boreholes, the eolian deposits are between about 5 and 15 ft (1.5 and 4.5 m) in thickness. In other boreholes, the surfical sands overly the

Hanford formation sand sequence. The texture of the Hanford formation sand sequence is similar to the eolian material making it hard to differentiate the two without being able to observe the structures (laminations).

4.3 NEW ILAW DISPOSAL SITE

4.3.1 Previous Studies

The new ILAW disposal site is an area where no previous construction or disposal sites exist so no major geologic studies have been carried out there. Studies relevant to the site are summarized in Tallman et al. (1979), DOE (1988), Lindsey et al. (1993, 1994a, 1994b), Lindsey (1996), Reidel and Reynolds (1998), and Reidel et al. (1998). Less data are available for the new ILAW site and it is generally of poorer quality compared to data from the existing disposal site. The first major activity was the drilling of borehole 299-E17-21 in 1998 at the southwest end of the site and obtaining the first high-quality data from the area.

4.3.2 Site Stratigraphy

The stratigraphy at the new ILAW disposal site consists of the Hanford formation and Ringold Formation overlying the Columbia River Basalt Group. Surfacial sediments are mainly eolian deposits consisting of reworked Hanford sands and silts.

The stratigraphy and the stratigraphic model developed for this study is summarized in Figures 4.2 and 4.11. This diagram is based upon more detailed cross-sections (Figures 4.12 through 4.16).

The stratigraphy of the new ILAW disposal site is divided from youngest to oldest into the following units:

- Eolian Deposits
- Hanford formation, sandy unit (H2 of Lindsey et al. 1994b)
  - Layer 3 (extends into upper gravelly unit)
  - Layer 2
  - Layer 1
- Hanford formation, basal gravel units (H3 of Lindsey et al. 1994b)
- Ringold Formation
  - Unit E
  - Lower Mud
  - Unit A
- Columbia River Basalt Group.

Sequences of sandy gravels to gravelly sands (G1, G2, G3, G4) and sand to silty sand units (S, S1, S2, S3) can be recognized in the Hanford formation layers (Table 4.2) but correlation across the area is

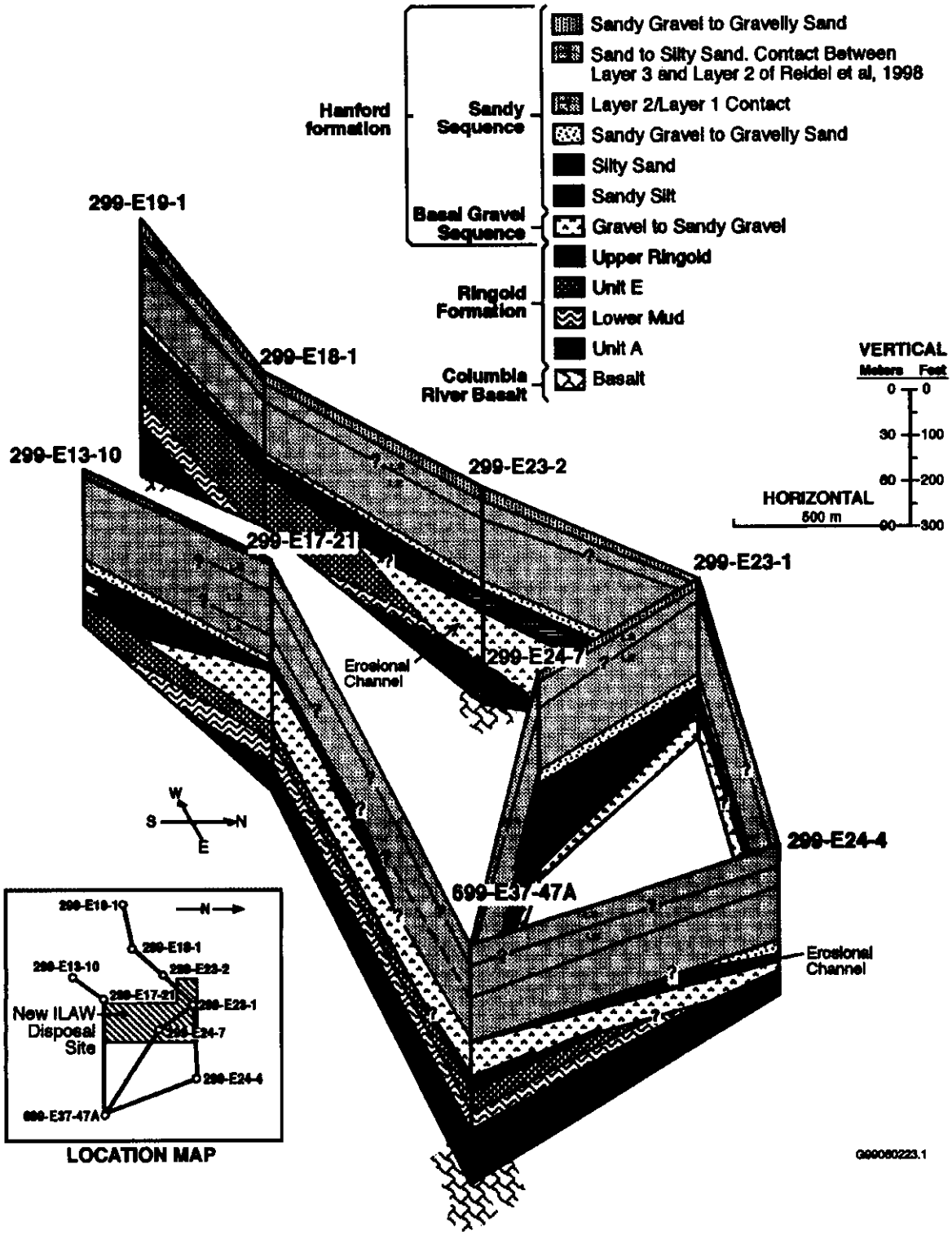

Figure 4.11. Fence Diagram of the New ILAW Disposal Site and Vicinity

Table 4.2. Stratigraphic Information from Boreholes in and Adjacent to the New ILAW Disposal Site

Borehole	Back-fill	Surface Sand (S)	Top of Layer 3 (L3)	Top of Layer 2 (L2)	Top of Layer 1 (L1)	Top of Sandy Gravel 1 (G1)	Surface Elevation [brass cap or casing (C)]	Top of Sand 1 (S1)	Top of Sandy Gravel 2 (G2)	Top of Sand to Silty Gravelly Sand 2 (S2)	Top of Gravel 3 (G3)	Top of Sand to Silty Sand 3 (S3)	Top of Gravel 4 (G4)	Thickness of Hanford Forma-tion	Top of Ringold	Top of Unit E	Silt	Top of Lower Mud	Thickness of Ringold	Top of Unit A	Basalt	Water Table Eleva-tion	Date of Water Level Measurement
E13-10	N	733	ND	ND	ND	NP	733(C)	733	713	705	537	514	494	239	449	494	NP	NP	ND	NP	NP	399.74	Mar-99
E17-12	N	719	669	647	564	704	719 (C)	694	NP	694	497	479	NP	290	429	429	NP	NP	ND	NP	NP	399.17	Mar-99
E17-13	31	NP	ND	647	ND	ND	719 (C)	689	NP	689	494	469	NP	265	424	424	NP	NP	ND	NP	NP	399.56	Mar-98
E17-17	N	716	ND	651	ND	716	717	702	NP	702	NP	546	492	299	417	492	442	NP	ND	NP	NP	399.8	Oct-98
E17-18	N	717	ND	648	ND	713	718	693	626	616	NP	546	483	291	426	483	434	NP	ND	NP	NP	399.27	Mar-99
E17-20	N	716	ND	646	ND	706	717	696	676	671	566	556	NP	ND	NP	491	436	NP	ND	NP	NP	400.55	Apr-97
E17-21	N	735	730	677		730	735	720	715	705	523	505	447	238	497	400	NP	357	ND	296	NP	403	Apr-98
E18-1	N	NA	ND	ND	ND	720	716	700	675	660	545	535	NP	215	505	505	NP	NP	ND	NP	NP	399.44	Mar-99
E18-3	N	718	ND	656	ND	715	718	703	ND	656	546	542	NP	235	483	483	NP	NP	ND	NP	NP	401.1	Jun-96
E18-4	N	718	ND	ND	ND	715	718	699	668	658	ND	568	NP	232	486	486	NP	NP	ND	NP	NP	401.17	Jun-96
E19-1	N	736	ND	ND	ND	735	736 (C)	716	686	672	520	506	NP	250	486	486	NP	346	285	306	201	ND	ND
E23-1	N	0 to 5	ND	665	ND	704	710 (C)	NP	689	665	489	477	454	ND	NP	454	417	NP	ND	NP	NP	399.63	Mar-99
E23-2	0	720	ND	628	ND	NP	721 (C)	720	NP	605	520	500	484	290	430	430	ND	NP	166	ND	264	401.59	Dec-94
E24-4	20	696	ND	646	ND	NP	697 (C)	696	NP	ND	ND	ND	431	270	426	466	ND	NP	ND	NP	NP	399.53	Aug-98
E24-7	N	0	ND	652	ND	716	716 (C)	708	NP	708	500	486	448	380	336	336	296	ND	70	ND	266	400.52	Jun-97
E24-16	N	715	ND	656	ND	714	715	706	626	616	526	496	NP	ND	NP	460	426	NP	ND	NP	NP	399.41	Mar-99
E24-17	N	716	ND	659	ND	711	716	706	NP	706	536	524	491	295	421	421	NP	NP	ND	NP	NP	399.59	Apr-97
E24-18	N	716	ND	664	ND	715	716	699	NP	699	506	481	456	325	391	391	NP	NP	ND	NP	NP	399.3	Mar-99
E37-47A	N	716	ND	ND	ND	NP	715	716	NP	716	526	NP	474	284	432	412	NP	350	231	304	201	405	Oct-96

N = Not present. Letter number designations in table headings refer to cross section units (Figures 4.12, 4.13, 4.14, and 4.15).
ND = Not determined.
NP = Not penetrated.

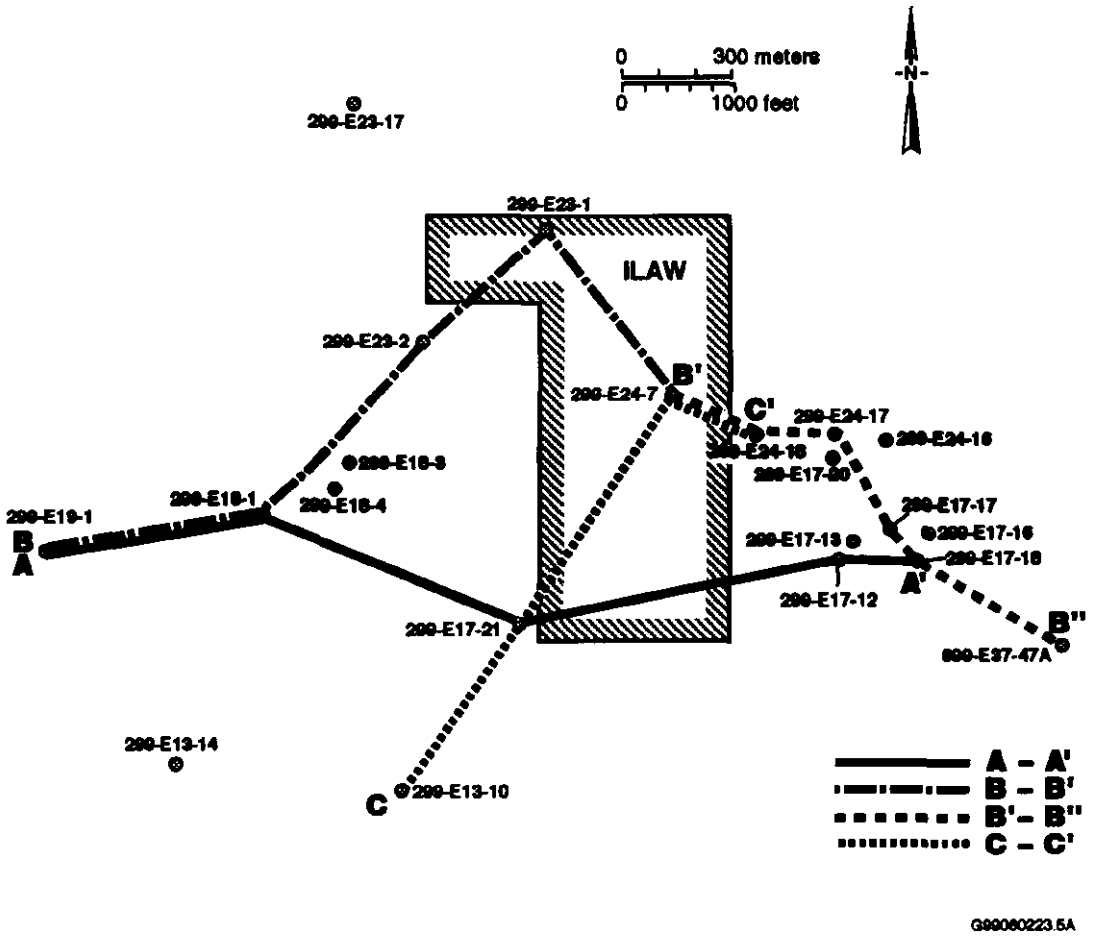

Figure 4.12. Map Showing Borehole Locations in the New ILAW Disposal Site and the Locations of Cross-Sections A-A', B-B', B'-B", and C-C'

tentative at this time because of the distance between boreholes, the poor quality of some data, and the local nature of thin units in the Hanford formation. Additional boreholes will be necessary to verify these correlations.

4.3.2.1 Columbia River Basalt Group

Previous studies (DOE 1988; Reidel and Fecht 1994a) have shown that the youngest lava flows of the Columbia River Basalt Group at the 200-East Area are those of the 10.5 million-year old Elephant Mountain Member. The Elephant Mountain Member is continuous beneath the new disposal site. No erosional windows are known or suspected to occur in the new ILAW disposal site area.

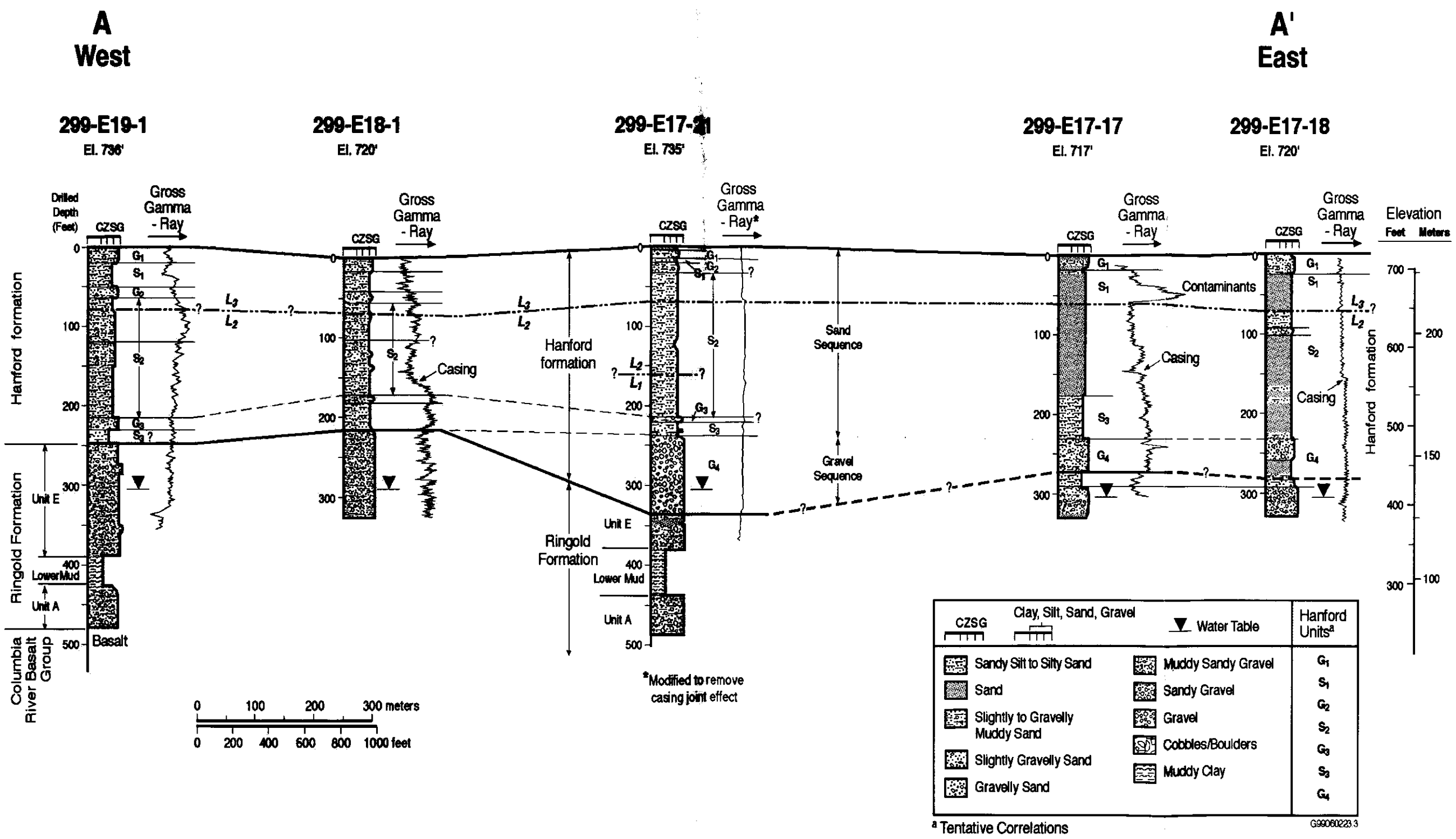

Figure 4.13. Cross-Section A-A' Across the New ILAW Disposal Site

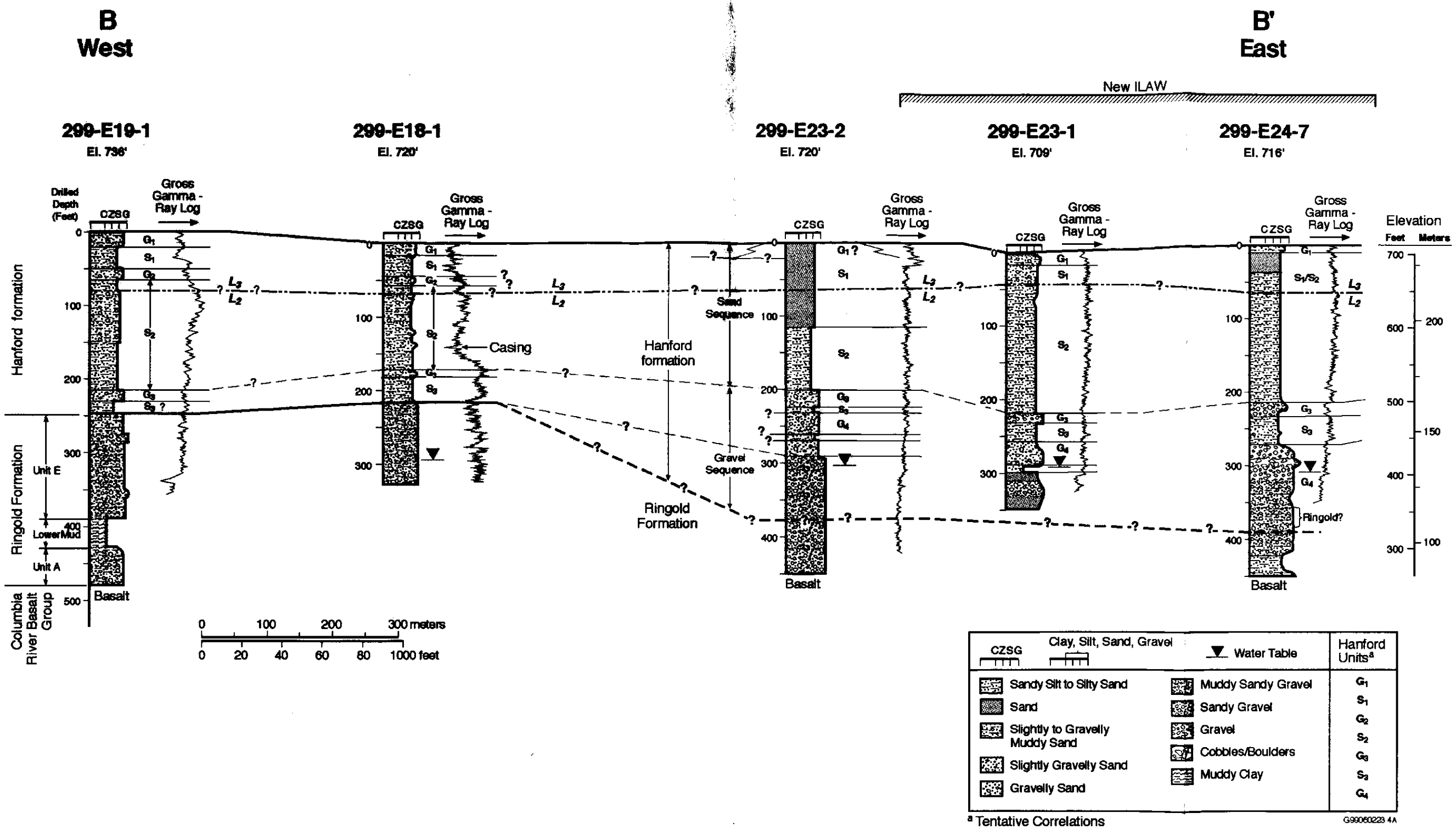

Figure 4.14. Cross-Section B-B' Across the New ILAW Disposal Site

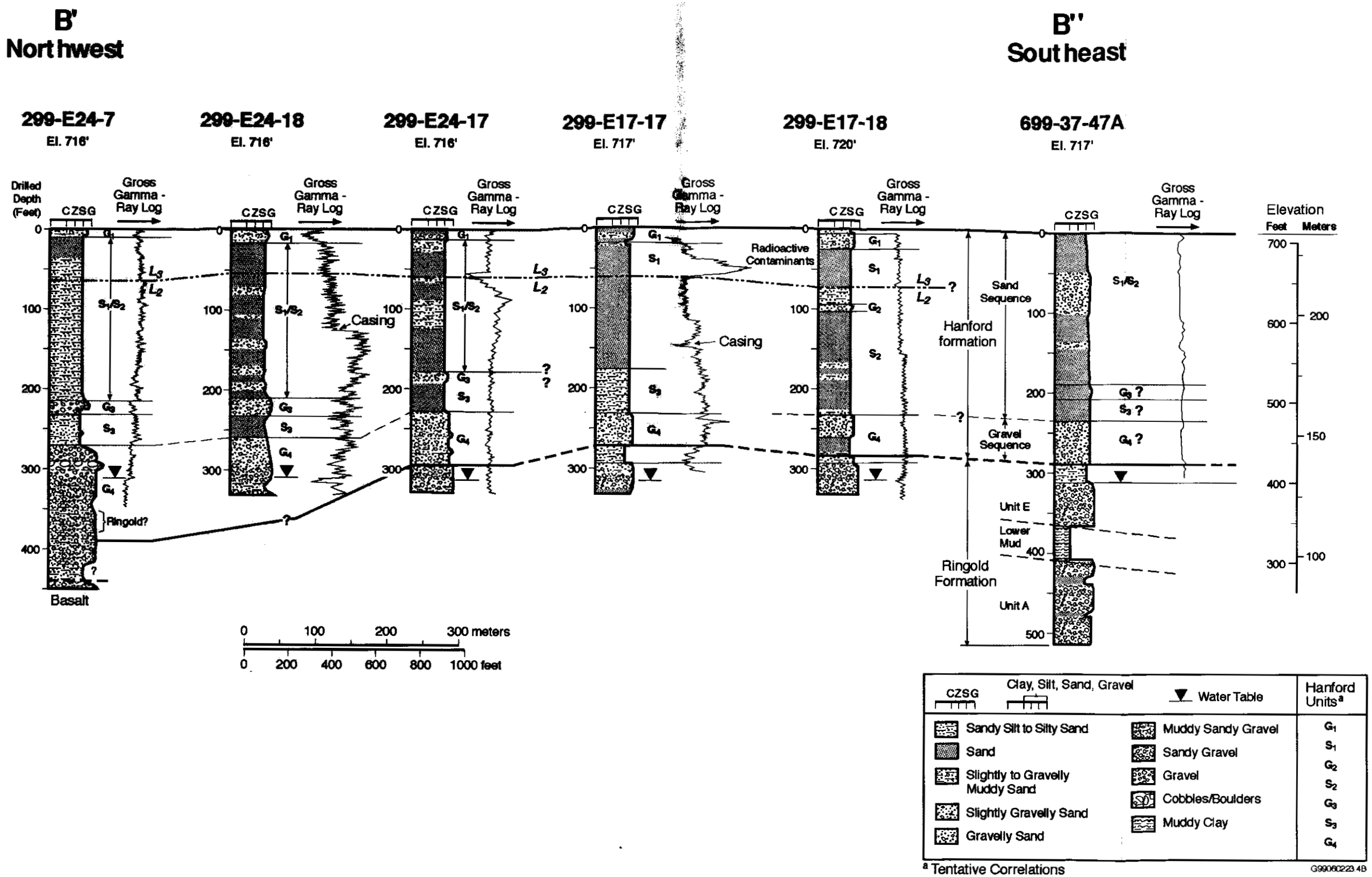

Figure 4.15. Cross-Section B'-B" Across the New ILAW Disposal Site

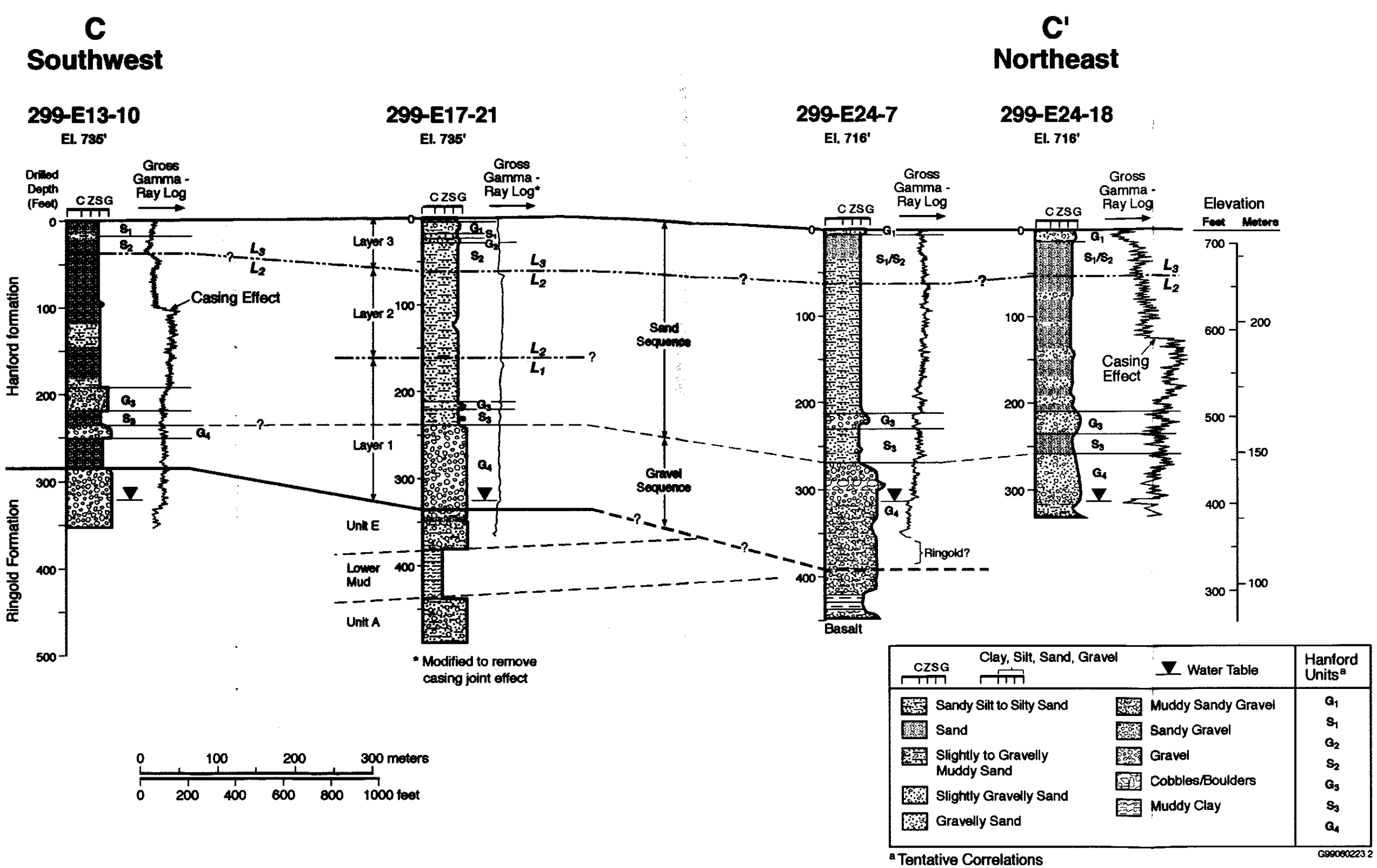

Figure 4.16. Cross-Section C-C' Across the New ILAW Disposal Site

4.3.2.2 Ringold Formation

Because few boreholes penetrate much of the entire Ringold Formation at the new ILAW disposal site (Figure 4.17), data are limited. The Ringold Formation reaches a maximum thickness of 285 ft (95 m) on the west side of the new ILAW disposal site and thins eastward. It consists of three units of Lindsey's (1996) member of Wooded Island. The member of Taylor Flats has been identified in borehole 699-47-37A (Lindberg et al. 1997) east of the site but this correlation was tentative. The deepest unit encountered is the lower gravel, Unit A. Lying above Unit A is the Lower Mud and overlying the Lower Mud is an upper gravel, Unit E. The upper Ringold (sand and silt of the member of Taylor Flat) is not present at the new ILAW disposal site (Figure 4.11). Unit A and Unit E are equivalent to mapping unit PLMcg (Figure 4.2), Pliocene-Miocene continental conglomerates of Reidel and Fecht (1994a, 1994b). The Lower Mud is equivalent the mapping unit PLMc, Pliocene-Miocene continental sand, silt, and clay beds of Reidel and Fecht (1994a, 1994b).

4.3.2.2.1 Unit A

Only 3 boreholes penetrated Unit A in the study area (Table 4.2). Unit A is 61 ft (19 m) thick on the west side of the new ILAW site but thins to the northeast (Figure 4.11). Unit A is described on borehole

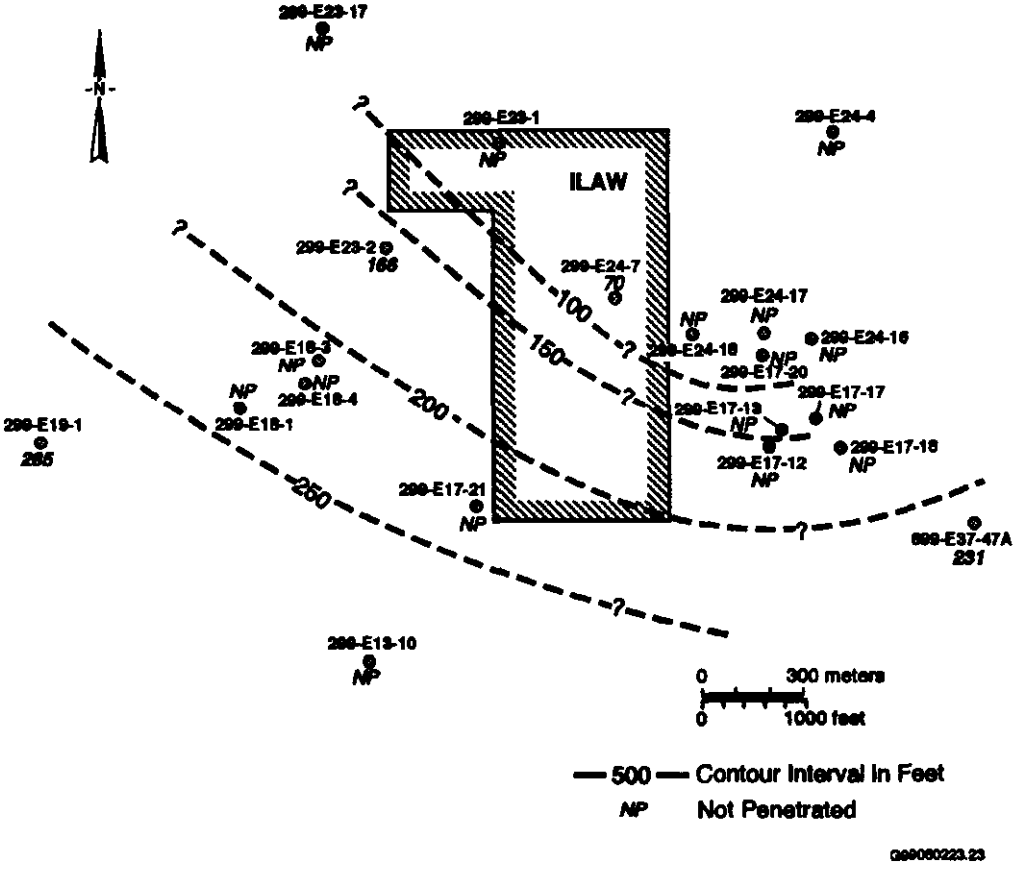

Figure 4.17. Isopach Map of the Ringold Formation at the New ILAW Disposal Site

logs as a sandy gravel consisting of both felsic and basaltic rocks. It is interpreted as Lindsey's (1996) fluvial gravel facies, which consists of conglomerates and is interpreted to be similar to Unit A in the existing disposal site (Section 4.2.2.2). There are sporadic yellow to white interbedded sands and silts with silt and clay lenses. Green-colored, reduced-iron stain is present on some grains and pebbles. Although the entire unit appears to be partially cemented, the zone produced abundant water in borehole 299-E17-21 (Reidel et al. 1998).

4.3.2.2.2 Lower Mud

Sixty-one feet (19 m) of the Lower Mud was encountered at the new ILAW site characterization borehole (299-E17-21). The upper most part (about 4 ft [1 m]) is described on borehole logs as a yellow sandy to silty mud and is interpreted as Lindsey's (1996) lacustrine facies, which consists of clays, silts, and silty sands. The silty clay grades downward into about 34 ft (10 m) of blue clay with beds of silt to slightly silty clay. The blue clay, in turn, grades down into 23 ft (7 m) of brown silty clay with organic rich zones and occasional wood fragments. The Lower Mud is absent in the center of the new ILAW site (Figure 4.11; boreholes 299-E23-1 and 299-E24-7).

4.3.2.2.3 Unit E

Unit E is described on borehole logs as a sandy gravel to gravelly sand. It is interpreted to consist of as much as 50 ft (15 m) of conglomerate with scattered cobbles up to 10 in. (25 cm) in size. The conglomerate consists of both felsic and basaltic clasts which are well rounded with a sand matrix supporting the cobbles and pebbles. Cementation of this unit ranges between slight and moderate. The upper contact of Unit E is not easily identified at the new ILAW site. In the western part of the study area, unconsolidated gravels of the Hanford formation directly overly the Ringold Unit E gravels. The dominance of basalt in the Hanford formation and the absence of any cementation are the key criteria used for distinguishing them here (Reidel et al. 1998). In the central and northeast part of the study area, Unit E is interpreted to have been eroded (e.g., boreholes 299-E24-7 and 299-E17-21, Figure 4.11). Unconsolidated gravels and sands typical of the Hanford formation replace them.

4.3.2.2.4 Upper Ringold (Member of Taylor Flat)

The upper Ringold is not present at the new ILAW disposal site but has been tentatively identified in the southeast corner of 200-East Area in borehole 699-E37-47A (Lindberg et al. 1997). These sediments do not appear to be present at the new ILAW disposal site (Figure 4.11).

4.3.2.2.5 Unconformity at Top of Ringold Formation

The surface of the Ringold Formation is irregular in the new ILAW disposal site area (Figure 4.18). A NW-SE trending erosional channel or trough is centered along the northeast portion of the site (Figures 4.11 and 4.18). The deepest portion of the trough occurs near borehole 299-E24-7 in the northern portion of the new ILAW disposal site. This trough is interpreted to be a smaller part of a much larger trough under the 200-East Area resulting from scouring by the Missoula floods or post-Ringold fluvial incision prior to the Missoula floods.

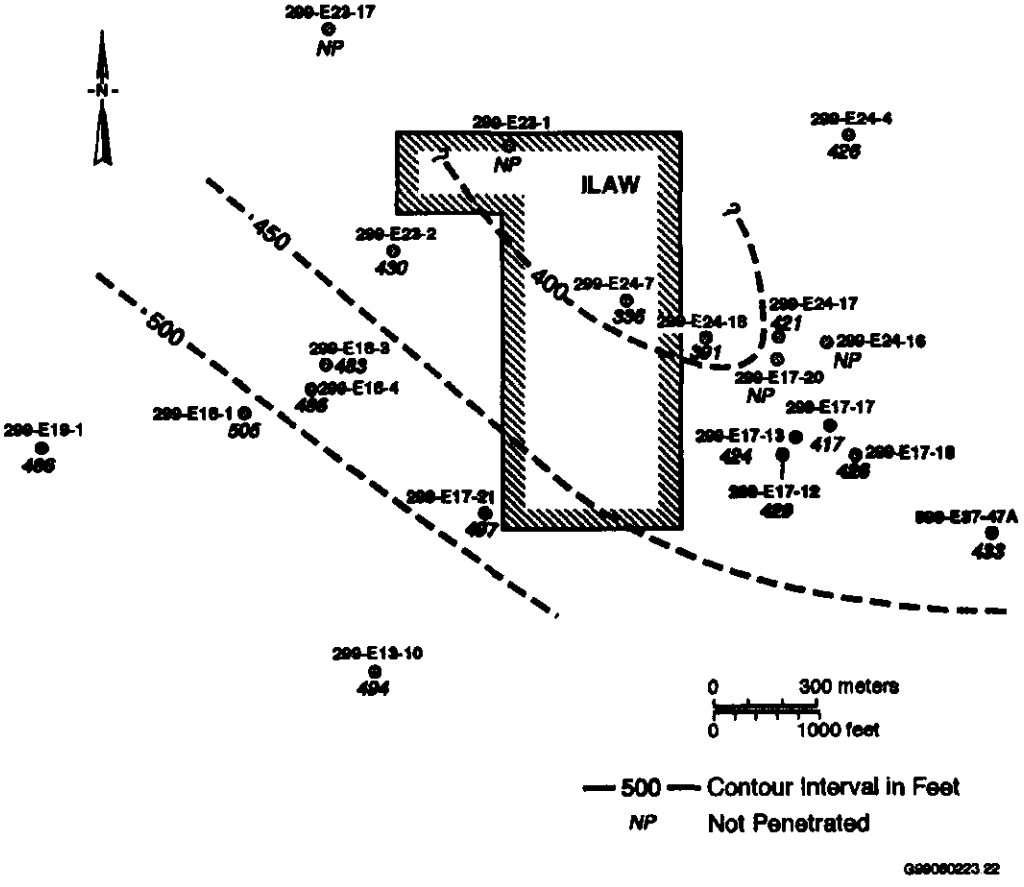

Figure 4.18. Structural Contour Map on the Surface of the Ringold Formation

4.3.2.3 Hanford Formation

The Hanford formation is as much as 380 ft (116 m) thick in and around the new ILAW disposal site (Figures 4.11 and 4.19). It thickens in the erosional channel cut into the Ringold Formation and thins to the southwest along the margin of the trough. It may thin northeast of the trough but this is based on only one data point (Figure 4.19).

At the new ILAW site, the Hanford formation consists mainly of sand-dominated facies and lesser amounts of silt-dominated and gravel-dominated facies. It has been described on borehole logs as poorly sorted pebble to boulder gravel and fine- to coarse-grained sand, with lesser amounts of interstitial and interbedded silt and clay. In previous studies of the new ILAW disposal site (Reidel et al. 1998), the Hanford formation was described as consisting of three units: an upper and lower gravel-dominated facies and a sand-dominated facies between the two gravel facies. The upper gravel-dominated facies appears to be thin or absent in the new ILAW disposal area. In Table 4.2, the elevations of the tops of several tentatively correlated units of the Hanford formation are given.

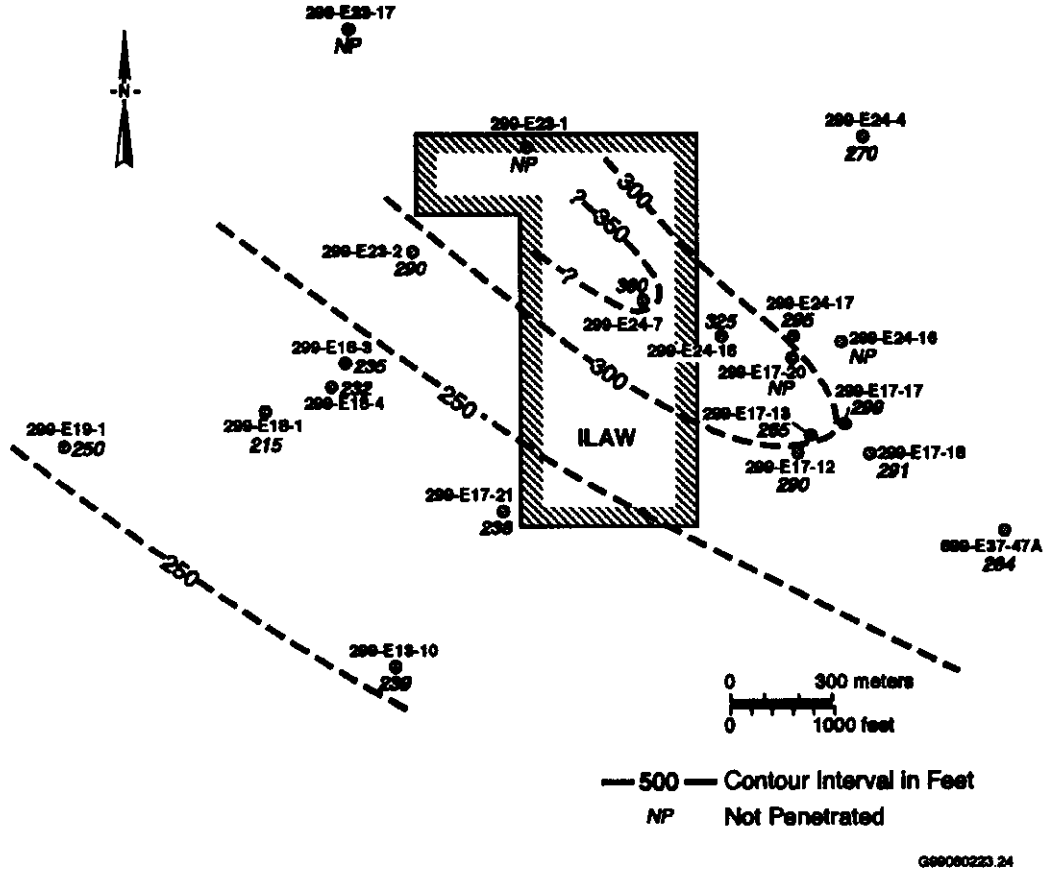

Figure 4.19. Isopach Map of the Hanford Formation at the New ILAW Disposal Site

4.3.2.3.1 Basal Gravel Sequence

The lowermost 88 ft (27 m) of the Hanford formation encountered in borehole 299-E17-21 consists of gravel-dominated facies. Drill core and cuttings from this borehole indicate that the unit is clast-supported pebble- to cobble-gravel with minor amounts of sand in the matrix. Cobbles and pebbles are almost exclusively basalt with no cementation. In outcroppings these deposits display massive bedding, plane to low-angle bedding and large-scale planar forset cross-bedding, but such features typically cannot be observed in borehole core. This unit either pinches out west of the new ILAW disposal site or becomes more sand rich. It thickens to the northeast. The gravel is interpreted to be Missoula flood gravels deposited in the erosional channel carved into the underlying Ringold Formation (Figure 4.18).

This basal gravel sequence is equivalent to unit H3 of Lindsey et al. (1994b) (Figure 4.2), and is equivalent to mapping unit Qfg1, Missoula Outburst flood gravel deposits of Reidel and Fecht (1994a, 1994b). The sand unit overlying this gravel has reversed polarity (Appendix B), indicating that these units are older than 780 ka.

4.3.2.3.2 Sandy Sequence

The upper portion of the Hanford formation consists of at least 240 ft (73 m) of sand-dominated and silt-dominated facies. These deposits have been described as fine- to coarse-grained sand with minor amounts of silt and clay and some gravelly sands. This sequence is equivalent to unit H2 of Lindsey et al. (1994a), and is equivalent to the following mapping units of Reidel and Fecht (1994a,b): Qfs1, Qfs2, and Qfs3, Missoula Outburst Flood Deposits consisting of sand, silt, and clay (Figure 4.2).

Three paleosols (soils) were identified in core and drill cuttings from borehole 299-E17-21 (Reidel et al. 1998). Paleosol Horizon 1 occurs at 163 ft (49 m) drilled depth (Figure 4.11), paleosol Horizon 2 at 58 ft (18 m) drilled depth, and paleosol Horizon 3 at 5 ft (1.5 m). The paleosol horizons are as much as 6 in. (15 cm) thick with a sharp upper surface. The horizons have a light brown color compared to the darker sands below and some $CaCO_3$ cementation. The lack of well-defined bedding laminations rhythmics like the sands below suggests some bioturbation but no root casts were observed in the core. The paleosol grades downward into normal sands.

The three paleosol horizons represent time intervals when soil development took place and are interpreted to represent three time periods between Missoula flood deposition. Reidel et al. (1998) called the layers defined by the paleosols: Layer 1 as that part of the Hanford formation extending from the paleosol horizon at 163 ft (49 m) to the top of the basalt gravel at 247 ft (75 m). Layer 2 extends from the top of the second paleosol horizon 58 ft (18 m) to the top of the first paleosol at 163 ft (49 m). Layer 3 extends from the top of the third paleosol horizon at 5 ft (1.5 m) depth to the second paleosol horizon at 58 ft (18 m) drilled depth. The presence or exact depth of these layers is known elsewhere at the new ILAW site and can only be inferred.

Layer 1. Layer 1 is 84 ft (26 m) thick in borehole 299-E17-21. It is a zone of sand and silt with a poorly developed caliche layer at the top. Only the upper several inches are cemented but $CaCO_3$ extends to a depth of about 10 ft (3.3 m) below the top. $CaCO_3$ fragments or grain coatings were found to a depth of at least 218 ft (66 m).

The lower 20 ft (6 m) of Layer 1 consists of interbedded sands and gravels. The basal gravel sequence underlying Layer 1 appears to grade upward into a sequence of interbedded sands and gravels. At least three upward fining zones of gravels to sands were recognized in Layer 1. These zones are equivalent to unit H2A of Lindsey et al. (1994a).

Planar-laminar sands with minor silt lenses dominate the upper 54 ft (16 m) of Layer 1. This sequence consists of fining upward sands, well-compacted, slightly $CaCO_3$-cemented sands, and well-laminated sands. $CaCO_3$ associated with development of the paleosol extends well down into this layer.

Layer 1 is part of unit H2 of Lindsey et al. (1994a), and is equivalent to mapping unit Qfs1 of Reidel and Fecht (1994a, 1994b) (Figure 4.2). Mapping unit Qfs1 is a Missoula Outburst Flood Deposits consisting of sand, silt, and clay that is 780 ka and has a reversed magnetic polarity. Paleomagnetic studies by the University of California, Santa Cruz, has shown that this layer has reversed magnetic polarity (Appendix B). Layer 1 has only been identified in borehole 299-E17-21. Data from surrounding boreholes is of too poor of quality to identify this layer.

Layer 2. The upper 90 ft (27 m) of Layer 2 is principally the sand- and silt-dominated facies. They have been described as fine- to medium-grained sand with minor amounts of interstitial silt. Throughout the sands are disseminated flakes of $CaCO_3$ and $CaCO_3$-cemented sand grains. Several fining upward zones were recognized as well as highly-compacted zones of sand and silt with faint laminations. Layer 2 was correlated to other boreholes using geologists logs and archived chip samples. In addition, the paleosol that forms the top of this layer appears to responsible for zones of lateral spreading of contaminants under waste disposal sites immediately east of the new ILAW disposal site.

Layer 2 is also part of unit H2 of Lindsey et al. (1994a), and may be equivalent to mapping unit Qfs2 of Reidel and Fecht (1994a, 1994b) (Figure 4.2). The mapping unit is a Missoula Outburst Flood Deposits consisting of sand, silt and clay that is older than 13 ka and younger than 780 ka. Mapping unit Qfs2 has a normal magnetic polarity.

Layer 3. Layer 3 is 53 ft (16 m) thick in borehole 299-E17-21. The paleosol at the top of Layer 3 is a 1.1 ft (3 cm) thick, oxidized and leached zone of pebbly, fine-grained sand and silt with some pebbles with a 4-in. (10-cm) poorly developed caliche zone (sand and silt cemented by $CaCO_3$). Several distinct gravelly sands are present within several feet of the paleosol at the top of this layer. This forms the surface of much of the new ILAW disposal site north of the eolian deposits.

The lower 25 to 30 ft (8 to 10 m) of Layer 3 consists principally of sand with interstitial silt and minor silt beds that are interpreted as lenses. Several minor silt beds are locally present. Gravelly sand as described on geologists logs marks a transition to finer-grained sand with more silt at a drilled depth of approximately 25 ft (8 m).

Layer 3 is interpreted to consist of the upper gravelly sequence and the upper part of the sandy sequence defined in previous studies. It is part of unit H2 of Lindsey et al. (1994) and is equivalent to mapping unit Qfs3 of Reidel and Fecht (1994a, 1994b) - Outburst Flood Deposits consisting of sand, silt and clay that is about 13 ka. An ash from the 13 ka eruption of Mt. St. Helens (Set S Ash) is typically found near the top of this unit in many places throughout the Pasco basin. The ash was not recognized in any of the boreholes near the new ILAW disposal site but has been identified as an excavation 100 m west of the site.

4.3.2.4 Eolian Unit

Eolian deposits cover the southern part of the new ILAW disposal site. Borehole 299-E17-21 was sited on a stabilized sand dune. The eolian unit is composed of fine- to coarse-grained sands with abundant silt. Calcium-carbonate coating found on the bottom of pebbles and cobbles in drill core through this unit is typical of Holocene caliche development in the Columbia Basin. This unit is equivalent to mapping unit Qd, Holocene Dune Sand, of Reidel and Fecht (1994a, 1994b) (Figure 4.2).

4.3.2.5 Clastic Dikes at the New ILAW Site

Clastic dikes have not been observed at the new ILAW site. Clastic dikes, however, have been observed in excavations surrounding the site (e.g., PUREX, US Ecology, and Canister Storage excavation). At the new ILAW site, clastic dikes are probably not observed because they are covered by wind

blown sediments and a cover of "old growth" sagebrush. The ubiquitous presence of clastic dikes in the 200-East Area suggests that they are probably present at the site.

5.0 SEISMIC DATA

Earthquake activity at the new and existing disposal sites is typical of the Hanford Site. Figure 5.1 shows the location of earthquakes that have occurred near the 200-East Area since monitoring began at Hanford in 1969. Table 5.1 summarizes the pertinent data for the earthquakes shown on Figure 5.1. Most of the earthquakes have been less than coda magnitude 3.0. Coda magnitude is a local magnitude and is an estimate of the Richter magnitude. Thirty-three percent of the earthquakes shown on Figure 5.1 occurred in the Columbia River Basalt Group. Sixteen percent were in the sub-basalt sediments and 51% were in the crystalline basement.

The principal geologic structures from Reidel and Fecht (1994a) are reproduced on Figure 5.1. A comparison of the location of earthquakes to the geologic structures indicates that there is no apparent pattern.

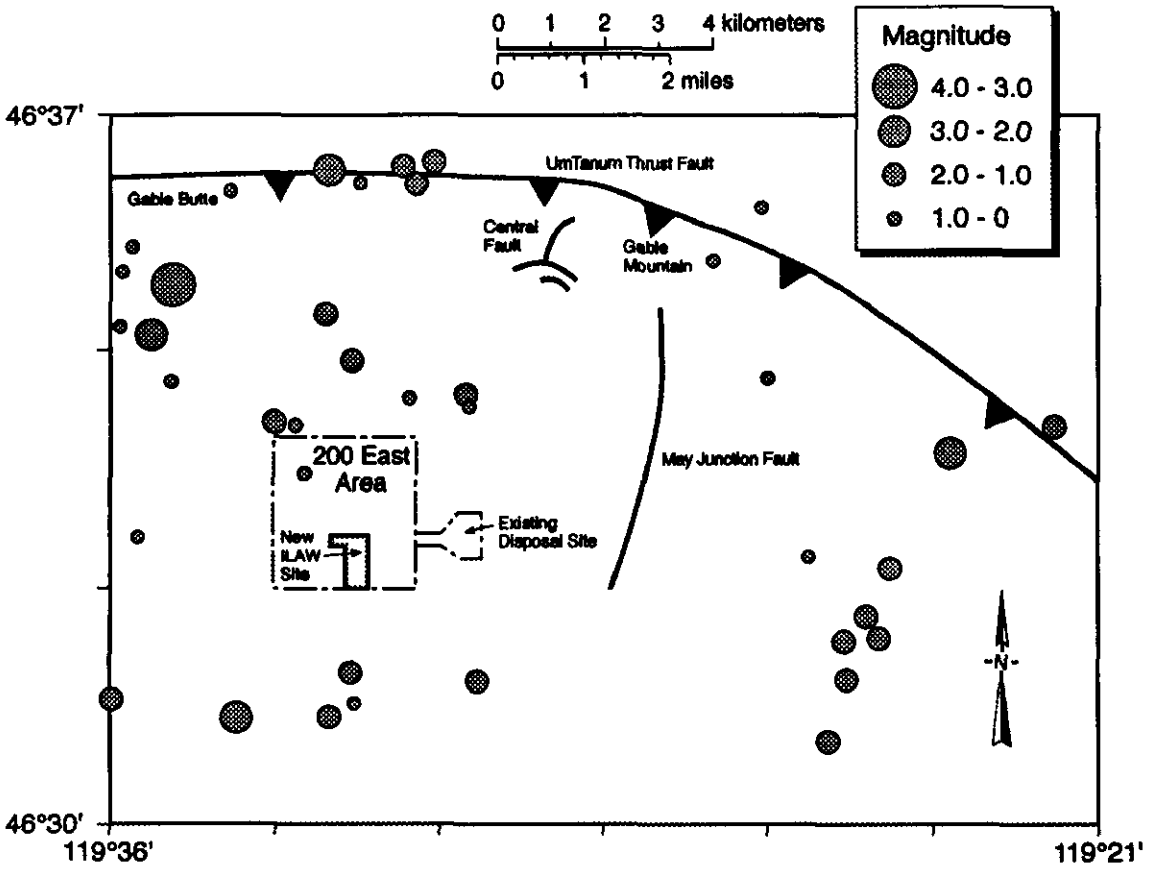

Figure 5.1. Map Showing the Location of Earthquakes Detected Since 1969

Table 5.1. Earthquakes in the Area Surrounding the Existing and New ILAW Disposal Sites

Event Number	Date	Latitude (degrees N minutes)	Longitude (degrees N minutes	Depth (km)	Magnitude (coda)	Geologic Layer
7003161548	3/16/70	46N31	119W34	21.5	2.1	Crystalline Basement
7110132218	10/01/71	46N34	119W31	18.2	1.0	Crystalline Basement
7302111101	2/11/73	46N33	119W36	13.56	0.6	Crystalline Basement
7506161959	6/16/75	46N37	119W33	4.65	2.5	Basalt
7501282012	10/28/75	46N35	119W32	19.02	1.0	Crystalline Basement
7805111831	5/11/78	46N36	119W27	16.37	0.8	Crystalline Basement
7805151210	5/15/78	46N32	119W25	17.79	1.5	Crystalline Basement
7808170243	8/17/78	46N37	119W31	4.91	1.0	Basalt
7808190250	8/19/78	46N37	119W31	6.85	1.2	Sub-basalt Sediments
7808221820	8/22/78	46N37	119W32	0.31	0.7	Basalt
7808242113	8/24/78	46N37	119W32	4.44	1.0	Basalt
8003252307	3/25/80	46N32	119W25	2.66	1.3	Basalt
8003262300	3/26/80	46N31	119W25	1.37	1.3	Basalt
8003292210	3/29/80	46N32	119W25	3.22	1.2	Basalt
800414733	4/14/80	46N33	119W26	0.44	0.8	Basalt
8004161834	4/16/80	46N33	119W25	7.56	1.1	Sub-basalt Sediments
8010221136	10/22/80	46N34	119W33	20.87	0.3	Crystalline Basement
8104161826	4/16/81	46N31	119W25	1.27	1.3	Basalt
8107200623	7/20/81	46N34	119W32	11.99	0.1	Sub-basalt Sediments
8108072202	8/7/81	46N31	119W36	15.45	1.5	Crystalline Basement
8312181118	12/18/83	46N34	119W34	15.65	1.5	Crystalline Basement
8612120307	12/12/86	46N34	119W31	3.94	0.9	Basalt
8707251409	7/25/87	46N34	119W33	15.59	0.3	Crystalline Basement
8807042056	7/4/88	46N36	119W26	16.62	0.7	Crystalline Basement
9003162235	3/16/90	46N31	119W33	7.83	1.2	Sub-basalt Sediments
9003162236	3/16/90	46N31	119W32	8.16	0.4	Sub-basalt Sediments
9003180506	3/18/90	46N32	119W32	4.13	1.2	Basalt
9008020211	8/2/90	46N35	119W33	14.75	1.0	Crystalline Basement
9011201718	11/20/90	46N35	119W35	25.24	2.1	Crystalline Basement
9201070846	1/7/92	46N35	119W35	24.38	0.9	Crystalline Basement
9201241911	1/24/92	46N35	119W26	19.72	0.9	Crystalline Basement
9411131510	11/13/94	46N36	119W36	24.74	0.4	Crystalline Basement

Table 5.1. (contd)

Event Number	Date	Latitude (degrees N minutes)	Longitude (degrees N minutes	Depth (km)	Magnitude (coda)	Geologic Layer
9411131650	11/13/94	46N35	119W35	28.22	3.3	Crystalline Basement
9411242107	11/24/94	46N35	119W36	25.40	0.7	Crystalline Basement
9412152020	12/15/94	46N36	119W36	25.18	0.3	Crystalline Basement
9603210923	3/21/96	46N32	119W31	21.88	1.1	Crystalline Basement
9708122312	8/12/97	46N34	119W24	0.27	2.1	Basalt
9809232334	9/23/98	46N36	119W34	14.16	0.9	Crystalline Basement
9901101816	1/10/99	46N34	119W22	0.26	1.4	Basalt

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Appendix A

Quality Assurance and Safety

Appendix A

Quality Assurance and Safety

All laboratory and field experiments are conducted under PNNL quality assurance (QA) requirements as described in the guidance provided in PNNL's Standards Based Management System (SBMS) and as specified in the Project QA Plan. Significant modifications to the QA plan are made in accordance with the guidance in the SBMS.

Project staff members are qualified and receive any training needed to carry out their assigned responsibilities.

Staff use equipment of known accuracy for data collection. For measurements necessary to substantiate test results, staff ensure that standards used for calibration are traceable to nationally recognized standards. Measuring and Test Equipment (M&TE) lists are generated by each task and maintained in the project files applicable to the specific task. M&TE used is identified in the laboratory record books or other data recording location to provide traceability to instrument calibrations.

Test procedures and methods are documented and deviations noted. New methods developed during the course of this work are documented and reviewed. All test procedures, data processing software, and supporting documentation undergo independent technical review by qualified PNNL staff.

Staff maintain records necessary to substantiate results and processes of research activities. After activities are completed, records are filed and maintained per the project Records Inventory and Disposition Schedule (RIDS).

All precautionary measures are taken in accordance with standard PNNL safety procedures to ensure that field work is conducted in a safe manner. No hazardous wastes have been generated during the conduct of work described in this report.

Appendix B

Paleomagnetic Study

Paleomagnetism of Borehole 299-E17-21 Sediments, Hanford, WA

prepared by Christopher J. Pluhar
under the supervision of Professor Robert S. Coe

University of California, Santa Cruz
Earth Sciences Dept.
1156 High St.
Santa Cruz, CA 95064-1077

Abstract

We have completed paleomagnetic analysis of seventeen sediment samples of the Hanford Formation from a drill core recovered from borehole 299-E17-21 at the Hanford DOE site. These analyses reveal dominantly reversed polarity directions, including that these sediments are older than the Brunhes-Matuyama magnetic reversal (780 ka).

Introduction

Seventeen minimally-consolidated, oriented samples were collected from the most fine-grained segments of the drill core (Table 1). The samples consisted of cubes "carved" from the drill core. Plastic sample boxes were placed over/around each cube before it was detached from the core. Sample lithology varied between fine and coarse grained sand, but in all cases was very loose and therefore likely sustained some randomization from shaking in transit from Washington to Santa Cruz. Upon arrival, samples were cemented with sodium silicate solution and in some cases were capped with alumina cement to prevent the loss of sample. Samples were analyzed in a 3-axis DC SQUID cryogenic magnetometer, housed in a shielded room at the UC Santa Cruz paleomagnetism lab.

Demagnetization Experiments

We conducted unusually detailed alternating field (AF) demagnetization experiments on the samples to reveal their characteristic remanent magnetization (ChRM) directions. Typical AF demag steps were; NRM, 1, 2, 3, 4, 5, 6, 7, 8, 10, 13, 16, 20, 25, 30, 35, 40,... milli-Tesla (mT). Demagnetization was considered complete when the remaining sample magnetization intensity was <10% of NRM, or more than 3 consecutive directions along a sample's demag path were highly scattered and non-collinear. Typically, samples dropped below 50% of their NRM intensity before the 10 mT AF step and the ChRM is at least partially revealed by 10 mT. This indicates low coercivity magnetization of the samples, leading to concern about the samples being overprinted *in situ*, or during drilling, transportation and storage. None of the rigorous paleomagnetic tests for sample overprinting (reversal test, fold test, conglomerate test) are available to us due to the nature of the samples (derived from one drill core and apparently containing no magnetic reversals). However, any *in situ* overprinting with a reversed-polarity direction would require that the samples existed during a reversed chron of significant length, still making them >780 ka. Furthermore, the observed ChRM is of similar inclination to that expected for the Hanford geographic area. Overprinting during drilling could have induced a uniform overprint, but since the observed ChRM is not parallel to the drill string (inclination direction ±90), it is unlikely caused by drilling. Overprinting by the earth's field during sample storage is possible, if the core segments were all stored parallel, and with their tops all toward the same direction. However, to produce the observed ChRM the cores would have to be stored flat side down with the core tops pointing in a northerly direction. This is not the case. The cores were stored flat side up and therefore overprinting during storage is unlikely unless the storage location possesses a uniform ambient field opposed to the earth's field.

Thermal demagnetization experiments were not conducted since the samples were extremely friable and contained in plastic sample boxes. It is very possible that thermal demag would yield superior results if samples could be cemented prior to removal from the drill core.

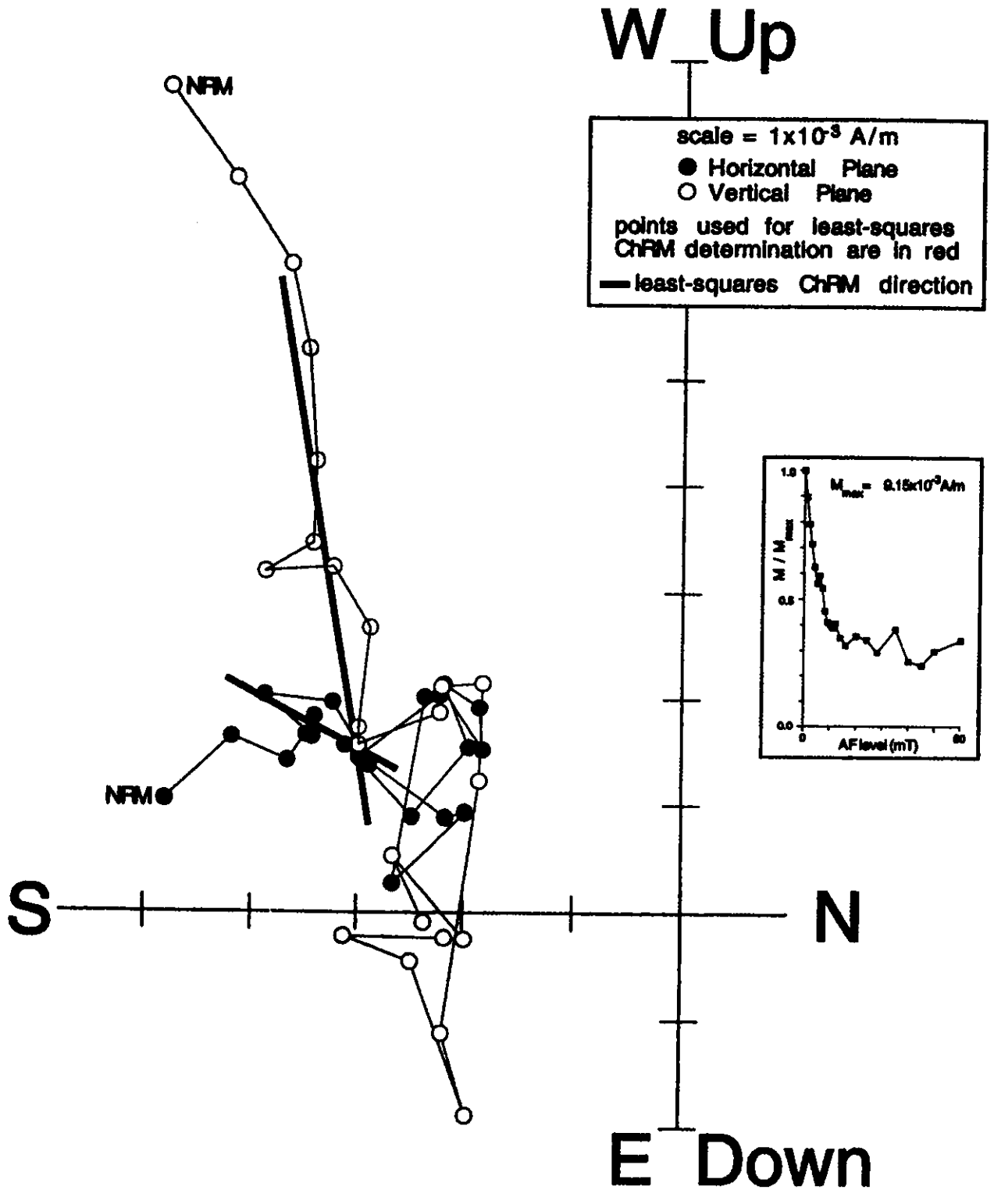
Least-squares Sample Analysis

We obtained the ChRM directions by fitting least-squares lines to the demagnetization data (see Zijderveld diagrams on the following pages). Typically, higher level demag segments of the demagnetization paths degenerated to highly-scattered, semi-random collections of points. Thus points chosen for least-squares fitting are at relatively low demag levels, although generally we

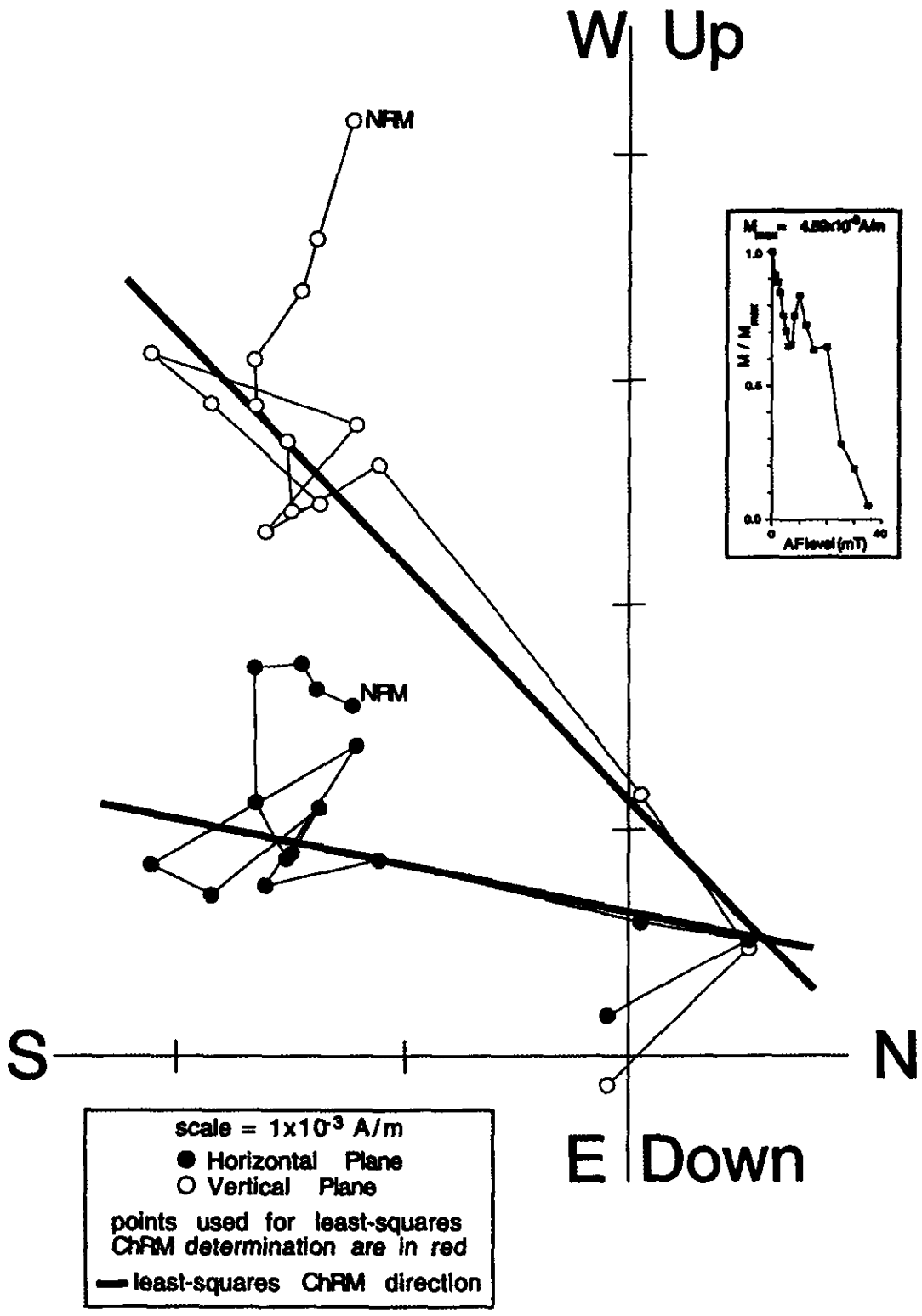
Table 1 - Borehole 299-E17-21 Stratigraphic, Lithologic and Paleomagnetic Summary

Sample Number	Core Segment	Depth Below Ground Surface (ft)	Lithology	Paleomagnetic Quality	Polarity	Misses the Origin?
1	31A	221	fine sand	Very Good	R	Yes
2	31A	220.5	fine sand	Very Good	R	* No?
3	31A	220	fine sand	Very Good	R	Yes
4	28A	207.5	coarse sand	Very Good	R	Yes
5	28A	206.5	coarse sand	Fair	R	Yes
6	27A	201	coarse sand	Fair	R	Yes
7	27A	200.25	coarse sand	Good	R	Yes
8	26A	197.6	medium sand	Poor	R	Yes
9	26A	197.25	medium sand	Fair	N	Yes
10	26A	196.9	medium sand	Poor	N -> R	Yes
11	26A	196.6	medium sand	Fair	N -> R?	Yes
12	26A	196.25	medium sand	Good	R	Yes
13	25A	191.3	coarse sand	Fair	R	Yes
14	25A	-	No Sample	-	-	-
15	25A	189.8	coarse sand	Fair	R	Yes
16	24A	182.3	coarse sand	Fair	R	Yes
17	24A	182	coarse sand	Excellent	R	Yes
18	24A	181.7	coarse sand	Very Good	R	Yes

* - If one includes the last point R - reversed polarity N - normal polarity



Sample 1 (from Core 31A)



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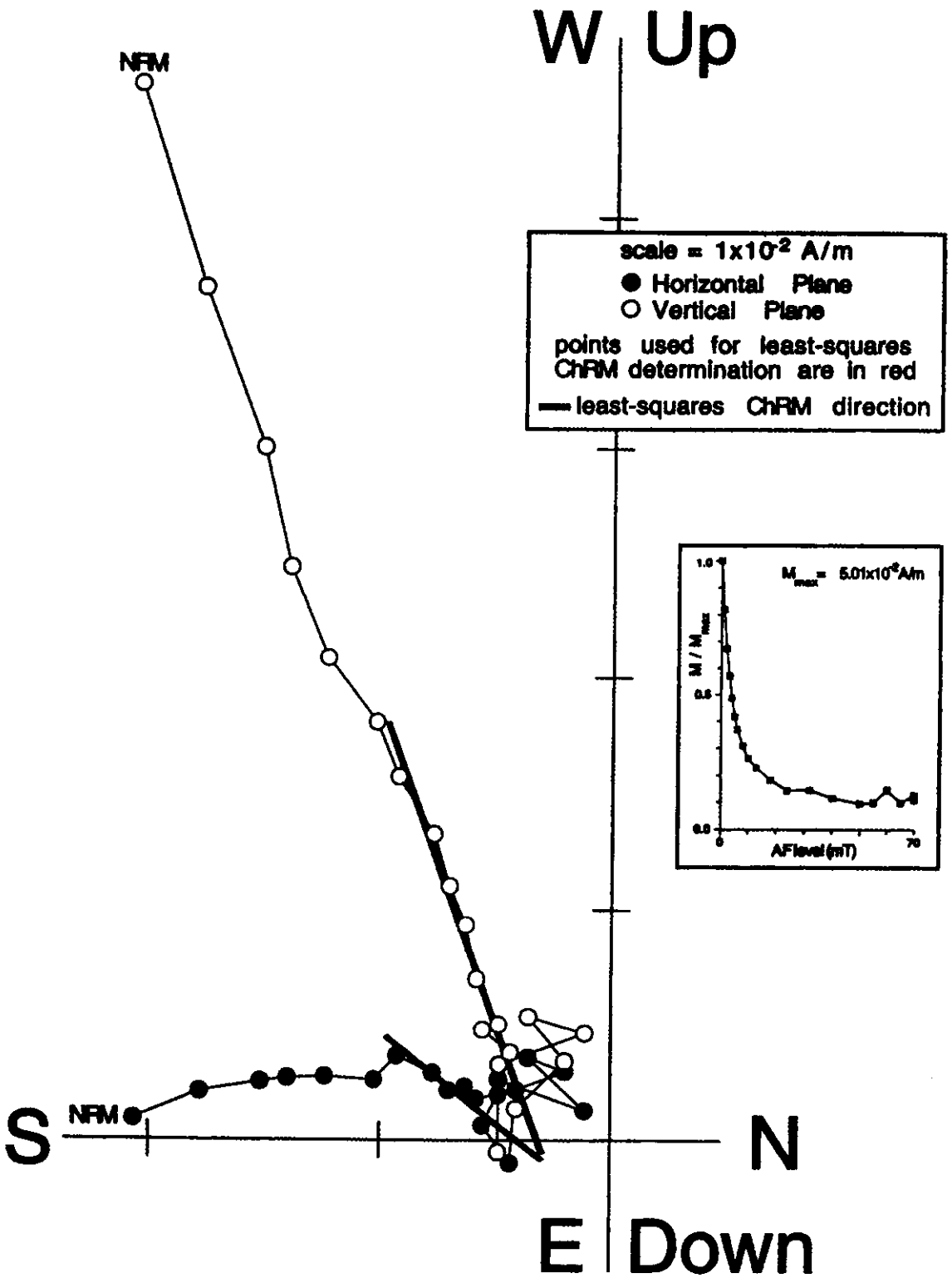

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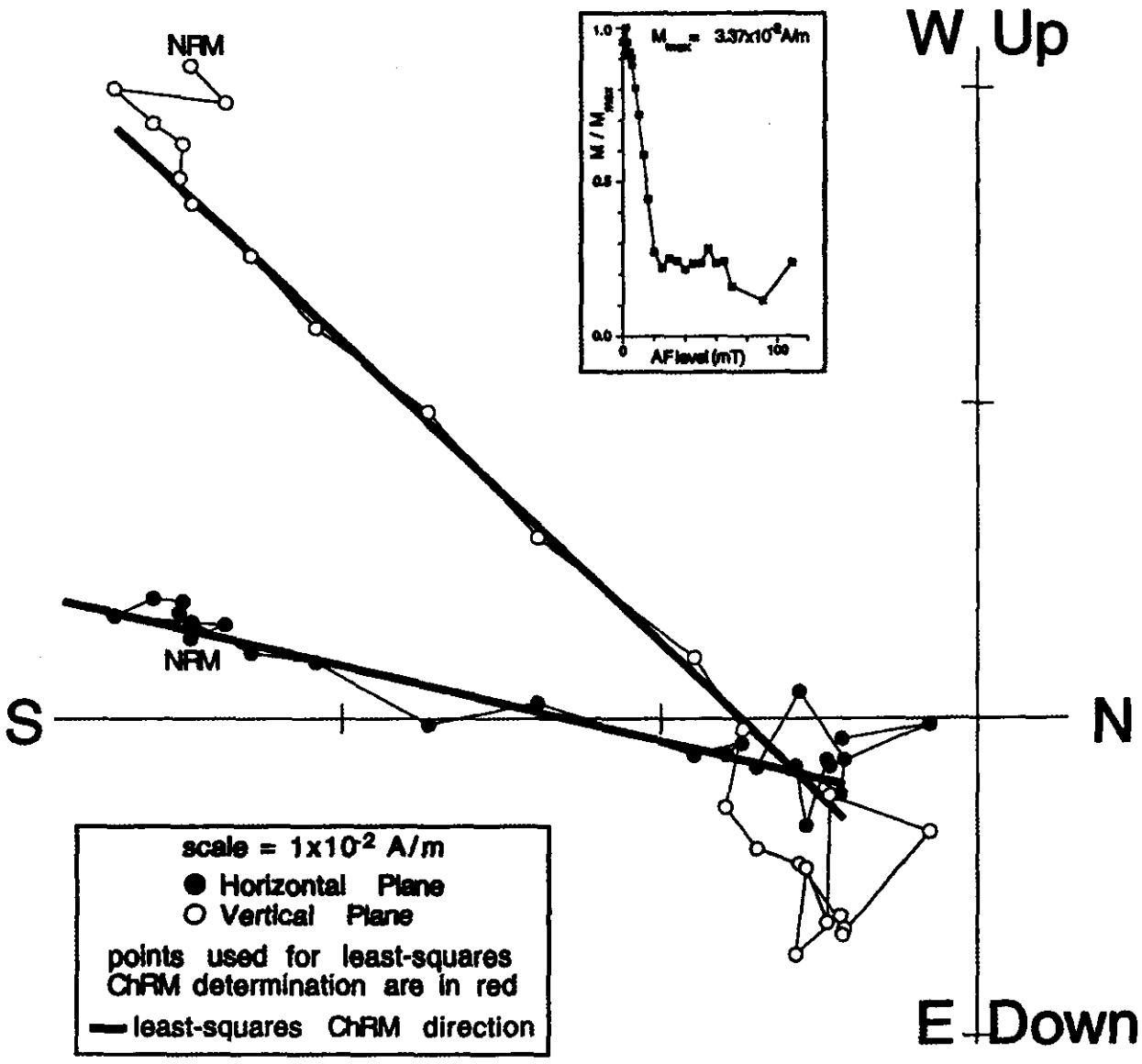

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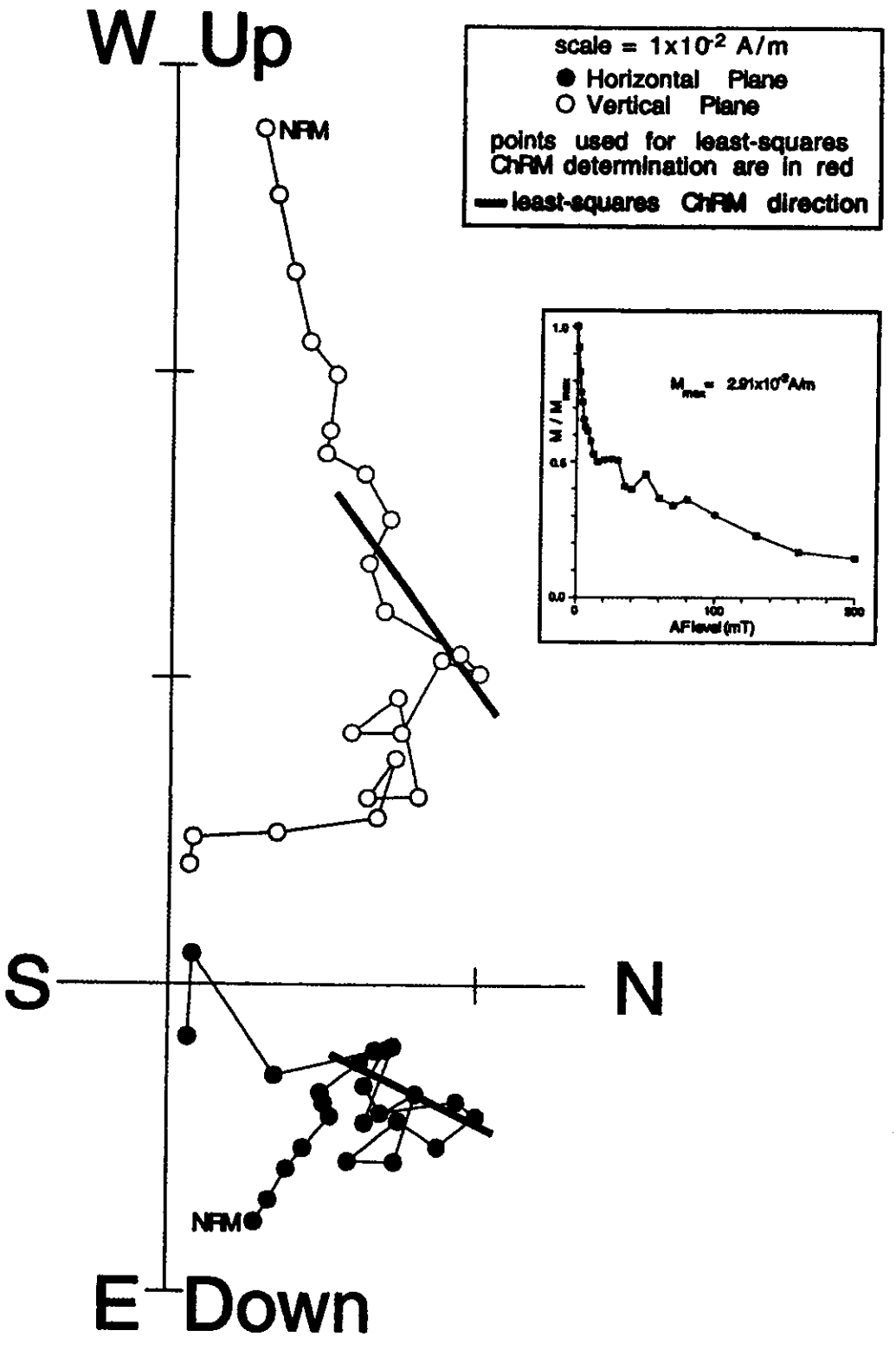

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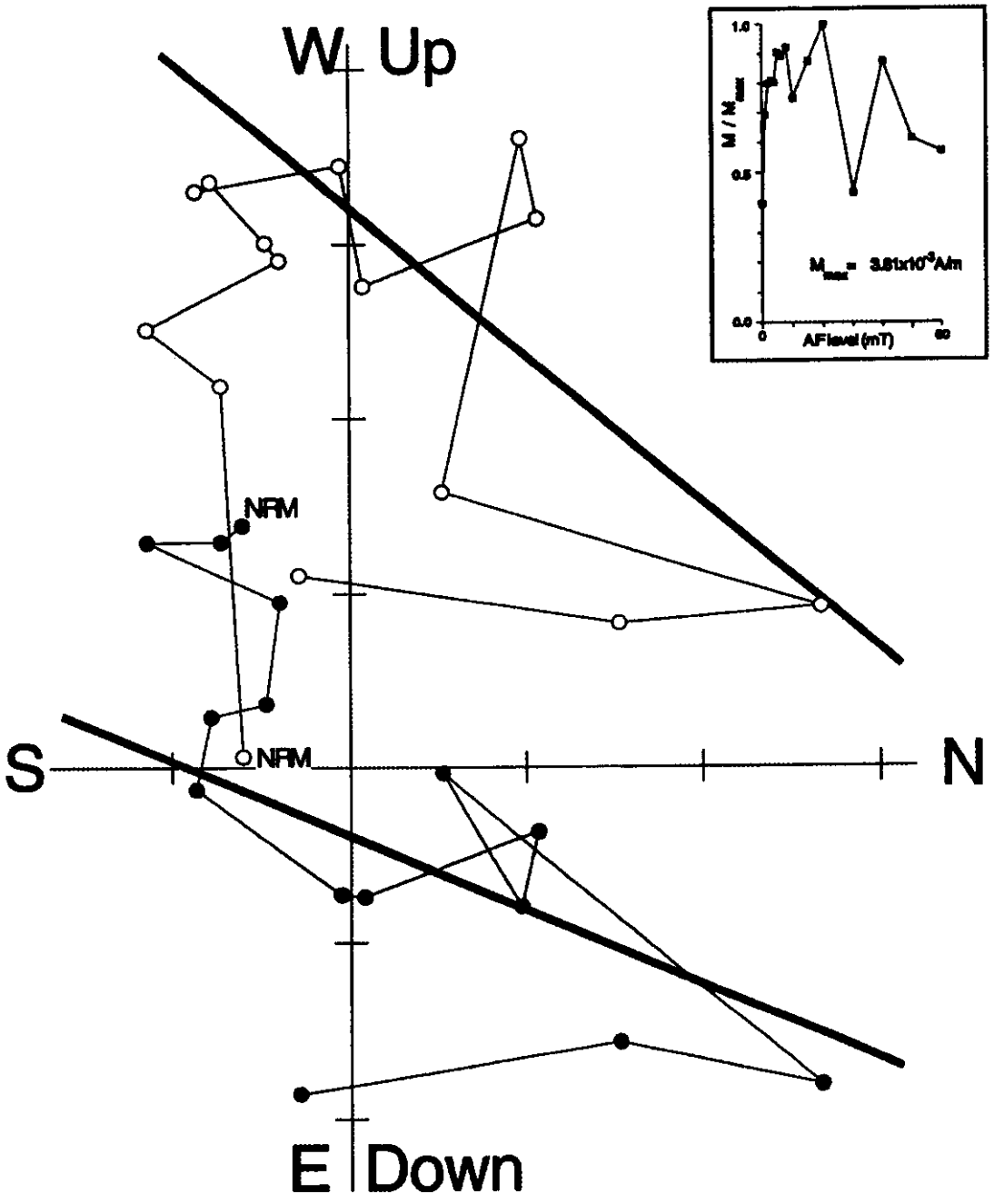
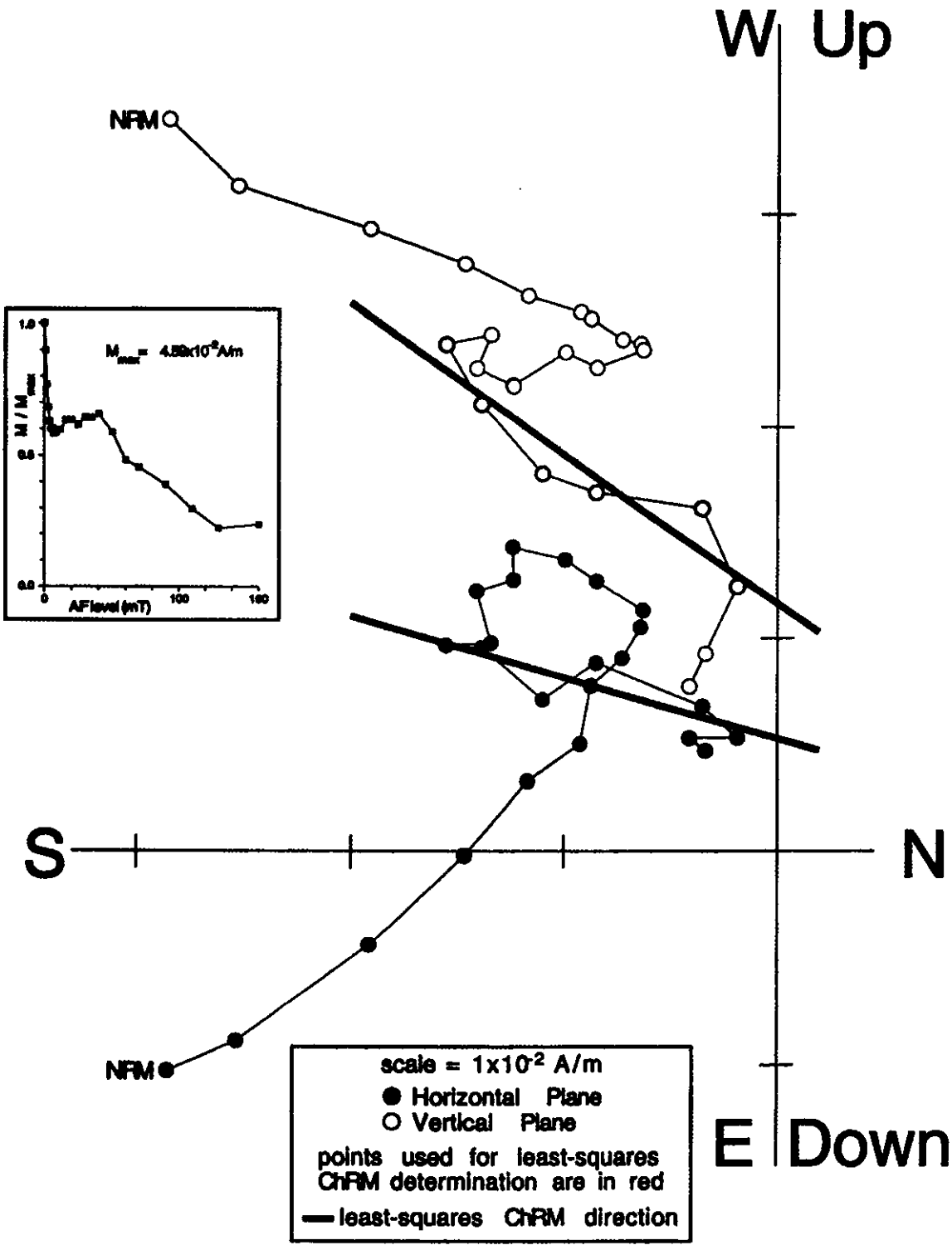


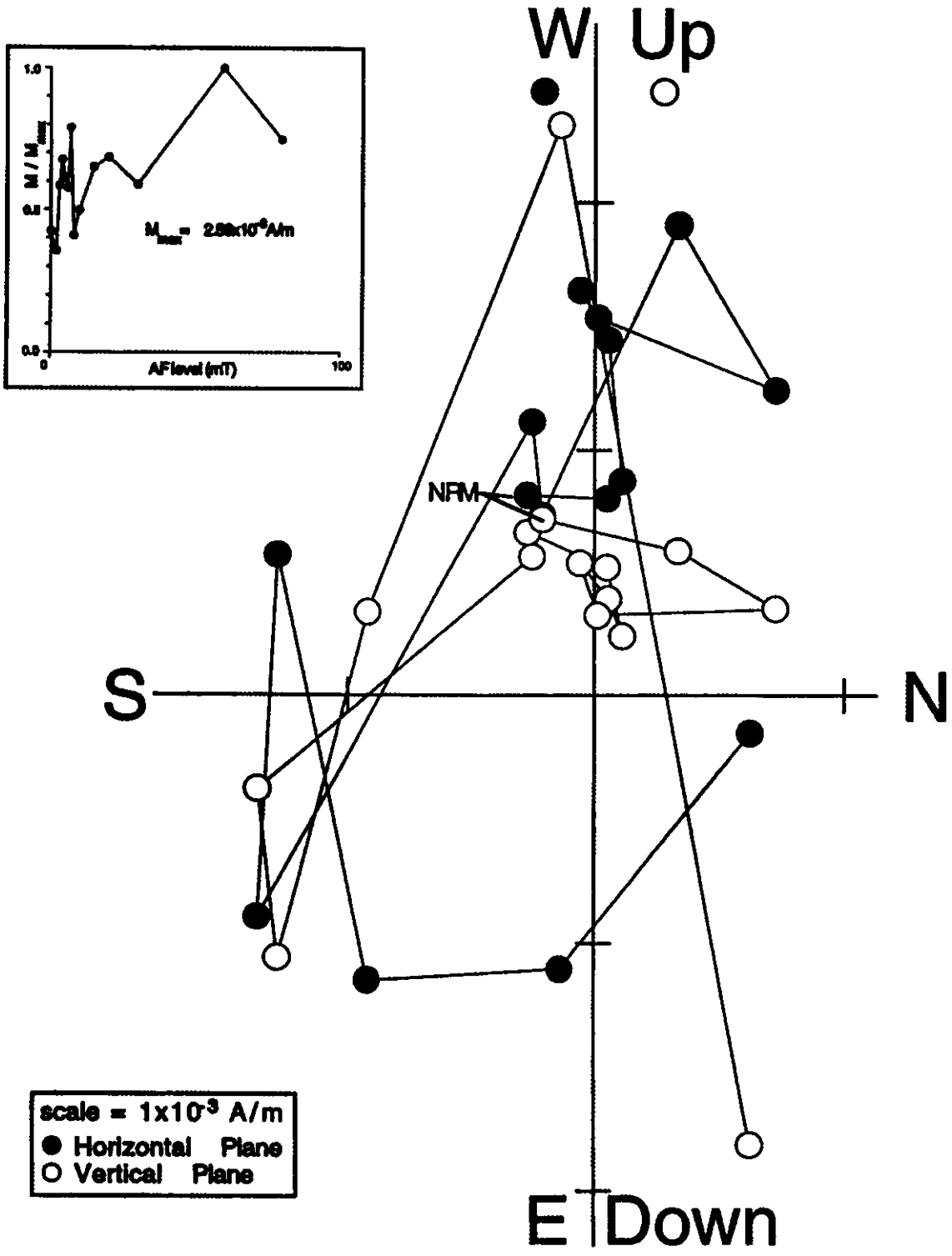
scale = 1×10^{-3} A/m
● Horizontal Plane
○ Vertical Plane

points used for least-squares ChRM determination are in red
— least-squares ChRM direction

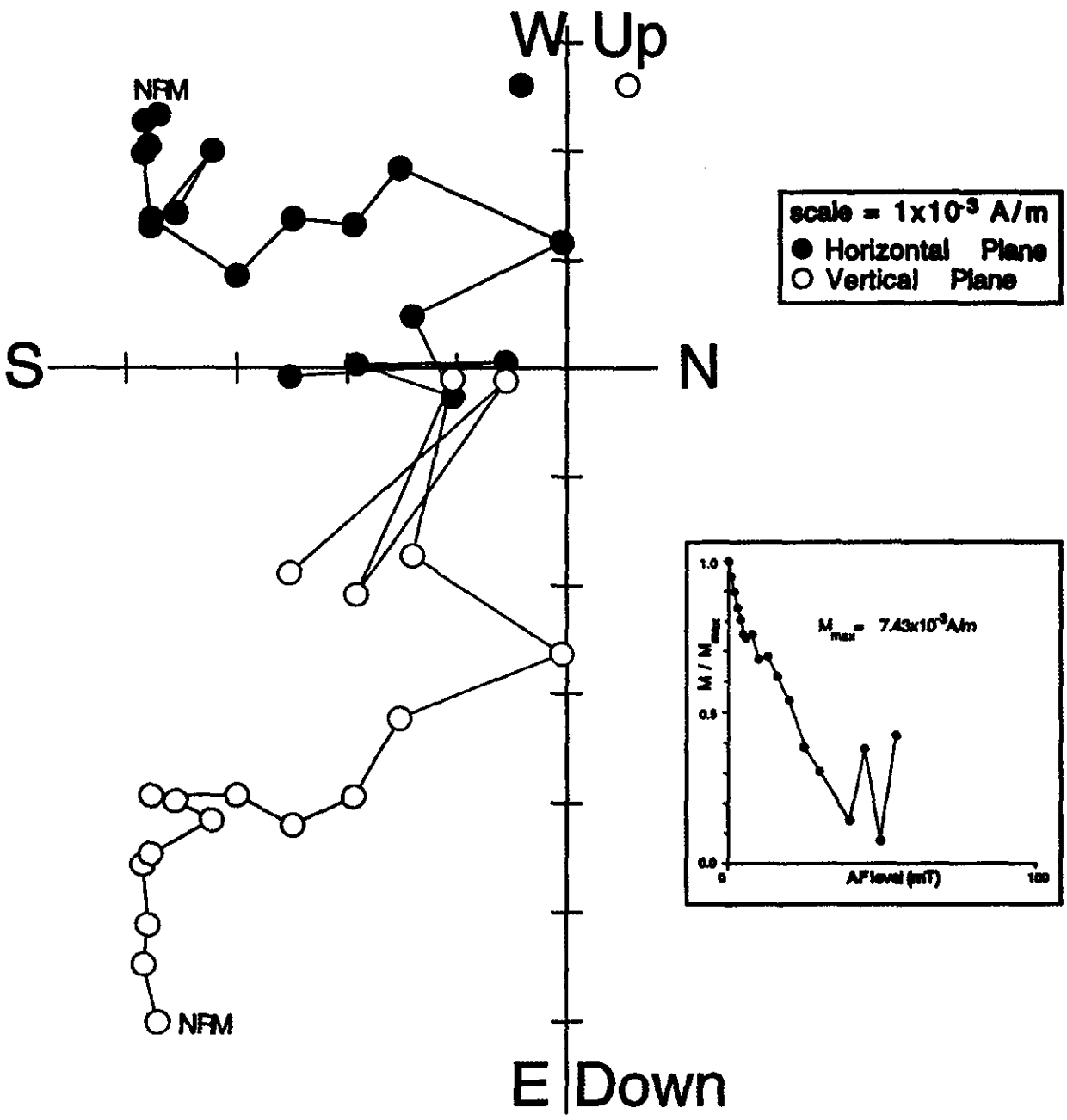
Sample 6 (from Core 27A)



Sample 7 (from Core 27A)



Sample 8 (from Core 26A)



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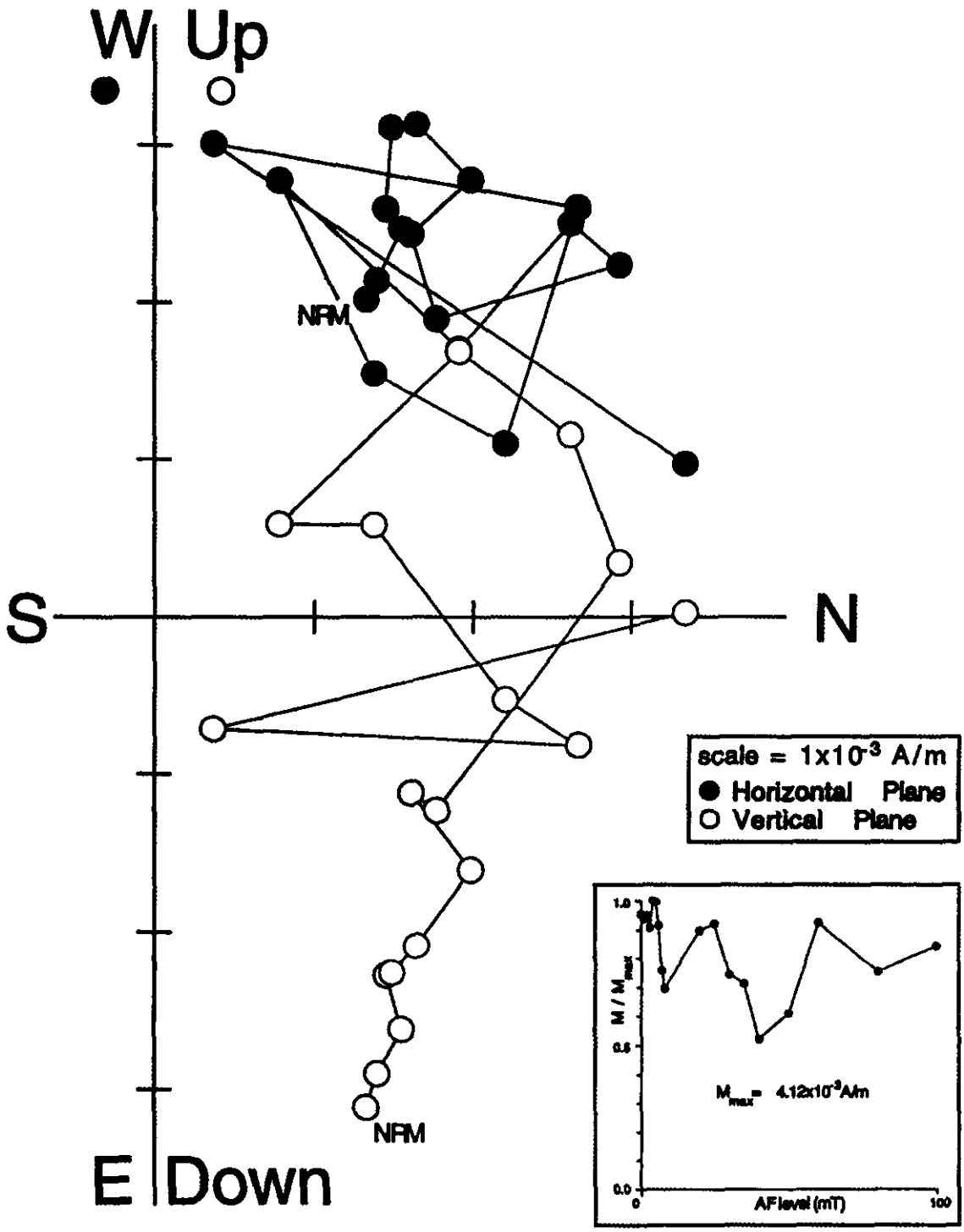

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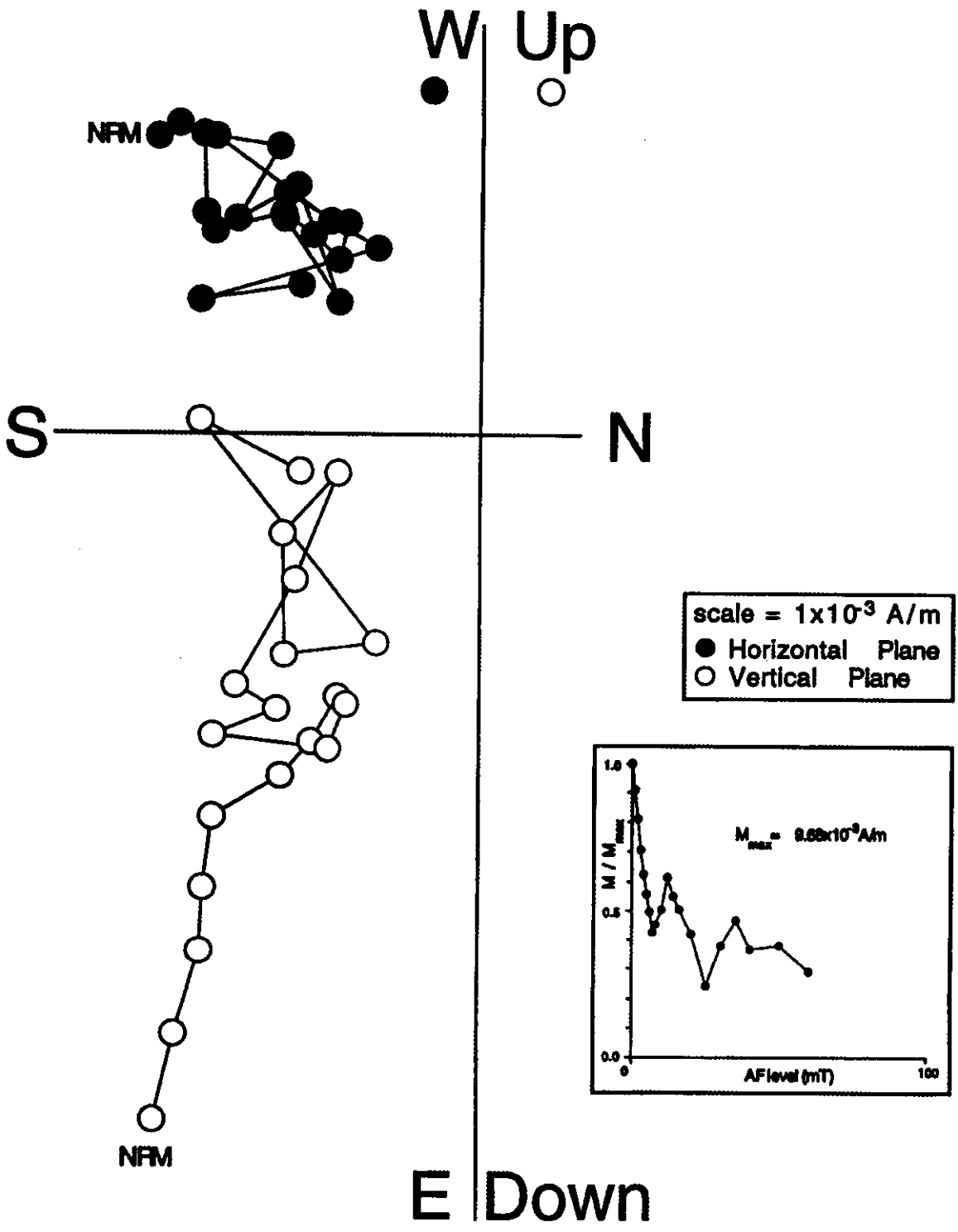

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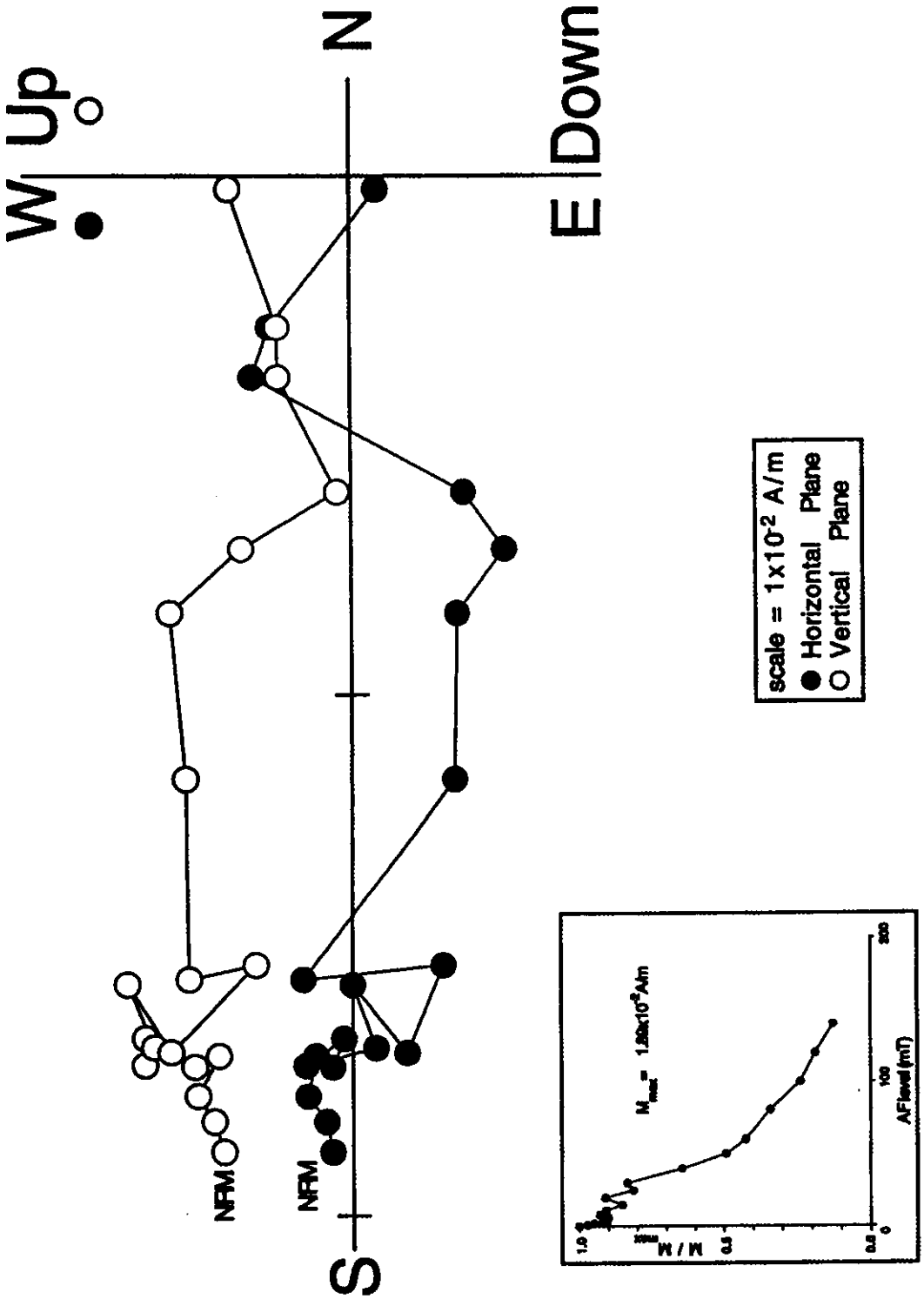

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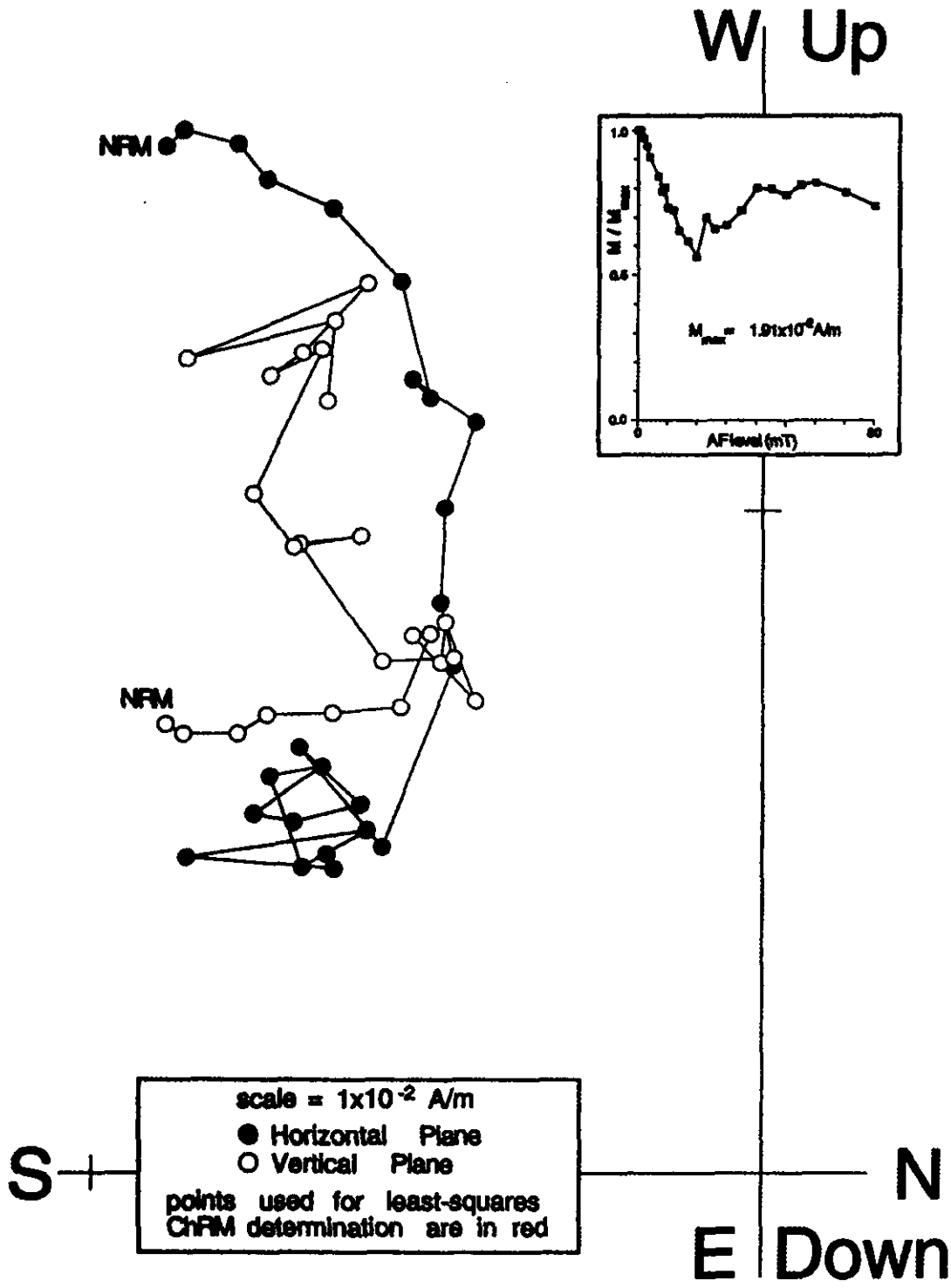

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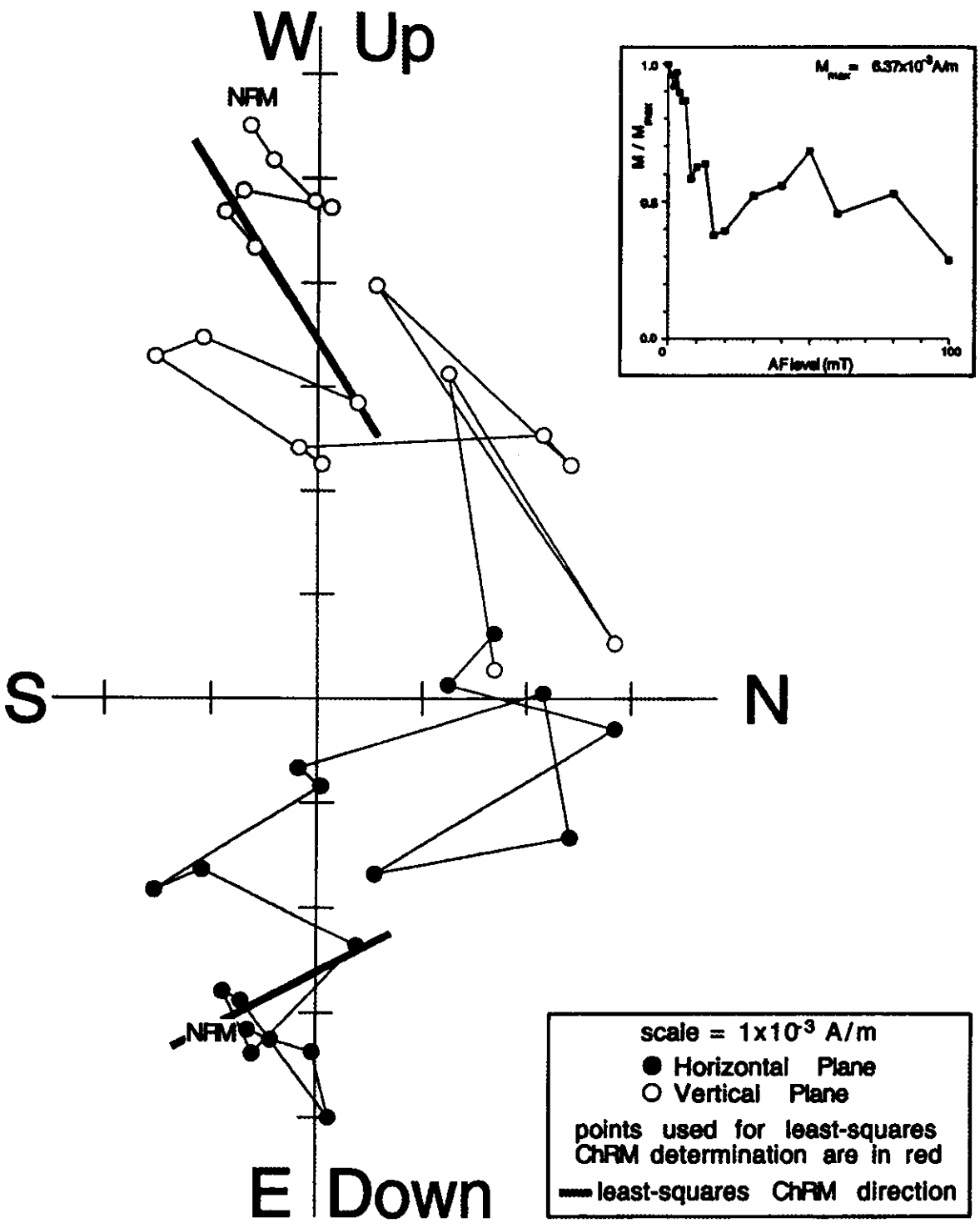
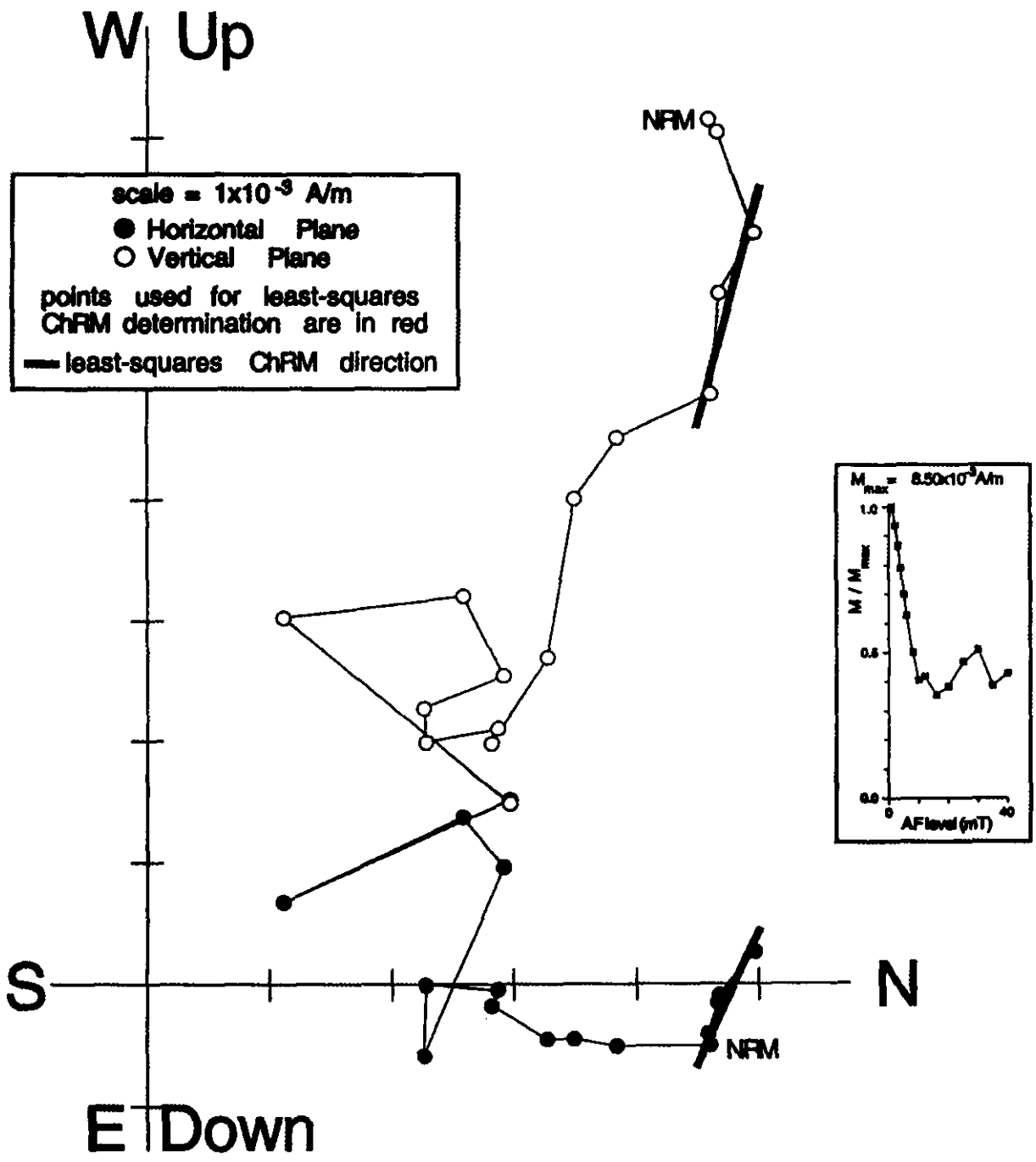
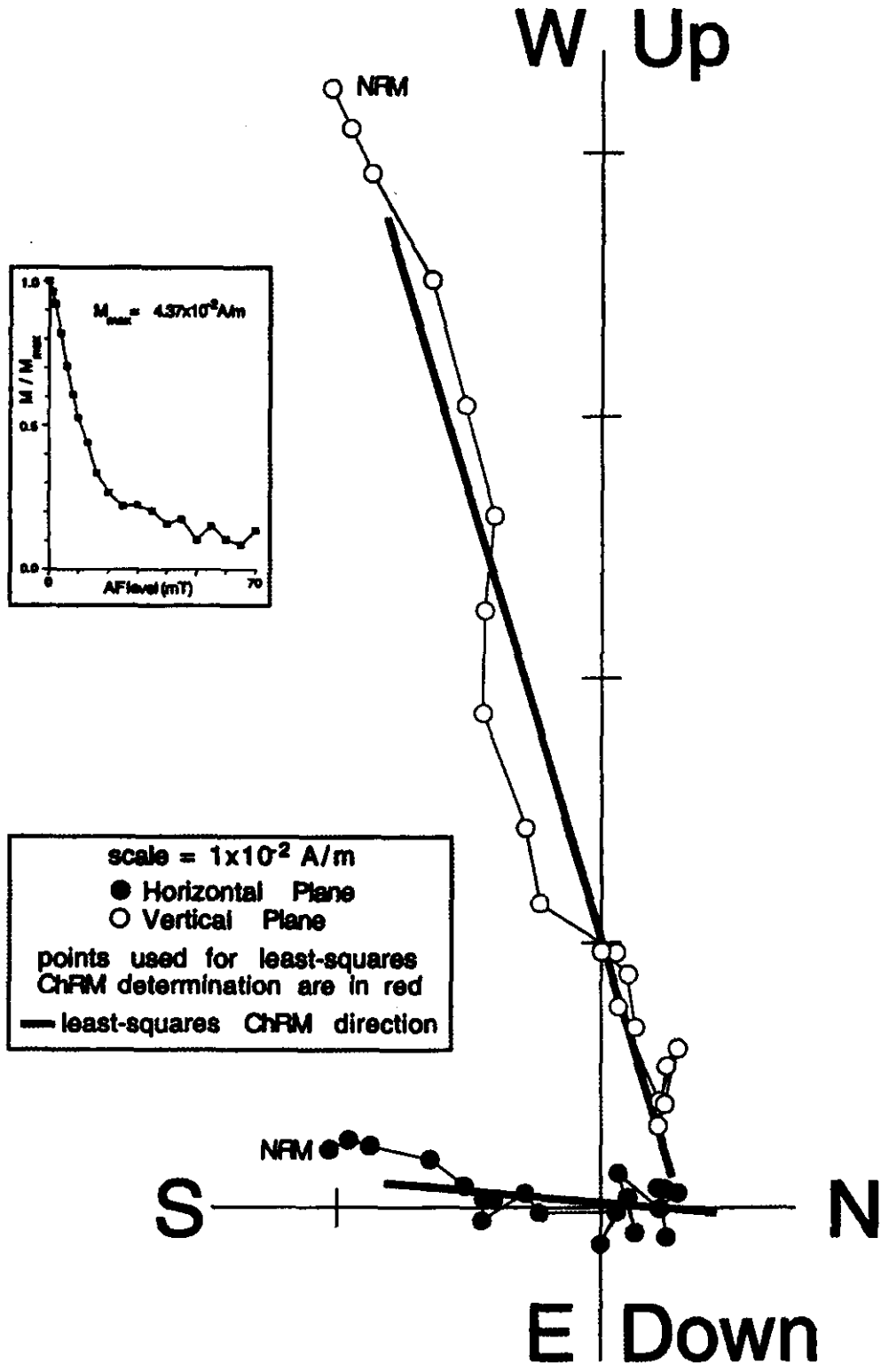


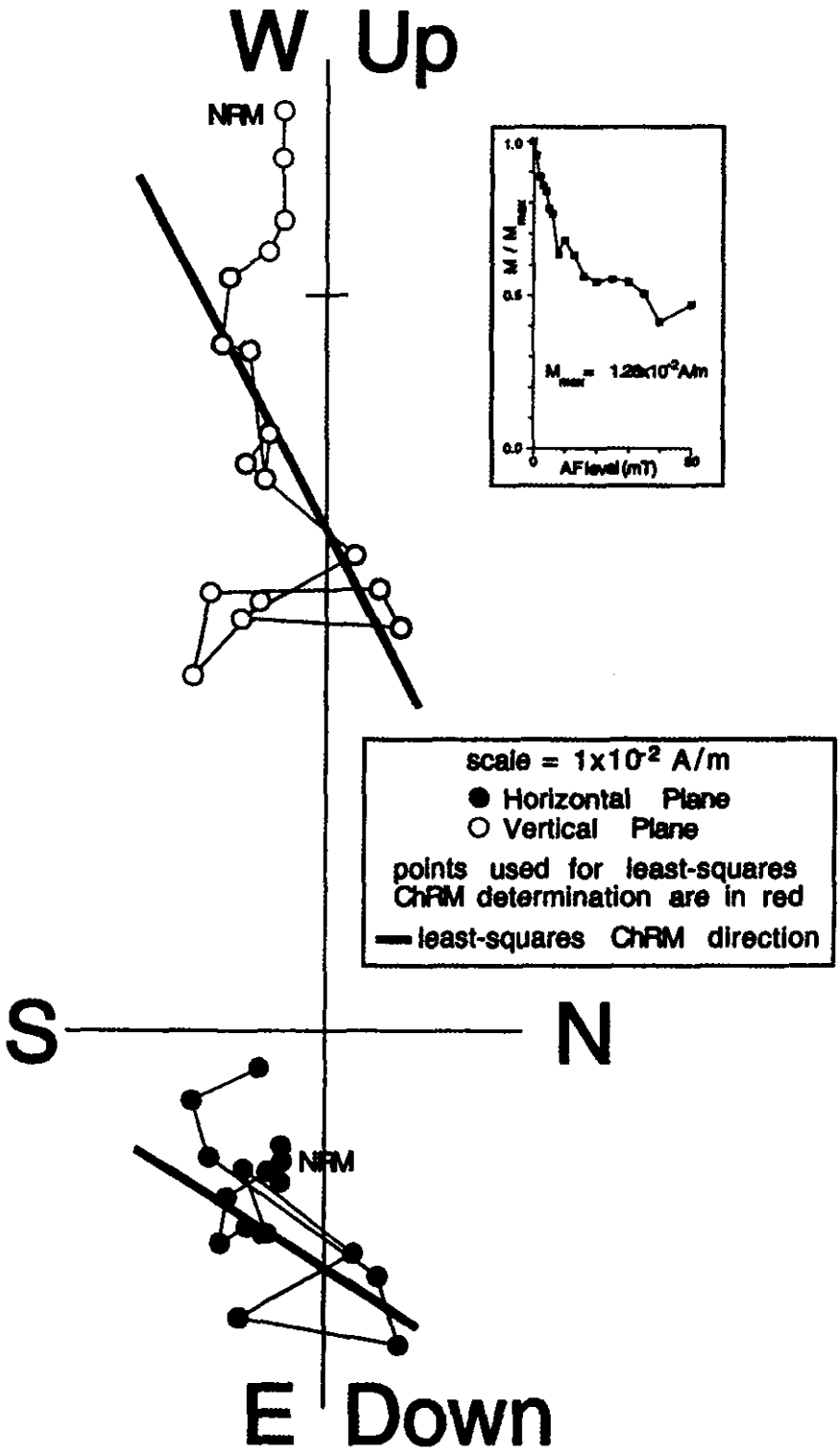
Sample 15 (from Core 25A)



Sample 16 (from Core 24A)



Sample 17 (from Core 24A)



Sample 18 (from Core 24A)

magnetic overprints. While least-squares analysis of some points is rather questionable, all such ChRM directions were chosen because of favorable agreement with samples derived from the same drill-core segment, creating the most plausible magnetostratigraphy.

Least-squares analysis was not performed on core segment 26A because of the highly scattered nature of the data and lack of a consistent ChRM for the core segment. Either magnetic overprint or physical disruption has degenerated the paleomagnetic quality of these samples. However, it is noteworthy that these samples nonetheless possess an upward inclination or the demag path heads towards an upwards inclination. We therefore interpret this core segment to be of reversed polarity.

Lithology only somewhat controls the quality of individual sample results. Samples 1-3 are the finest-grained and yield some of the best results (Table 1). However, samples 8-12 are the next-finest-grained and yield the poorest results, with very coarse-grained samples 4-7 and 13-18 yielding fair to good results.

Magnetostratigraphy

The figure on the next page shows the ChRMs of each core segment in equal area stereographic projection. Presumably, within each core segment there has been a minimum of disruption from drilling and therefore the ChRMs from each segment will be oriented consistently relative to each other. As one can see, this is plausibly true - each cluster of directions only occupies approximately one quadrant. The ChRM inclination is essentially that expected for the geographic latitude of the drilling site during a reversed-polarity chron. Note that only core 26A fails to provide well-grouped, easily-interpreted directions. We believe this results from disruption of the core while drilling, rather than the samples indicating some normal polarity chron.

Orientation between core segments should be random, as we understand it, due to the method of core retrieval. However, this appears not to be the case, resurrecting the possibility that the ChRM is some sort of uniformly-induced overprint like that which might be acquired from earth's field applied to a neatly stored drill core.

Observations

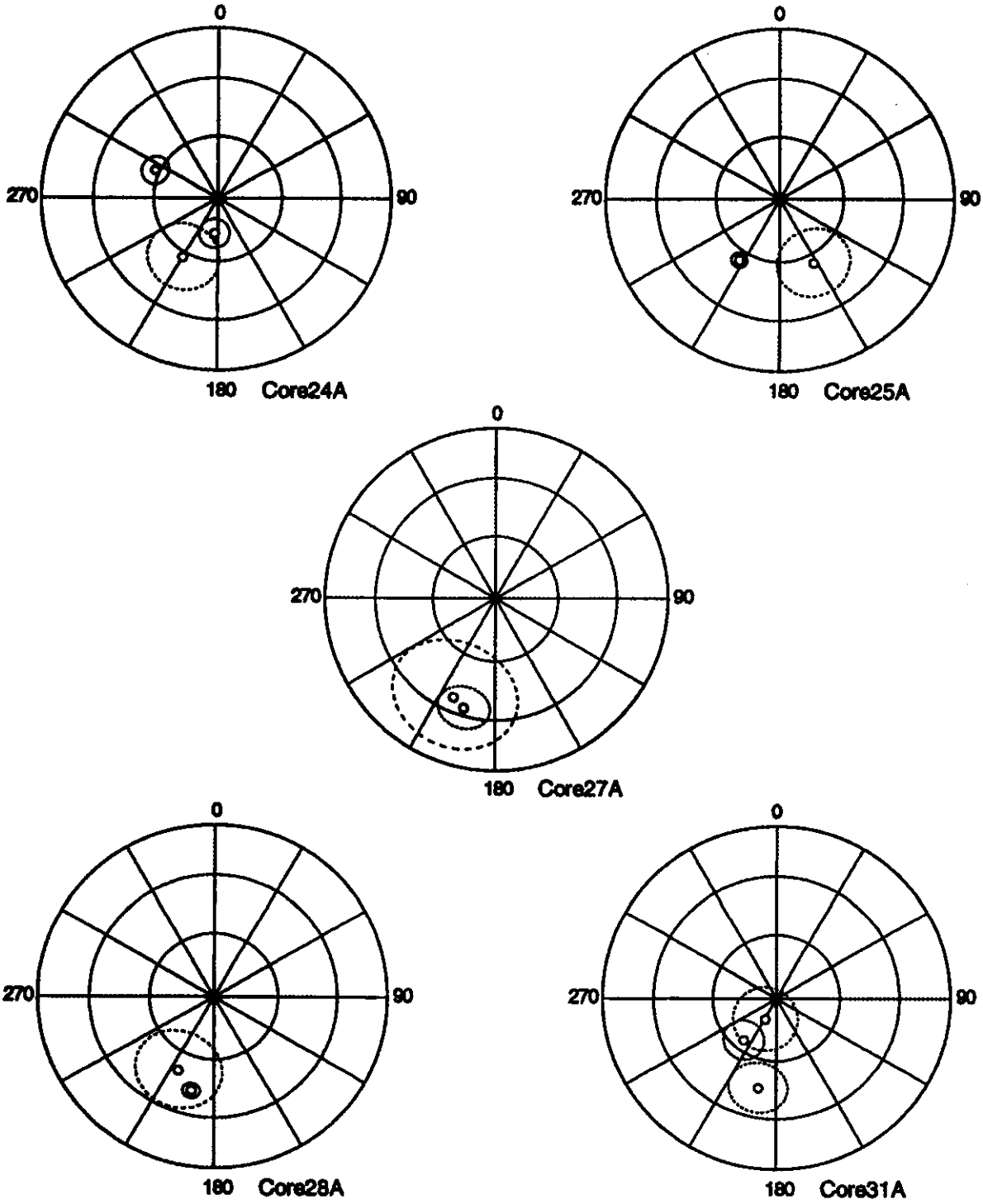
1. All but three samples have reversed polarity (i.e., upward) remanent magnetizations.
2. Of the three normal polarity samples, the demagnetization paths of two appear headed towards reversed polarity.
3. Essentially the demagnetization paths of all seventeen samples miss the origin.

Interpretations

1. The samples we have analyzed were magnetized mainly in a reversed polarity magnetic field, and was probably also deposited in a reversed field. Therefore, the age of these sediments is greater than 780 ka.
2. Only 5 of the seventeen samples have a low-coercivity normal-polarity overprint (samples 6, 9, 10, 11, 13).
3. Some samples appear to have a small, high-coercivity normal overprint, possibly resulting from the mineral geothite. While almost all samples become unstable at the higher AF levels, and therefore fail to decay smoothly to the origin.

Conclusions

Despite the lack of consolidation, paucity of fine-grained material, and non-ideal demagnetization behavior, the reversed paleomagnetic signal strongly suggests that this core is older than 780 ka. Either it is a primary magnetization acquired at or shortly after deposition (our preferred interpretation) or it is a secondary overprint. In either case it was acquired in a reversed polarity chron, the youngest known of which ended 780 ka ago.



Sample Characteristic Remanent Magnetization Directions
Presented in equal-area stereographic projections and plotted separately for each core segment, except Core 26A which did not yield ChRMs (see text). Open circles signify projection onto the upper-hemisphere, and each direction is accompanied by an alpha 95.

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Appendix C

Summary Stratigraphic Cross Sections for the Existing and New Immobilized Low-Activity Waste Disposal Sites

Appendix C

Summary Stratigraphic Cross Sections for the Existing and New Immobilized Low-Activity Waste Disposal Sites

This appendix provides summary diagrams showing cross sections for the existing and new Immobilized Low-Activity Waste (ILAW) disposal sites based on the more detailed geology presented in Section 4.0. Figures C.1, C.2, and C.3 are for the existing ILAW disposal site. Figures C.4, C.5, and C.6 are for the new ILAW disposal site. These figures were constructed to show the principal features of both sites for use in the ILAW Performance Assessment. Thin, local layers or layers with uncertain extent that depicted in the cross sections in Section 4.0 were omitted. Clastic dikes are not shown because their locations are not known even though they are suspected of being present.

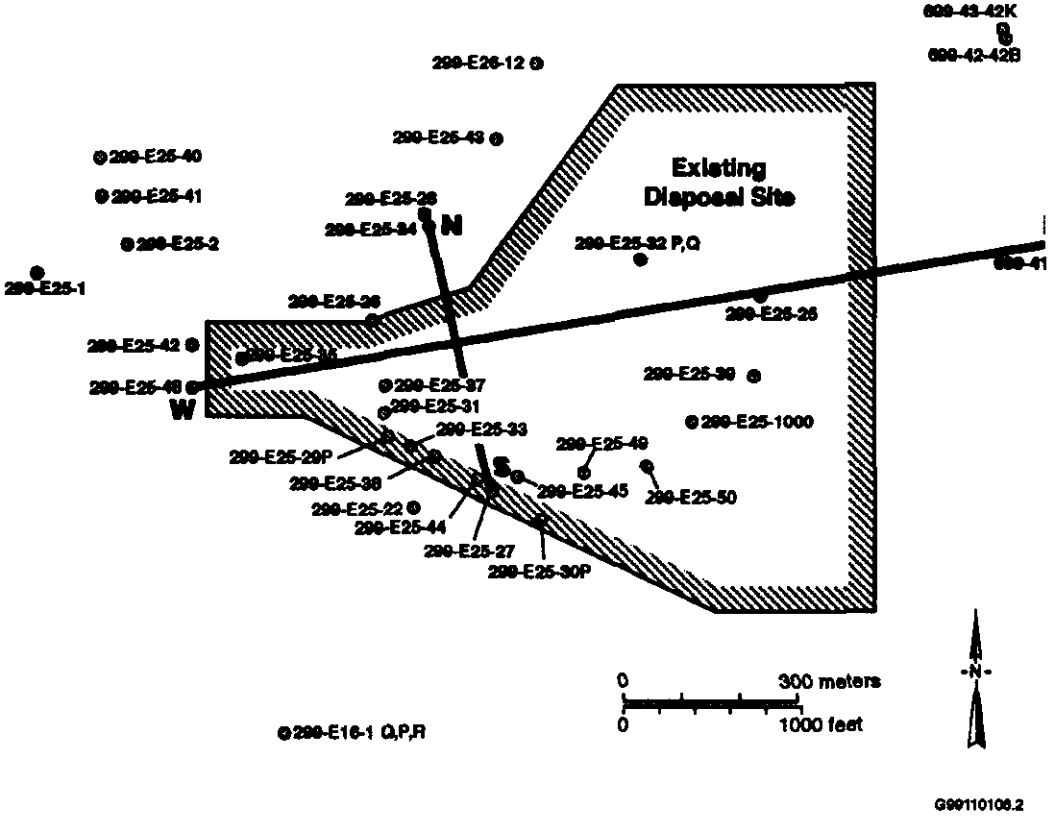

Figure C.1. Map of the Existing ILAW Disposal Site Showing the Locations of the Summary Cross Sections

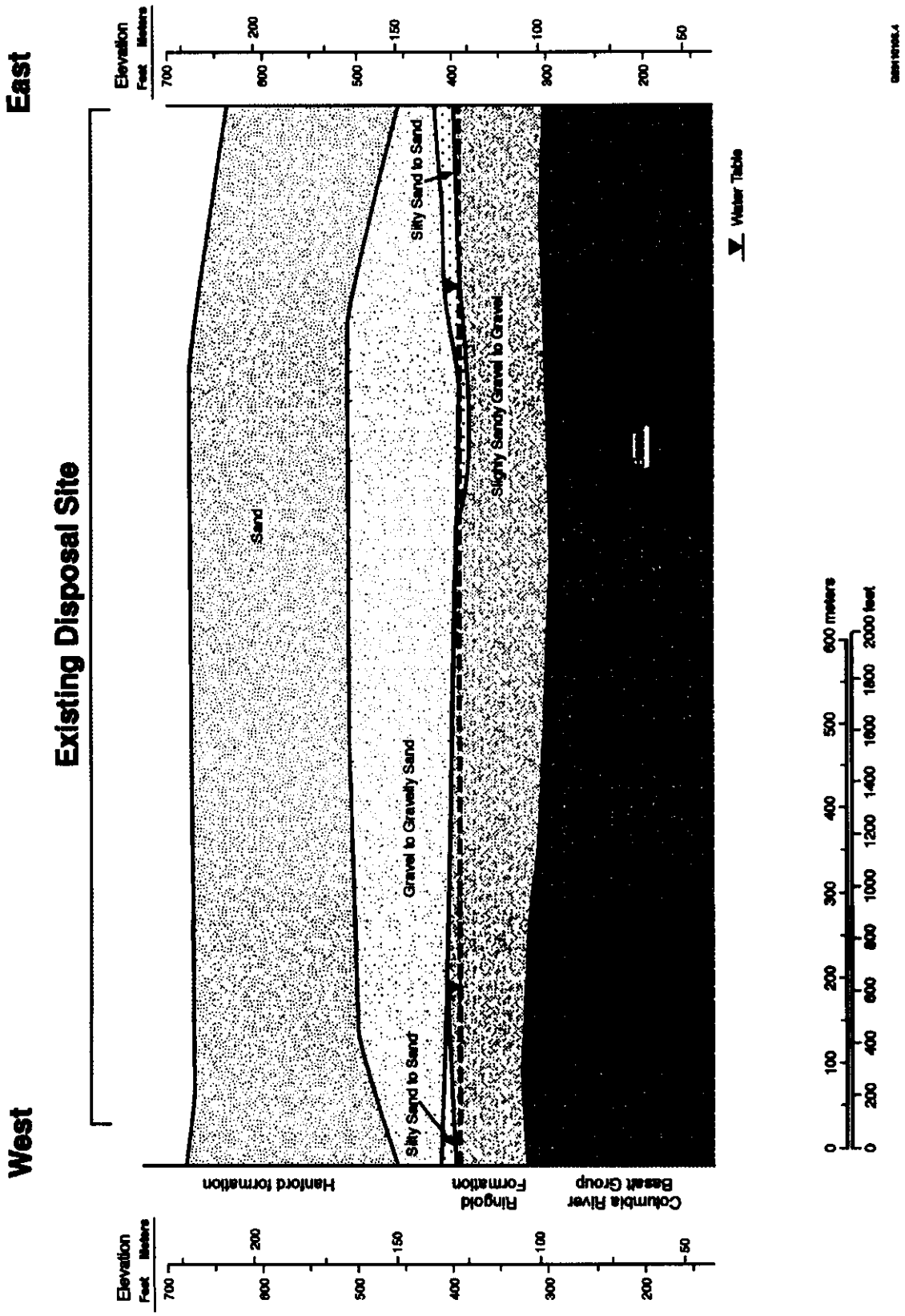

Figure C.2. Summary Diagram of a West to East Cross Section for the Existing ILAW Disposal Site

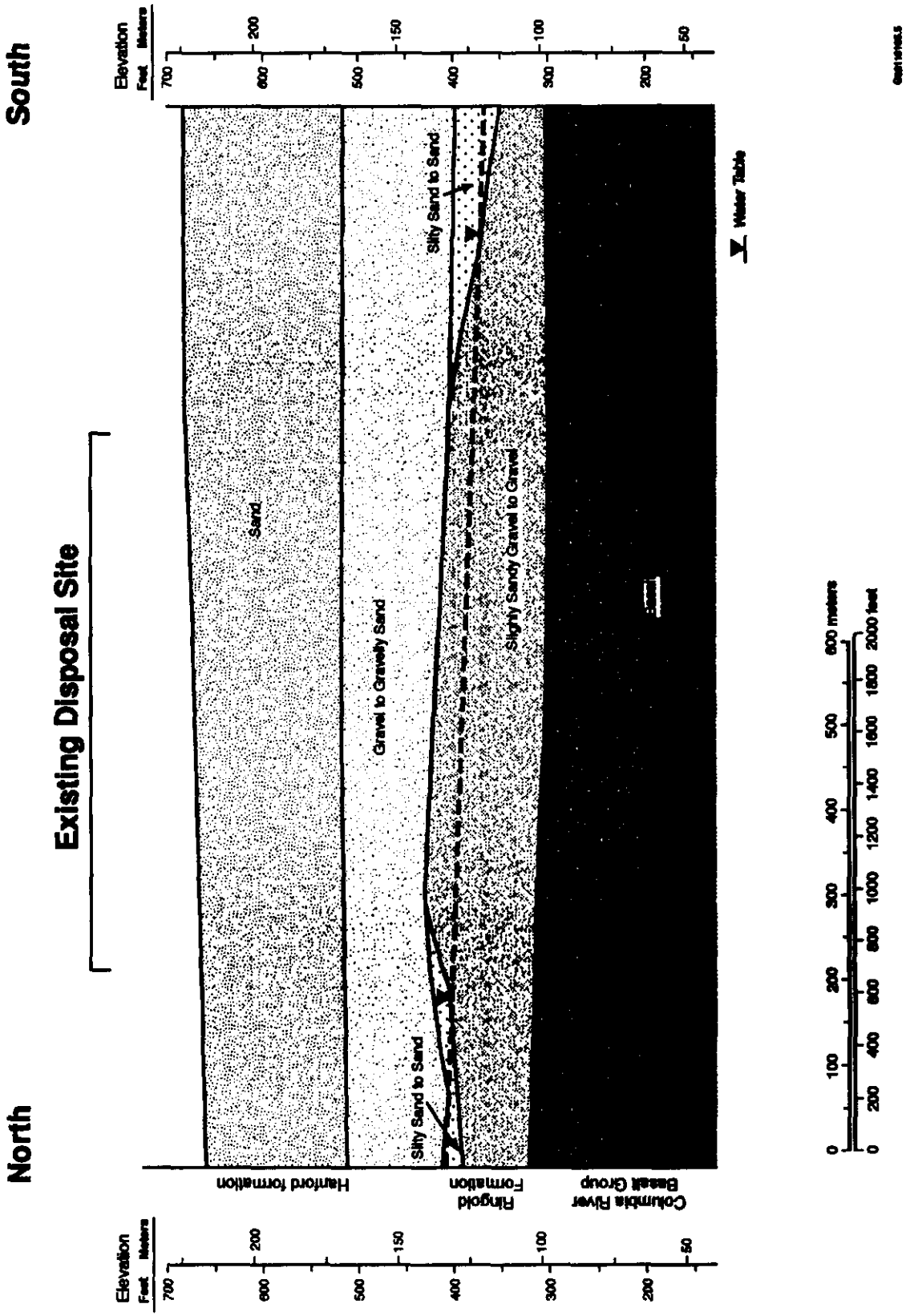

Figure C.3. Summary Diagram of a North to South Cross Section for the Existing ILAW Disposal Site

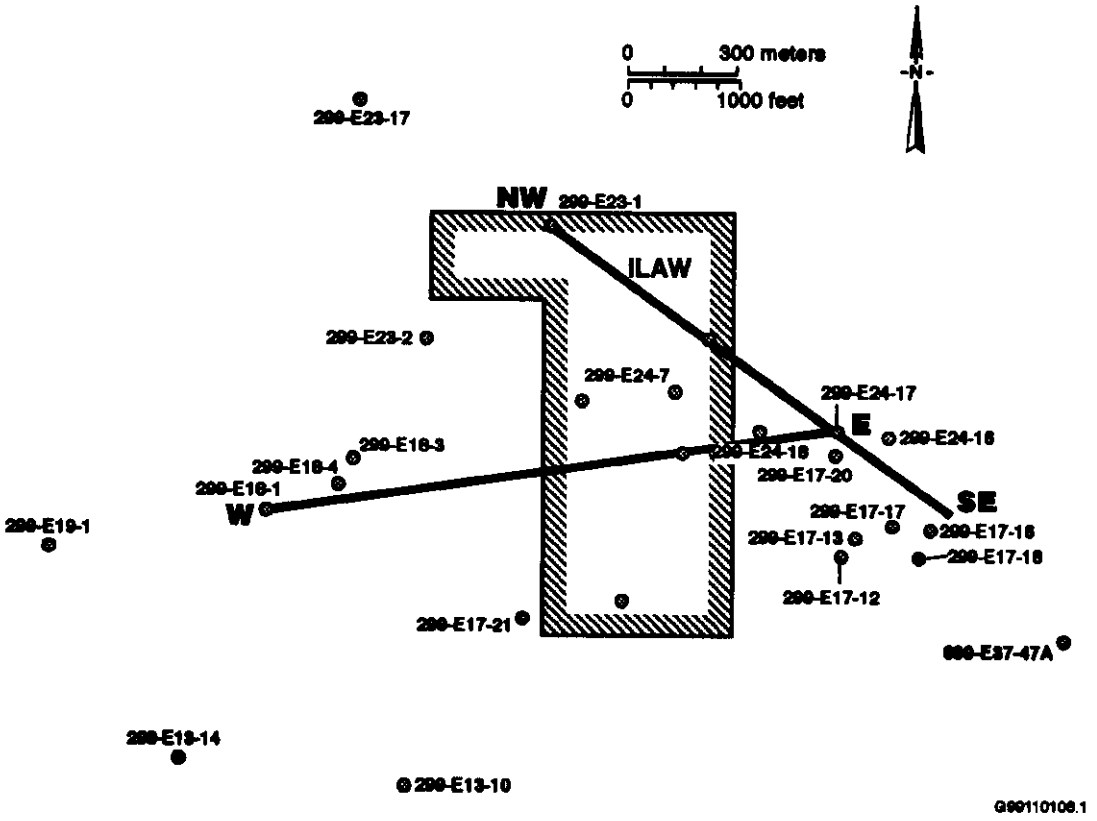

Figure C.4. Map of the New ILAW Disposal Site Showing the Locations of the Summary Cross Sections

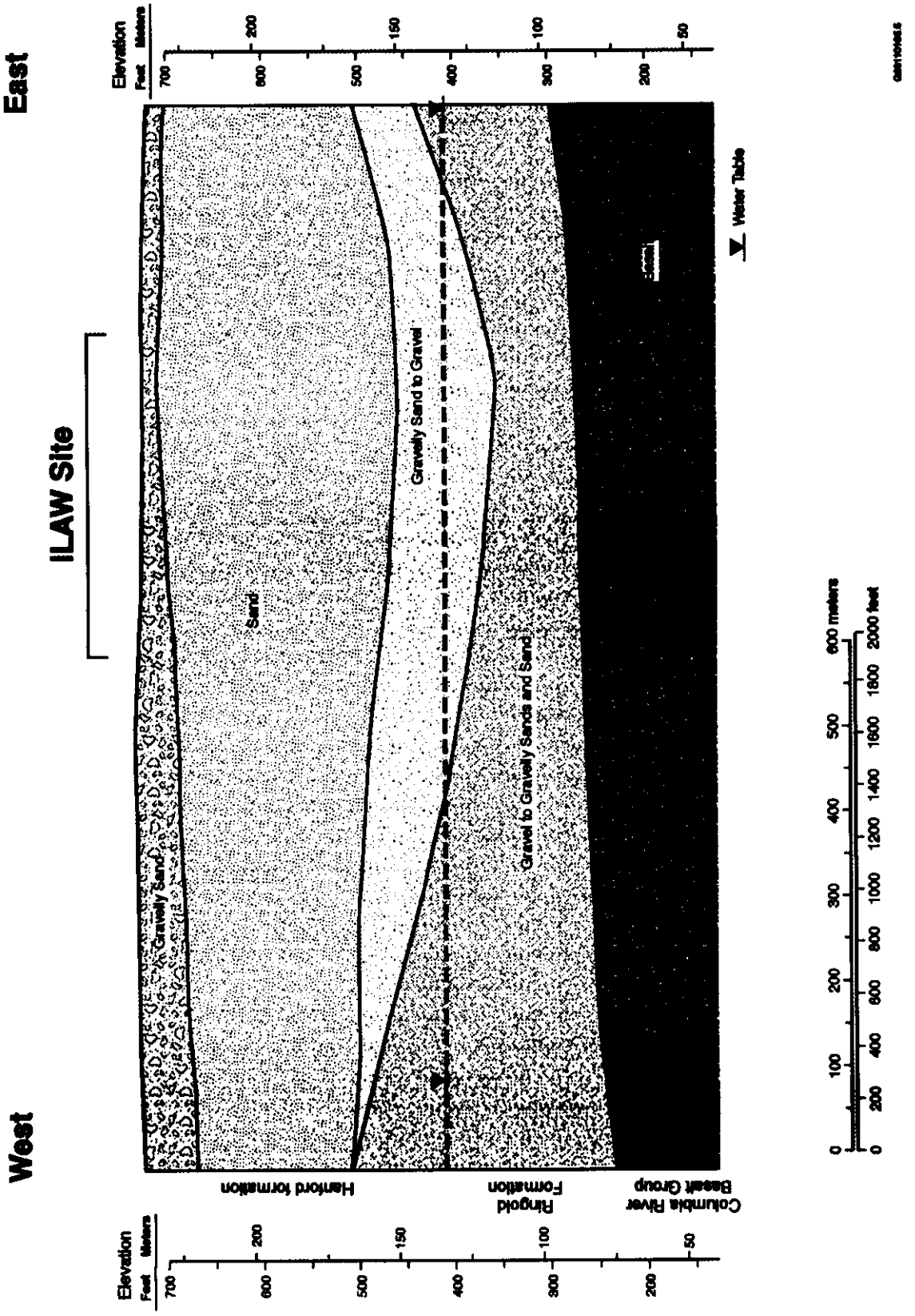

Figure C.5. Summary Diagram of a West to East Cross Section for the New ILAW Disposal Site

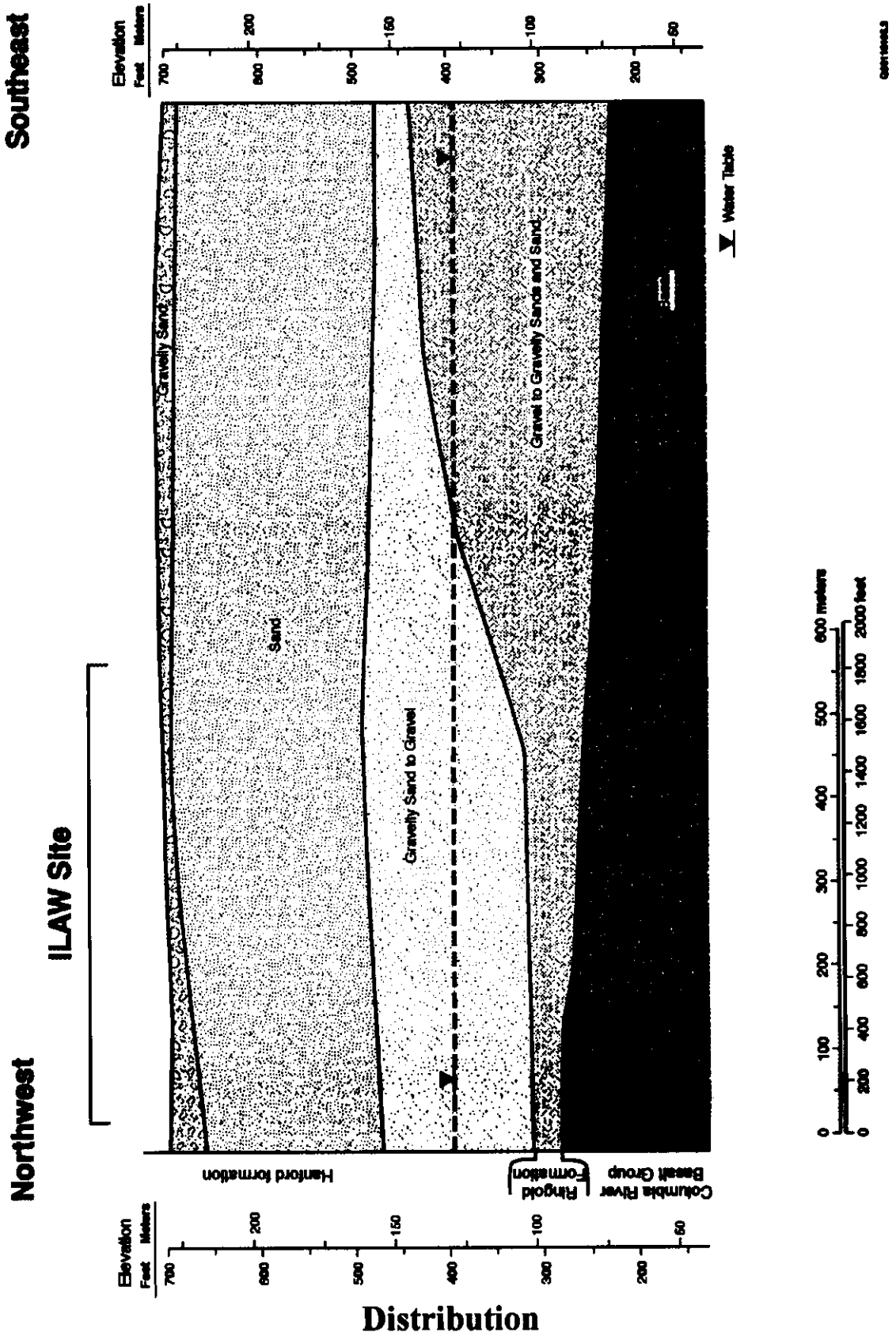

Figure C.6. Summary Diagram of a Northwest to Southeast Cross Section for the New ILAW Disposal Site

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Section 3 of 5

Document Information			
Document #	**HNF-5636**	**Revision**	**0**
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Projects			
Other Information			

APPENDIX H

IMMOBILIZED LOW ACTIVITY TANK WASTE

INVENTORY DATA PACKAGE

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IMMOBILIZED LOW ACTIVITY WASTE INVENTORY DATA PACKAGE

1.0 INTRODUCTION

1.1 BACKGROUND

Radionuclide and chemical inventories in the Immobilized Low Activity Waste (ILAW) product are needed to support the 2001 Low Level Tank Waste Performance Assessment (ILAW PA). Previously, radionuclide inventories were generated for the Performance Assessment (Mann 1998) based on ORIGEN2 calculations of total radionuclide production, with adjustments for estimated losses to obtain total glass inventories (Schmittroth 1995). New inventories are needed that reflect current operational planning and include nominal and reasonable bounding values that account for the variability between individual ILAW packages.

1.2 OBJECTIVES

The objective of this study is to provide radionuclide and chemical inventories for the 2001 ILAW PA that are based on 1) the Tank Waste Retrieval System (TWRS) Characterization Program tank-by-tank Best Basis Inventories (BBI), 2) the latest U.S. Department of Energy – Office of River Protection guidance, 3) the privatization contract for Phase 1 waste retrieval and vitrification, 4) available information on the BNFL, Inc. pretreatment and vitrification processes, and 5) proposed operating scenarios for retrieval of waste from double shell tanks (DST) and single shell tanks (SST) and delivery of feed to BNFL, Inc. and future low level waste vitrification contractors. These inventories address variability between individual ILAW packages as a function of time due to processing sequence. Both nominal and reasonable upper bounding values, along with a general assessment of uncertainties for key inventory components, are provided.

1.3 APPROACH

Nominal ILAW package radionuclide and chemical inventories are based on the latest edition of the Tank Waste Remediation System Operation and Utilization Plan (TWRSO&UP) (Kirkbride 1999), which incorporates BBI tank inventories, DOE guidance, the privatization contract requirements for Phase 1, and waste retrieval operations planning studies. The project planning case (Case 3) is used, which is based on the April 1, 1999, DOE Guidance (Taylor 1999), and completes processing in 2034. The TWRSO&UP provides processed inventories at the time of vitrification for each batch of LAW feed vitrified into ILAW. These batchwise inventories included losses associated with tank retrieval and feed preparation, but did not include offgas losses. For this study, the ILAW inventories were adjusted for estimated losses of volatile species during the vitrification process.

Inventories of trace organic and dangerous waste constituents not covered by the TWRSO&UP are treated as bounded by the land disposal restriction treatment standards

described in the Tank Waste Remediation System - Privatization Project Dangerous Waste Permit Application (BNFL 1999).

Reasonable upper bounds are developed for the total ILAW inventory and representative ILAW package inventory for key inventory components based on Best Basis tank inventories, global process based tank inventories, total reactor production, batch-to-batch variations from the tank processing operations, and Phase 1 contract specifications. The bounding values and uncertainties are based on qualitative considerations and conservative assumptions since consistent quantitative uncertainty information on the tank inventories, separation factors, and process losses are not available at this time.

2.0 LAW PROCESSING

The LAW processing involves 1) retrieval of tank contents, 2) producing LAW feed through separation of solid and liquid components by water washing and caustic leaching, 3) pretreating the liquid LAW feed to concentrate and remove selected components as required in the Phase 1 contract, and 4) vitrification of the pretreated LAW feed with recycle of captured offgasses. Figure1 provides a simplified process flow diagram for the ILAW processing.

Feed material transferred to BNFL Inc. and Phase 2 treatment contractors is subjected to a series of pretreatment and treatment operations, such as caustic leaching, radionuclide separations, and immobilization. Current models are based on the Project Hanford Management Contract (PHMC) understanding of these operations (Kirkbride 1999). As discussed in Kirkbride 1999,

"It is unlikely that future Private Contractors will propose drastically different flowsheets or come to drastically different conclusions about the final product volume unless DOE's long term strategy undergoes major changes. Those volumes are driven by a relatively small number of parameters that are for the most part understood and not expected to change."

These models could be improved by more specific details of the Phase 1 and Phase 2 processes from BNFL Inc. and the Phase 2 contractor as they become available.

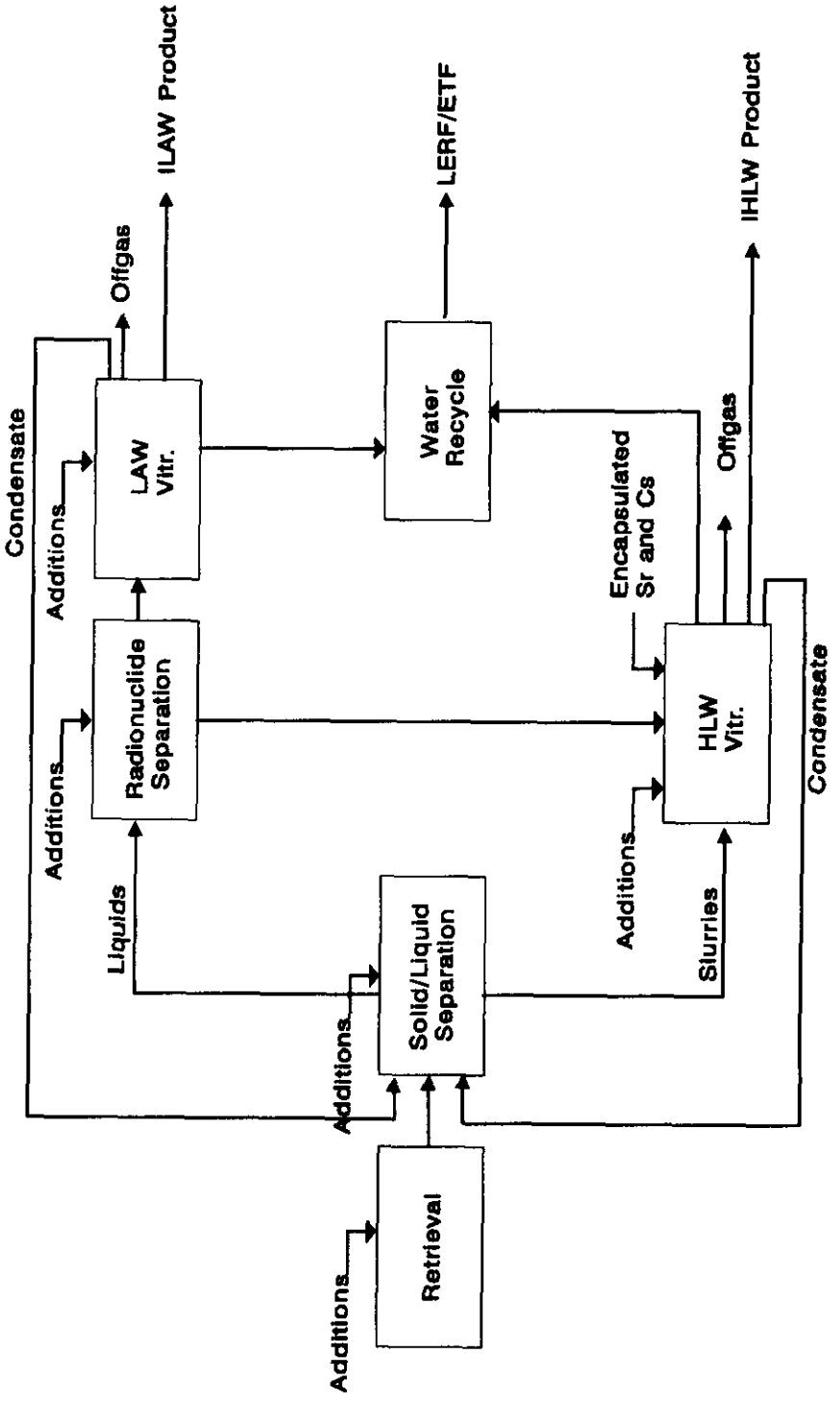
2.1 TANK INVENTORIES

The DST and SST inventories developed for the TWRSO&UP (Kirkbride 1999) provide the starting point for the ILAW inventories. The tank inventory for the TWRSO&UP is based on the tank-by-tank best basis inventory (BBI) data as of October 1, 1998, (LMHC 1998). The BBI includes 46 radionuclides and 25 chemicals. For the TWRSO&UP studies, the BBI values were adjusted for waste transfers not accounted for in the BBI, data were added for non-BBI analytes that are in the BNFL contract, and the BBI inventories were adjusted to a common date (October 1, 1998). Details of these adjustments can be found in the TWRSO&UP (Kirkbride 1999).

The BBIs were developed by considering and reconciling all sources of tank inventory information (sample results, engineering assessments, and inventory predictions from the

Hanford Defined Waste (HDW) model). The HDW model (Agnew 1997) supports the BBI effort by providing the basis for distribution on a tank-by-tank basis for radionuclides that were not represented by tank specific sample data.

Figure 1 Simplified Process Flowsheet for ILAW Processing



2.2 LIQUID AND SOLID PARTITIONING

In the TWRSO&UP the BBI tank-by-tank inventories were partitioned into water soluble and water-insoluble phases using the most recent water wash data for each tank (Hendrickson 1998). Caustic wash data (Colton 1997) were applied to the HLW feed calculations (Kirkbride 1999). The tank inventory components were distributed between liquid and solid phases in the TWRSO&UP by applying tank specific wash factors for every BBI analyte (Hendrickson 1998). Global caustic leach factors were applied to the water-insoluble phases to model the LAW generated as part of the HLW feed preparation.

2.3 FEED DELIVERY

The project planning case (Case 3) in the TWRSO&UP is based on the April 1, 1999, DOE Guidance (Taylor 1999). This option completes processing in 2034 assuming Glass Property Model oxide loadings in HLW (Kirkbride 1999).

This processing scenario assumes the following (Kirkbride 1999):

- BNFL Inc. will start processing by their Integrated Master Plan (IMP) dates.
- The BNFL Inc. facilities can start up and operate at their proposed maximum production rates (i.e., no capacity ramp up) as given in the contract.
- BNFL Inc. stores the entrained solids at their facility rather than returning them to the DST system.
- Phase 2 starts in 2018 with 60 MT ILAW/day rates
- A transition period (Phase 1B-Prime) bridges the completion of Phase 1 contract quantities in 2012 and the start of Phase 2 in 2018.

2.4 PHASE 1 AND PHASE 2

Based on Case 3 of the TWRSO&UP, Phase 1 produces a total of 117,605 MT of ILAW, which corresponds to approximately 19,295 ILAW packages. The Phase 1 contractor will deliver the ILAW product in 1.4 m cubic packages. Each package contains 2.3 m^3, or 6095 kg, of glass. Phase 2 produces a total of 301,374 MT of ILAW, which corresponds to approximately 49,446 ILAW packages. Since no specific guidance is provided for Phase 2 ILAW packaging, the Phase 1 standard package was used for Phase 2. Table 2.1 summarizes the ILAW volume, mass, and number of packages for the reference case (Case 3 of the TWRSO&UP) (Kirkbride 1999).

Table 2.1. Summary of Phase 1 and Phase 2 ILAW Package Production

	Total m^3 glass	Total MT glass	Total Packages
Phase 1	44379	117605	19295
Phase 2	113726	301374	49446
Total	158105	418979	68741

Phase 1 actually consists of two phases, as specified in the BNFL contract. Phase 1B meets minimum order quantities specified by contract and Phase 1B-Prime is for additional BNFL Inc. operations through February 2018, the period of performance for the Phase 1 contract.

2.5 PRETREATMENT

The following description of the LAW pretreatment process is summarized from the TWRS-P Project Dangerous Waste Permit Application (BNFL 1999). Pretreatment of LAW feed involves concentrating the waste feed and removing strontium, transuranics (TRU), cesium, technetium, sulfates, and entrained solids from the waste feed prior to vitrification. The LAW feed stream is concentrated in the LAW Feed Evaporator. The LAW Feed Evaporator is a continuous, forced-circulation evaporator that concentrates the feed to provide consistent feed for the ion-exchange process. Condensate is collected, analyzed, and transferred to the 200 Area Effluent Treatment Facility. Non-condensable gases extracted from the evaporator system are routed to the pretreatment building offgas treatment system. Following evaporation, the concentrated LAW is sent to the ultrafiltration process to separate entrained solids. For certain wastes, strontium and TRU removal is accomplished by adding reagents to precipitate the strontium and TRU out of solution, where they are removed by ultrafiltration. The liquid fraction is passed through successive ion exchange systems to remove cesium and technetium. If required, sulfate is removed by a further ion exchange process.

2.6 VITRIFICATION

The concentrated LAW from the melter feed evaporator is combined with glass forming chemicals and mixed. Dry glass formers (e.g., silica, alumina, boric acid, calcium silicate) are tailored to the waste feed of each batch to obtain the desired glass formulation. The waste and glass former slurry is transferred as a continuous feed to LAW joule-heated melters. The operating temperature in the LAW melters is expected to be approximately 1050-1200 °C. The chemically active region of the melt is the cold cap, which will be at 600-800 °C. Superheated gases and volatile feed components are released into the melter offgas treatment system. The solids and a fraction of the semi-volatile components entrained in the offgas are captured and recycled back into the process. The glass content of an ILAW package is 6095 kg. The density of the LAW glass is 2.65 MT/m^3 which correlates with the net glass volume per package of 2.3 m^3 (Kirkbride 1999). The ILAW package is a 1.4 m cube with an external volume of 2.74 m^3 (Kirkbride 1999).

2.7 OFFGAS LOSSES AND RECYCLE

Pretreated LAW vitrification feed contains large amounts of material that, because of boiling point, decomposition temperature, or low solubility in the glass melt, become volatile during vitrification. Over half of the mass in LAW feed is volatile under melter conditions. Nearly all inorganic constituents (e.g., carbonate, nitrate, nitrite, water) and perhaps small molecular weight organics containing carbon, hydrogen, and nitrogen are likely to volatize or

decompose, and be released as an emission source during vitrification. Steam distillation is another pathway for analytes to be transported from the melter (cold cap) to the offgas treatment system. Some semi-volatile components are partially recaptured and recycled so there is a net loss to the volatiles streams. The balance of the semi-volatiles is completely recaptured and vitrified. Table 2.2 shows the fraction of each volatile or semi-volatile feed component that is retained in the ILAW product based on current limited knowledge of the BNFL Inc. offgas treatment process (Kirkbride 1999).

Table 2.2. Net Volatility Around Low-Activity Waste Vitrification

Feed Component	Fraction Retained in ILAW
Volatiles lost during vitrification	
Water	0.0
Carbon	0.0
Hydrogen	0.0
Nitrogen	0.0
Noble gases	0.0
Hydroxide	0.0
Nitrite	0.0
Nitrate	0.0
Cyanide	0.0
Carbonate	0.0
Ammonia	0.0
Semi volatiles partially captured and recycled	
Sulfur	0.9
Mercury	0.2
Iodine	0.25
Selenium	0.9
Semi volatiles captured by offgas scrubbing and recycled	
Cesium	1.0
Technetium	1.0
Boron	1.0
Silver	1.0
Ruthenium	1.0
Molybdenum	1.0
Chlorine	1.0
Fluorine	1.0

2.8 PHASE 1 PRIVATIZATION CONTRACT LIMITATIONS

The Phase 1 privatization contract with BNFL Inc. (DOE-RL 1996 MOD A006 1998) specifies radionuclide and dangerous waste concentration limits in the ILAW product. These specifications include:

- Class C limits as defined in 10 CFR 61.55 and as described in NRC's Branch Technical Position on Concentration Averaging and Encapsulation. (alpha emitting transuranic nuclides with half-life greater than 5 years < 100 nCi/g)
- Average concentration of ^{137}Cs <3 Ci/m^3, average concentration of ^{90}Sr < 20 Ci/m^3, and average concentration of ^{99}Tc < 0.1 Ci/m^3.
- On average, remove at least 80% of the ^{99}Tc present in the LAW feed.
- The ILAW product shall be acceptable for land disposal under the State of Washington Dangerous Waste Regulations, WAC 173-303, and RCRA LDR in 40 CFR 268.

Phase 2 requirements are assumed to be the same as Phase 1.

3.0 NOMINAL INVENTORIES

The batch-by-batch ILAW radionuclide and chemical inventories are listed in Appendix HA for the reference Phase 1 and Phase 2 operating scenario. These are based on the TWRSO&UP inventory that was the basis for Table 3.5.1 in Kirkbride 1999, with additional factors from Table 2.2 applied to account for offgas losses during vitrification. These are based on processing both the water-soluble and insoluble fractions of the tank inventories, with sufficient pretreatment to remove technetium, cesium, strontium, and TRU to meet specifications on average concentrations. The requirement to remove 80% of the ^{99}Tc in the LAW feed was not imposed on these batch inventories. Every batch is at or below the average concentration specification limit for ^{99}Tc, ^{137}Cs, ^{90}Sr, and TRU. No hazardous organic chemicals are included in the nominal inventories because they are not expected to survive the vitrification process (Kirkbride 1999). Radionuclide batch inventories have been decayed to the time of processing. These inventory values represent partitioning of the tank wastes, and do not include any additives to the waste feed such as glass formers or other chemicals for removals (except for sodium added for feed processing).

The following components of the original batch inventories were reduced to zero by the offgas removal correction: ^{14}C, ^{3}H, CO_3, H, H_2O, NO_2, NO_3, OH, NH_3, and TOC.

The batch inventory data values were zero for several components that were identified in Kirkbride 1999 as being required for characterizing the HLW feed Envelope D. These components included CN-, Co+3, Nd+3, Pd+2, Pr+3, Pu+4, Rb+, Rh+3, Ru+3, Sb+5, Ta+5, Tc+7, Te+6, Th+4, Tl+3, V+5, W+6, and Y+3.

The TWRSO&UP inventory as currently configured does not remove ^{134}Cs or Cs+ from the LAW feed along with ^{137}Cs removals. Therefore the ^{134}Cs and Cs+ values were adjusted so that the ILAW to BBI ratios were the same as for ^{137}Cs. This adjustment was also applied to the Appendix HA values.

The batch inventory values for ^{79}Se and ^{126}Sn have the same half-life basis as the BBI, which are based on ORIGEN2 values (see Appendix HC for a list of relevant half lives from the ORIGEN2 library). Recent studies have indicated that improved half-life values could be used

for these radionuclides (Harmsen 1998). Table 3.1 shows the old and new half-life values and the factor that could be used to adjust the activity values for these radionuclides. The amounts of ^{79}Se and ^{126}Sn expressed in curies in Appendix HA and in the remaining tables in this report should be multiplied by the adjustment factor in Table 3.1 to reflect these improved half-lives. The values in this report are based on the old half-lives for consistent comparisons with the BBI and existing data.

Table 3.1 Half-Life Corrections for ^{79}Se and ^{126}Sn

Component	ORIGEN2 Half-life (years)	New Half-life (years)	Activity Adjustment Factor
^{79}Se	6.50E+04	8.05E+05	0.08
^{126}Sn	1.00E+05	2.46E+05	0.40

4.0 UPPER BOUNDS FOR RADIONUCLIDES AND CHEMICALS

4.1 TOTAL ILAW INVENTORIES

The major sources of uncertainty for the total ILAW inventory are the uncertainties in the tank inventories, the split between HLW and LAW (the wash and leach factors and radionuclide removal factors, and offgas losses of volatile and semi-volatile components. Currently, uncertainties for the total tank inventories, wash and leach factors, and offgas losses during vitrification have not been consistently quantified. Therefore, the approach was taken to estimate bounding inventories for most components by neglecting the processing losses.

The batchwise nominal inventories described in Section 3 are decayed to the processing date. For comparison with other inventory values and the development of bounding values, each batch inventory was decay corrected to a common date of 1/1/94, the date for the BBI radionuclide values. The individual batch inventories were then summed for Phase 1, Phase 2, and total ILAW inventories. The chemical inventories were also converted from kg-moles to kg.

For comparison, the total tank inventories (adjusted tank-by-tank BBI from the TWRSO&UP, including both LAW and HLW feed tanks) were separated into Phase 1 and Phase 2 inventories. The Phase 1 tanks are those shown in Table 4.1, which are based on the Case 3 tank operations described in Kirkbride 1999. The tanks are shown in the approximate order of retrieval. All other tanks were taken to be Phase 2. This is not precise, since some of the wastes in these tanks will be processed in phase 2, and some of the wastes will end up in HLW. The actual tank retrieval sequence and selection of tanks for Phase 1B and Phase 1B-Prime has not been approved by DOE. The tank sequence will be finalized in the multiyear work plan. It is likely that some changes will be made to the tanks listed in Table 4.1. Such changes may affect the distribution of inventory between Phase 1 and Phase 2 but should not affect the total inventory.

Table 4.1 Phase 1 Tanks

	LAW Tanks	HLW Tanks
Phase 1B	AN107 AN104 AN102 AN105 SY101 AN103 AZ101* AZ102*	AZ101 SY102 AW103 AZ102 AY102 C106 AY101
Phase 1B-Prime	AW101 AW104 AP105 AP104 AP101	C104 AW104 C102 AW105

*pretreated, staged waste

Note: The actual tank retrieval sequence and selection of tanks for Phase 1B and Phase 1B-Prime has not been approved by DOE.

Table 4.2 lists these ILAW inventories and compares them with the TWRSO&UP total tank inventories, the Global tank inventories based on process knowledge (Kupfer 1999), and the total radionuclide production in the fuel in the reactors before it was processed (Watrous 1997). The difference between the ILAW inventory and the tank inventory can be attributed to the high level waste (HLW) fraction, residual tank heel, radionuclide separations to meet contract specifications, and losses to the offgas stream. The global tank inventory values and the reactor production values generally provide support to the BBI sum-of-tank values. Additional discussion for selected components can be found in Appendix HB.

Table 4.3 shows the resulting upper bounding values for Phase 1, Phase 2, and Total ILAW inventories based on these comparisons. For most components, the upper bound limit on total ILAW inventory was taken as the BBI tank inventory, neglecting any processing and separations losses. For radionuclides limited by the contract specifications (^{99}Tc, ^{137}Cs, ^{90}Sr, and TRU), the contract limits were used as upper bounds. Neglecting the processing losses between the tank inventory and the ILAW inventory provides a very conservative bounding value, but was used to compensate for the lack of uncertainty information on the separations factors (wash and leach effectiveness, offgas treatment, solids retention). Additional discussion for several special case components follows.

^{99}Tc

The ^{99}Tc values for the batch-by-batch Phase 1 and Phase 2 ILAW inventories from the TWRSO&UP did not include the contract requirement to reduce the feed ^{99}Tc by 80%. Therefore, The ^{99}Tc summation value for the total ILAW was adjusted downward to be 20% of the BBI total tank inventory. The Phase 1 and Phase 2 totals for ^{99}Tc were scaled proportionately. This overestimates the ILAW inventory since it assumes that all of the ^{99}Tc in

the tanks is represented in the feed. The resulting total inventory is 48% less than the total of the TWRSO&UP ILAW inventory in Appendix HA (1.21E4 Ci). Users should be aware that use of the ^{99}Tc values from Appendix HA will result in a total inventory that is high by about a factor of 2. It is likely that BNFL will meet the 80% reduction requirement by applying separations to selected batches or types of feed, so that many of the batch inventories may not be affected. Upper bound values in Table 4.3 are 15% higher than the nominal inventories to allow for uncertainties in the tank inventories, but not exceed the total reactor production. Consistent with the assumption that the Phase 1 requirements will be applied to Phase 2 as well, these limitations provide reasonable bounding inventory values.

The best basis value for ^{99}Tc agrees reasonably well with the process knowledge based (global) estimate. The best basis value is likely the more valid since the global estimate does not account for known losses of ^{99}Tc that occurred during fuel separation operations (Kupfer 1999). There is good evidence that 20% or more of the technetium produced was separated from the waste stream during initial fuel reprocessing, mainly co-processed with the UO_3 and sent offsite, but with minor losses to the environment as well (Schmittroth 1995). The HDW global inventory for ^{99}Tc may be biased high by about 32% due to it's not accounting for the fractional separation of Tc to the uranium product stream in the uranium recovery, PUREX and REDOX processes (cribbing, offsite shipment, U contaminant). Approximately 60% of the tank summation inventory is based on the HDW model (Kupfer 1999). The BBI ^{99}Tc total tank inventory of 28,900 Ci is 87% of the total reactor production. The total production value for ^{99}Tc is likely known within 10% since it depends primarily on well known fission product yields and the production reactor histories.

The only way the nominal total ^{99}Tc ILAW inventory could be larger would be for the tank inventory to be higher. However, the tank inventory is constrained by the total reactor production. The ILAW inventory could be smaller due to any ^{99}Tc not retrieved from the tanks or incorporated into IHLW, or to smaller than expected tank inventories. A reasonable estimated uncertainty in the ILAW ^{99}Tc total inventory would be on the order of 15% to account for these effects, with the assumption that the Phase 1 requirements will be applied to Phase 2 as well.

^{137}Cs, ^{90}Sr

The ^{137}Cs and ^{90}Sr inventory in the ILAW are also constrained by the BNFL Inc. Phase 1 contract specifications. The ILAW inventory values are the sum of the batch values that include the decay correction to the reference date of 1/1/1994. This explains why they are higher than strictly applying the concentration limit to the entire ILAW volume at the reference date. BNFL could exceed the ^{137}Cs and ^{90}Sr ILAW inventory in Table 4.2 by simply making more glass at the concentration limit. The upper bound values in Table 4.3 were created by increasing the contract limited values based on the nominal ILAW glass volume of 158105 m^3 by a factor of 1.3 to allow for uncertainty in the total volume of ILAW glass produced. Based on these constraints, the uncertainty in the ^{137}Cs and ^{90}Sr total ILAW inventory in Table 4.2 is estimated to be on the order of 30%.

The best-basis values for ^{137}Cs and ^{90}Sr agree with the global values. The majority of the tank summation inventory is based on samples.

The TWRSO&UP inventory as currently configured does not remove ^{134}Cs or Cs+ from the LAW feed along with ^{137}Cs removals. Therefore the ^{134}Cs and Cs+ values were adjusted so that the ILAW to BBI ratios were the same as for ^{137}Cs. This adjustment was also applied to the Appendix HA values.

TRU

Bounding values for the TRU isotopes (as defined in the Phase 1 privatization contract limits for TRU isotopes with half-lives greater than five years as interpreted in Kirkbride 1999) neptunium, plutonium, americium, and curium inventories (except ^{242}Cm and ^{241}Pu) were developed by adjusting the sum of these component inventories to the contract limit of 100 nCi/g (contract limit). The upper bound values in Table 4.3 were created by increasing the contract limited values based on the nominal ILAW mass of 418979 metric tons by a factor of 1.3 to allow for uncertainty in the total mass of ILAW glass produced. The relative proportions of these components were kept the same as in the sum of batch inventory. The inclusion of ^{241}Pu in the TRU limits in the TWRSO&UP is questionable because ^{241}Pu decays primarily by emitting a beta particle. Only 0.0024% of the decays result in alpha particle emission. Since the ^{241}Pu curie inventory is comparable to the major TRU isotopes ^{239}Pu and ^{241}Pu, the ILAW inventory values for the TRU isotopes could be as much as 30% higher than the values in Appendix HA and still be within the 100 nCi/g limit. An overall uncertainty for the total TRU would thus be on the order of 30 %. Individual component uncertainty could be higher.

^{126}Sn

Most of the best-basis (tank-by-tank summation) and all of the global inventory estimate for ^{126}Sn are based on the HDW model. The HDW curie value of ^{126}Sn could be reduced by a factor of 0.4 to account for a recently updated half life value, and by a factor of 0.78 to account for a better fission yield value. The nominal ILAW inventory value of 423 Ci is approximately 36% of the tank inventory. The tank inventory is approximately 75% of the total reactor production. An overall uncertainty on the order of 300% is likely for the ^{126}Sn inventory to cover the uncertainty in the fraction of the tank waste that makes it to the ILAW product.

^{79}Se

Most of the best-basis (tank-by-tank summation) and all of the global inventory estimate for ^{79}Se are based on the HDW model. These ORIGEN2 based calculations of ^{79}Se production could be reduced by a factor of 0.85 to account for a lower fission yield and by a factor of 0.08 to account for a recently updated half life value. The total BBI tank value is only 20% greater than the ILAW inventory. To provide an additional safety margin, the upper bounding ILAW inventory was created by increasing the tank inventory by a factor of 1.3 to be comparable to the total production value. The uncertainty in the nominal ILAW inventory is estimated to be on the order of 70% to account primarily for the tank inventory uncertainties.

^{129}I

The best-basis of ^{129}I is somewhat larger than the global estimate. The global (HDW model) estimate conservatively assumes that all of the ^{129}I in the fuel was routed to the waste tanks. Thus the reason for the higher tank sum is not inherently obvious. The difference could be due to sample error, but is likely not due to underestimated model values. Both best basis and global inventory values are likely to be significantly higher than actual values (Kupfer 1999). The calculated ^{129}I production in the fuel could be reduced by a factor of 0.76 to account for a better fission yield value (Harmsen 1998). The nominal ILAW inventory is based on the TWRSO&UP assumption that only a fraction of the ^{129}I would be incorporated into the ILAW product, with the bulk of the ^{129}I diverted through the offgas system to the atmosphere or other solid waste forms. If the ^{129}I cannot be released to atmosphere or a secondary waste product, then the ILAW inventory would be comparable to the tank inventory. The BBI sum of tank value was used as the upper bound total ILAW ^{129}I inventory. Since this 101 Ci value is a factor of 1.6 higher than the total produced, an adequate safety margin is assured to account for uncertainties in production and tank inventories. The uncertainty in the nominal ILAW ^{129}I inventory is large, in the range of 300-500%, to reflect the uncertainty in the amount of ^{129}I returned to the ILAW glass from the offgas treatment system.

^{226}Ra, ^{228}Ra, ^{227}Ac, ^{229}Th, ^{231}Pa

The tank summation inventories for these isotopes (alpha decay chain daughters of uranium and thorium isotopes) are based essentially on the HDW model estimates, due to lack of any direct analytical data from samples. The estimate for these daughter radionuclides is substantially overpredicted due to the lack of proper second-order decay functions in the HDW model (Kupfer 1999). The buildup of these daughter products from decay of the uranium and thorium in the ILAW will overshadow the initial inventories (Kupfer 1999).

Table 4.2 Comparison of Nominal ILAW Inventory With Tank Inventory and Total Production

	ILAW Inventory (radionuclides are in Ci at 1/1/94 chemicals are in kg)			BBI Sum of Tanks (radionuclides are in Ci at 1/1/94 chemicals are in kg)			Global Inventory (Kupfer 1999)	Total Produced (Watrous 1997)
	Phase 1	Phase 2	Total	Phase 1	Phase 2	Total	Total	Total
3-H	0.00E+00	0.00E+00	0.00E+00	6.17E+03	1.84E+04	2.46E+04	3.40E+04	2.38E+05
14-C	0.00E+00	0.00E+00	0.00E+00	1.19E+03	3.20E+03	4.38E+03	4.81E+03	2.56E+03[a]
59-Ni	6.86E+01	9.82E+01	1.67E+02	2.39E+02	6.19E+02	8.58E+02	9.34E+02	1.14E+03[a]
60-Co	2.02E+03	2.16E+03	4.18E+03	1.27E+04	7.22E+03	1.99E+04	1.23E+04	3.47E+04[a]
63-Ni	6.70E+03	9.49E+03	1.62E+04	2.38E+04	6.07E+04	8.45E+04	9.20E+04	1.14E+05[a]
79-Se	2.16E+02	3.84E+02	6.00E+02	2.73E+02	4.44E+02	7.17E+02	7.73E+02	1.00E+03
90-Sr[d]	8.58E+05	3.64E+06	4.50E+06	1.89E+07	4.10E+07	5.99E+07	7.16E+07	1.04E+08[c]
93-Zr	5.22E+02	7.33E+02	1.25E+03	1.49E+03	2.63E+03	4.12E+03	3.63E+03	4.74E+03
93m-Nb	3.64E+02	4.72E+02	8.36E+02	8.34E+02	1.69E+03	2.53E+03	2.69E+03	3.48E+03
99-Tc[d]	1.75E+03	4.03E+03	5.79E+03	7.96E+03	2.10E+04	2.89E+04	3.26E+04	3.32E+04
106-Ru	2.35E+02	6.58E+02	8.94E+02	1.26E+05	5.62E+02	1.27E+05	1.04E+05	1.14E+05
113m-Cd	3.20E+03	4.77E+03	7.97E+03	7.60E+03	9.05E+03	1.67E+04	1.69E+04	2.24E+04
125-Sb	4.14E+04	1.07E+04	5.20E+04	2.30E+05	1.61E+04	2.47E+05	2.08E+05	2.19E+05
126-Sn	2.10E+02	2.12E+02	4.23E+02	4.54E+02	7.02E+02	1.16E+03	1.19E+03	1.53E+03
129-I	1.12E+01	1.08E+01	2.20E+01	5.54E+01	4.53E+01	1.01E+02	6.30E+01	6.41E+01
134-Cs[e]	2.87E+02	8.89E+01	3.76E+02	8.59E+04	1.18E+03	8.71E+04	8.89E+04	8.89E+04
137-Cs[d]	1.91E+05	7.20E+05	9.11E+05	3.70E+07	2.67E+07	6.37E+07	4.64E+07	1.20E+08[c]
151-Sm	3.56E+05	4.23E+05	7.80E+05	9.24E+05	1.68E+06	2.61E+06	2.75E+06	3.54E+06
152-Eu	1.34E+02	1.74E+02	3.07E+02	7.42E+02	7.07E+02	1.45E+03	1.48E+03	1.89E+03
154-Eu	1.05E+04	2.72E+04	3.77E+04	9.40E+04	8.91E+04	1.83E+05	1.47E+05	1.74E+05
155-Eu	1.46E+04	1.69E+04	3.15E+04	1.23E+05	5.29E+04	1.76E+05	1.36E+05	1.60E+05
226-Ra	2.64E+02	7.69E+02	1.03E+03	1.81E+02	9.61E+02	1.14E+03	6.31E-02	7.72E-02[b]
227-Ac	2.86E-02	3.19E-02	6.05E-02	8.72E+01	3.17E-01	8.75E+01	8.76E+01	1.08E+02[b]
228-Ra	1.22E+01	2.10E+01	3.32E+01	3.92E+01	3.83E+01	7.75E+01	7.71E+01	6.44E+01[b]
229-Th	1.66E-01	1.74E-01	3.40E-01	9.19E-01	8.87E-01	1.81E+00	1.81E+00	2.92E+01[b]
231-Pa	1.51E-01	1.86E-01	3.37E-01	1.52E+02	7.50E-01	1.53E+02	1.56E+02	1.91E+02[b]
232-Th	6.93E-01	5.87E-01	1.28E+00	2.46E+00	1.95E+00	4.40E+00	2.11E+00	6.88E+01[c]
232-U	9.25E+00	2.54E+01	3.46E+01	2.31E+01	1.26E+02	1.49E+02	1.23E+02	3.02E+03[c]
233-U	3.50E+01	9.56E+01	1.31E+02	8.40E+01	4.88E+02	5.72E+02	4.76E+02	1.17E+04[c]
234-U	1.28E+01	3.13E+01	4.41E+01	1.02E+02	2.39E+02	3.42E+02	3.46E+02	3.56E+04[c]
235-U	5.21E-01	1.27E+00	1.79E+00	3.92E+00	1.07E+01	1.46E+01	1.45E+01	1.47E+03[c]
236-U	5.39E-01	8.89E-01	1.43E+00	7.54E+00	4.87E+00	1.24E+01	9.57E+00	1.17E+03[c]
237-Np	4.47E+01	3.63E+01	8.10E+01	1.10E+02	7.49E+01	1.85E+02	1.41E+02	2.76E+02[c]
238-Pu	4.40E+01	6.23E+01	1.06E+02	1.84E+03	8.51E+02	2.70E+03	2.77E+03	1.30E+05[c]
238-U	1.32E+01	3.51E+01	4.83E+01	7.91E+01	2.49E+02	3.28E+02	3.22E+02	3.29E+04[c]
239-Pu	8.81E+02	2.16E+03	3.05E+03	2.36E+04	3.19E+04	5.55E+04	3.91E+04	3.72E+06[c]
240-Pu	1.60E+02	3.65E+02	5.25E+02	5.82E+03	5.43E+03	1.13E+04	8.93E+03	6.79E+05[c]
241-Am	4.61E+03	6.23E+03	1.08E+04	7.35E+04	3.32E+04	1.07E+05	6.99E+04	7.99E+05[f]
241-Pu	2.93E+03	4.24E+03	7.17E+03	1.27E+05	3.97E+04	1.66E+05	2.29E+05	9.98E+06
242-Cm	1.05E+01	4.70E+01	5.76E+01	9.99E+01	7.20E+01	1.72E+02	7.70E+01	1.10E+02

	ILAW Inventory (radionuclides are in Ci at 1/1/94 chemicals are in kg)			BBI Sum of Tanks (radionuclides are in Ci at 1/1/94 chemicals are in kg)			Global Inventory (Kupfer 1999)	Total Produced (Watrous 1997)
	Phase 1	Phase 2	Total	Phase 1	Phase 2	Total	Total	Total
242-Pu	2.08E-02	2.41E-02	4.49E-02	8.37E-01	2.35E-01	1.07E+00	1.16E+00	4.25E+01
243-Am	5.40E-01	1.49E-01	6.89E-01	1.63E+01	1.31E+00	1.76E+01	9.34E+00	4.19E+01
243-Cm	2.76E+00	3.97E+00	6.73E+00	2.58E+01	8.85E+00	3.47E+01	1.00E+01	1.37E+01
244-Cm	5.10E+01	4.96E+01	1.01E+02	6.45E+02	1.38E+02	7.84E+02	2.42E+02	3.14E+02
Ag+	8.91E+01	1.89E+01	1.08E+02	1.49E+03	2.08E+01	1.51E+03	8.93E+03	
Al(OH)4-	3.53E+05	4.96E+06	5.31E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Al+3	1.44E+06	2.62E+06	4.05E+06	1.84E+06	6.43E+06	8.27E+06	7.85E+06	
As+5	4.37E+00	1.33E+01	1.76E+01	5.24E+00	1.55E+01	2.08E+01	0.00E+00	
B+3	5.06E+02	1.49E+02	6.54E+02	6.41E+03	1.25E+02	6.53E+03	0.00E+00	
Ba+2	7.05E+00	1.15E+01	1.86E+01	1.11E+03	5.86E+02	1.70E+03	0.00E+00	
Be+2	0.00E+00	6.14E-01	6.14E-01	1.08E+02	6.04E-01	1.09E+02	0.00E+00	
Bi+3	3.61E+02	9.59E+03	9.96E+03	6.27E+03	6.25E+05	6.31E+05	5.80E+05	
Ca+2	6.64E+03	4.12E+04	4.78E+04	4.23E+04	2.77E+05	3.19E+05	2.14E+05	
Cd+2	4.05E+01	2.25E+01	6.30E+01	3.69E+02	4.91E+01	4.18E+02	8.20E+03	
Ce+3	1.08E+02	2.22E+03	2.33E+03	2.98E+03	2.35E+05	2.38E+05	8.80E+03	
Cl-	2.78E+05	6.53E+05	9.31E+05	2.60E+05	6.77E+05	9.37E+05	5.00E+05	
CN-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E+05	1.09E+05	0.00E+00	
CO3-2	0.00E+00	0.00E+00	0.00E+00	2.69E+06	6.76E+06	9.46E+06	4.83E+06	
Cr(OH)4-	2.49E+04	3.81E+05	4.05E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cr (TOTAL)	6.15E+04	2.12E+05	2.74E+05	7.83E+04	5.94E+05	6.72E+05	7.85E+05	
Cs+[e]	4.54E+02	6.67E+02	1.12E+03	1.17E+05	8.88E+02	1.18E+05	0.00E+00	
Cu+2	6.34E-01	9.86E-02	7.33E-01	3.15E+02	6.18E-01	3.15E+02	0.00E+00	
F-	2.25E+05	7.69E+05	9.94E+05	3.74E+05	8.28E+05	1.20E+06	1.36E+06	
Fe+3	7.37E+03	3.74E+04	4.48E+04	2.59E+05	1.14E+06	1.40E+06	1.23E+06	
H2O	0.00E+00	0.00E+00	0.00E+00	4.84E+07	3.86E+07	8.70E+07	0.00E+00	
Hg+2	2.49E+01	1.67E+02	1.92E+02	4.55E+02	1.64E+03	2.10E+03	2.10E+03	
K+	4.98E+05	3.36E+05	8.33E+05	5.68E+05	3.07E+05	8.75E+05	4.81E+05	
La+3	3.93E+02	1.13E+02	5.06E+02	1.29E+04	3.84E+04	5.13E+04	5.10E+04	
Li+	2.92E+01	9.55E-01	3.02E+01	2.81E+01	2.32E+00	3.04E+01	0.00E+00	
Mg+2	1.89E+02	9.54E+01	2.84E+02	3.29E+03	9.10E+01	3.38E+03	0.00E+00	
Mn+4	5.85E+03	7.93E+03	1.38E+04	4.23E+04	1.54E+05	1.96E+05	1.05E+05	
Mo+6	5.99E+02	2.20E+01	6.21E+02	1.31E+03	5.56E+00	1.31E+03	0.00E+00	
Na+	1.26E+07	4.43E+07	5.69E+07	1.20E+07	3.70E+07	4.90E+07	5.42E+07	
NH3	0.00E+00	0.00E+00	0.00E+00	2.48E+05	2.53E+05	5.01E+05	0.00E+00	
Ni+2	7.70E+03	2.28E+04	3.05E+04	3.74E+04	1.42E+05	1.80E+05	1.11E+05	
NO2-	0.00E+00	0.00E+00	0.00E+00	4.74E+06	7.90E+06	1.26E+07	0.00E+00	
NO3-	0.00E+00	0.00E+00	0.00E+00	8.39E+06	4.41E+07	5.25E+07	0.00E+00	
OH (BOUND)	0.00E+00	0.00E+00	0.00E+00	5.90E+06	1.52E+07	2.11E+07	0.00E+00	
OH-	0.00E+00	0.00E+00	0.00E+00	1.45E+06	2.21E+06	3.66E+06	2.30E+07	
Pb+2	3.55E+03	4.28E+03	7.83E+03	1.78E+04	6.62E+04	8.40E+04	2.79E+05	

	ILAW Inventory (radionuclides are in Ci at 1/1/94 chemicals are in kg)			BBI Sum of Tanks (radionuclides are in Ci at 1/1/94 chemicals are in kg)			Global Inventory (Kupfer 1999)	Total Produced (Watrous 1997)
	Phase 1	Phase 2	Total	Phase 1	Phase 2	Total	Total	Total
PO4-3	2.73E+05	4.88E+06	5.16E+06	2.19E+05	5.34E+06	5.56E+06	6.00E+06	
Rh+3	NA	NA	NA	5.19E+01	0.00E+00	5.19E+01	0.00E+00	
Ru+3	NA	NA	NA	1.21E+00	0.00E+00	1.21E+00	0.00E+00	
Se+6	4.29E-01	1.04E-01	5.33E-01	5.53E-01	5.86E-02	6.11E-01	0.00E+00	
Si+4	3.79E+04	3.83E+05	4.20E+05	1.37E+05	8.03E+05	9.41E+05	5.70E+05	
SO4-2	4.95E+05	2.90E+06	3.39E+06	4.61E+05	3.45E+06	3.91E+06	5.00E+06	
Sr+2	1.34E+02	2.07E+03	2.20E+03	9.96E+02	4.45E+04	4.55E+04	3.13E+04	
Te+6	NA	NA	NA	3.04E+02	0.00E+00	3.04E+02	0.00E+00	
Th+4	NA	NA	NA	NA	NA	NA	2.56E+04	
Ti+4	1.39E+01	1.04E+00	1.49E+01	2.60E+02	2.87E-01	2.60E+02	0.00E+00	
Tl+3	NA	NA	NA	2.54E+04	0.00E+00	2.54E+04	0.00E+00	
TOC	0.00E+00	0.00E+00	0.00E+00	7.43E+05	1.25E+06	2.00E+06	4.00E+06	
U(TOTAL)	7.41E+03	9.92E+03	1.73E+04	8.36E+03	6.78E+04	7.61E+04	9.65E+05	
V+5	NA	NA	NA	1.68E+01	0.00E+00	1.68E+01	0.00E+00	
W+6	NA	NA	NA	NA	NA	NA	1.59E+04	
Zn+2	1.43E+03	5.53E+02	1.98E+03	2.45E+03	4.44E+02	2.89E+03	0.00E+00	
Zr+4	6.48E+03	5.80E+03	1.23E+04	4.24E+05	4.09E+04	4.65E+05	4.40E+05	

a) These were corrected values based on improved activation calculations described in Harmsen 1998.
b) These are daughter products of uranium and thorium that were not treated correctly in the HDW model because uranium, thorium, and plutonium were decayed prior to separations (Kupfer 1999). The inventory values for these radioisotopes may be significantly in error and their long term growth should be calculated concurrently with the calculation of waste migration and elemental retardation. The reason for the discrepancy between BBI and Global Inventory needs further investigation.
c) These are total production values with no product separations.
d) Isotope quantity limited by contract (see Section 2.8). Values in table for ILAW inventory may exceed contract concentration limits due to decay between the reference date (1/1/94) and the date of batch processing.
e) The TWRSO&UP inventory as currently configured does not remove ^{134}Cs or Cs+ from the LAW feed. Therefore the ^{134}Cs and Cs+ ILAW values were adjusted so that the ILAW to BBI ratio was the same as for ^{137}Cs.
f) ^{241}Am is overestimated by approximately a factor of 10 in Watrous 1997 because the parent ^{241}Pu was not separated. The HDW model corrected for this.
g) Zero entries in the ILAW inventory indicate the component was 100% released to the offgas system.
h) NA entries refer to components where inventory information is not available.
i) The ^{90}Sr will have ^{90}Y daughter in equilibrium. The ^{137}Cs will have ^{137m}Ba daughter in equilibrium.
j) U (total) was treated in TWRSO&UP as Total U - U radionuclides

Table 4.3 Upper Bound Inventories for ILAW

Upper Bound Inventories (Ci for radionuclides and kg for chemicals)				
Component	Phase 1	Phase 2	Total	Basis
3-H	6.17E+03	1.84E+04	2.46E+04	In Tank Inventory
14-C	1.19E+03	3.20E+03	4.38E+03	In Tank Inventory
59-Ni	2.39E+02	6.19E+02	8.58E+02	In Tank Inventory
60-Co	1.27E+04	7.22E+03	1.99E+04	In Tank Inventory
63-Ni	2.38E+04	6.07E+04	8.45E+04	In Tank Inventory
79-Se	3.55E+02	5.77E+02	9.32E+02	In Tank Inventory*1.3
90-Sr	1.11E+06	4.74E+06	5.85E+06	contract limit
93-Zr	1.49E+03	2.63E+03	4.12E+03	In Tank Inventory
93m-Nb	8.34E+02	1.69E+03	2.53E+03	In Tank Inventory
99-Tc	2.02E+03	4.64E+03	6.65E+03	contract limit; 20% of BBI
106-Ru	1.26E+05	5.62E+02	1.27E+05	In Tank Inventory
113m-Cd	7.60E+03	9.05E+03	1.67E+04	In Tank Inventory
125-Sb	2.30E+05	1.61E+04	2.47E+05	In Tank Inventory
126-Sn	4.54E+02	7.02E+02	1.16E+03	In Tank Inventory
129-I	5.54E+01	4.53E+01	1.01E+02	In Tank Inventory
134-Cs	3.73E+02	1.16E+02	4.89E+02	Adjusted to ^{137}Cs
137-Cs	2.48E+05	9.36E+05	1.18E+06	contract limit
151-Sm	9.24E+05	1.68E+06	2.61E+06	In Tank Inventory
152-Eu	7.42E+02	7.07E+02	1.45E+03	In Tank Inventory
154-Eu	9.40E+04	8.91E+04	1.83E+05	In Tank Inventory
155-Eu	1.23E+05	5.29E+04	1.76E+05	In Tank Inventory
226-Ra	1.81E+02	9.61E+02	1.14E+03	In Tank Inventory
227-Ac	8.72E+01	3.17E-01	8.75E+01	In Tank Inventory
228-Ra	3.92E+01	3.83E+01	7.75E+01	In Tank Inventory
229-Th	9.19E-01	8.87E-01	1.81E+00	In Tank Inventory
231-Pa	1.52E+02	7.50E-01	1.53E+02	In Tank Inventory
232-Th	2.46E+00	1.95E+00	4.40E+00	In Tank Inventory
232-U	2.31E+01	1.26E+02	1.49E+02	In Tank Inventory
233-U	8.40E+01	4.88E+02	5.72E+02	In Tank Inventory
234-U	1.02E+02	2.39E+02	3.42E+02	In Tank Inventory
235-U	3.92E+00	1.07E+01	1.46E+01	In Tank Inventory
236-U	7.54E+00	4.87E+00	1.24E+01	In Tank Inventory
237-Np	1.66E+02	1.35E+02	3.00E+02	contract limit
238-Pu	1.63E+02	2.31E+02	3.94E+02	contract limit
238-U	7.91E+01	2.49E+02	3.28E+02	In Tank Inventory
239-Pu	3.26E+03	8.02E+03	1.13E+04	contract limit
240-Pu	5.94E+02	1.35E+03	1.95E+03	contract limit
241-Am	1.71E+04	2.31E+04	4.01E+04	contract limit
241-Pu	1.27E+05	3.97E+04	1.66E+05	In Tank Inventory
242-Cm	9.99E+01	7.20E+01	1.72E+02	In Tank Inventory
242-Pu	7.70E-02	8.93E-02	1.66E-01	contract limit
243-Am	2.00E+00	5.53E-01	2.55E+00	contract limit
243-Cm	1.02E+01	1.47E+01	2.49E+01	contract limit
244-Cm	1.89E+02	1.84E+02	3.73E+02	contract limit
Ag+	2.98E+03	4.16E+01	3.03E+03	In Tank Inventory

Upper Bound Inventories (Ci for radionuclides and kg for chemicals)				
Component	Phase 1	Phase 2	Total	Basis
Al(OH)4-	4.52E+05	1.22E+07	1.08E+07	TWRSO&UP normalized to Al+3
Al+3	1.84E+06	6.43E+06	8.27E+06	In Tank Inventory
As+5	1.05E+01	3.10E+01	4.15E+01	In Tank Inventory
B+3	1.28E+04	2.51E+02	1.31E+04	In Tank Inventory
Ba+2	2.22E+03	1.17E+03	3.39E+03	In Tank Inventory
Be+2	2.16E+02	1.21E+00	2.18E+02	In Tank Inventory
Bi+3	6.27E+03	6.25E+05	6.31E+05	In Tank Inventory
Ca+2	4.23E+04	2.77E+05	3.19E+05	In Tank Inventory
Cd+2	7.38E+02	9.82E+01	8.36E+02	In Tank Inventory
Ce+3	5.96E+03	4.69E+05	4.75E+05	In Tank Inventory
Cl-	2.60E+05	6.77E+05	9.37E+05	In Tank Inventory
CN-	0.00E+00	1.09E+05	1.09E+05	In Tank Inventory
CO3-2	2.69E+06	6.76E+06	9.46E+06	In Tank Inventory
Cr(OH)4-	3.17E+04	1.06E+06	9.95E+05	TWRSO&UP normalized to Cr(total)
Cr(TOTAL)	7.83E+04	5.94E+05	6.72E+05	In Tank Inventory
Cs+	1.17E+05	8.88E+02	1.18E+05	Adjusted to ^{137}Cs
Cu+2	6.30E+02	1.24E+00	6.31E+02	In Tank Inventory
F-	3.74E+05	8.28E+05	1.20E+06	In Tank Inventory
Fe+3	2.59E+05	1.14E+06	1.40E+06	In Tank Inventory
H2O	4.84E+07	3.86E+07	8.70E+07	In Tank Inventory
Hg+2	4.55E+02	1.64E+03	2.10E+03	In Tank Inventory
K+	5.68E+05	3.07E+05	8.75E+05	In Tank Inventory
La+3	1.29E+04	3.84E+04	5.13E+04	In Tank Inventory
Li+	5.62E+01	4.64E+00	6.09E+01	In Tank Inventory
Mg+2	6.57E+03	1.82E+02	6.75E+03	In Tank Inventory
Mn+4	4.23E+04	1.54E+05	1.96E+05	In Tank Inventory
Mo+6	2.61E+03	1.11E+01	2.62E+03	In Tank Inventory
Na+	1.20E+07	3.70E+07	4.90E+07	In Tank Inventory
NH3	2.48E+05	2.53E+05	5.01E+05	In Tank Inventory
Ni+2	3.74E+04	1.42E+05	1.80E+05	In Tank Inventory
NO2-	4.74E+06	7.90E+06	1.26E+07	In Tank Inventory
NO3-	8.39E+06	4.41E+07	5.25E+07	In Tank Inventory
OH (BOUND)	5.90E+06	1.52E+07	2.11E+07	In Tank Inventory
OH-	1.45E+06	2.21E+06	3.66E+06	In Tank Inventory
Pb+2	1.78E+04	6.62E+04	8.40E+04	In Tank Inventory
PO4-3	2.19E+05	5.34E+06	5.56E+06	In Tank Inventory
Rh+3	1.04E+02	0.00E+00	1.04E+02	In Tank Inventory
Ru+3	2.43E+00	0.00E+00	2.43E+00	In Tank Inventory
Se+6	1.11E+00	1.17E-01	1.22E+00	In Tank Inventory
Si+4	1.37E+05	8.03E+05	9.41E+05	In Tank Inventory
SO4-2	4.61E+05	3.45E+06	3.91E+06	In Tank Inventory
Sr+2	9.96E+02	4.45E+04	4.55E+04	In Tank Inventory
Te+6	6.08E+02	0.00E+00	6.08E+02	In Tank Inventory
Th+4			2.56E+04	Global
Ti+4	5.19E+02	5.75E-01	5.20E+02	In Tank Inventory

Upper Bound Inventories (Ci for radionuclides and kg for chemicals)				
Component	Phase 1	Phase 2	Total	Basis
Tl+3	5.08E+04	0.00E+00	5.08E+04	In Tank Inventory
TOC	3.25E+05	8.33E+05	1.16E+06	Organic chemicals from Table 4.6
U(TOTAL)	8.36E+03	6.78E+04	7.61E+04	In Tank Inventory
V+5	3.36E+01	0.00E+00	3.36E+01	In Tank Inventory
W+6			3.18E+04	Global
Zn+2	4.90E+03	8.89E+02	5.79E+03	In Tank Inventory
Zr+4	4.24E+05	4.09E+04	4.65E+05	In Tank Inventory

4.2 ILAW PACKAGE UPPER BOUNDS

The main contributor to the variability in the inventory in an ILAW package or group of packages are the tank-to-tank variations in inventories. Each batch of LAW feed represents one or more tank contents after it has been retrieved and subjected to the wash and leach processes. The approach taken was to combine the bounding ILAW total inventory and batch-to-batch variations in inventory values along with the Phase 1 BNFL Inc. contract radionuclide limits to determine bounding concentrations for the ILAW packages. The Phase 2 limits are assumed to be the same as for Phase 1. The intent was not to identify the extreme concentration limits of an individual package, but to provide reasonable bounding values. There could be situations where recycle buildup, filter cleanouts, or other situations provide small amounts of ILAW that approach the acceptability limits for some components. However, reasonable variations for groups of packages were judged to be adequately represented by the batch to batch variability, which primarily reflects the variability in the tank concentrations.

Table 4.4 shows concentration values for the average Phase 1, average Phase 2, and the maximum batch concentration based on the batchwise inventories described in Section 3, but decay corrected to the reference date of 1/1/94. The processing assumptions used in the TWRSO&UP for Case 3 included both small batches representing internal processing by BNFL Inc. as well as the major batches. Individual batches may be pretreated LAW, ion exchange column wash, HLW caustic wash, etc. As such the averaging effect that normally occurs due to the internal parallel treatment and blending operations of the vitrification facility are not apparent. Thus the maximum to average ratio shown in Table 4.4 should be greater than what actually will occur in the vitrification plant. With the exception of Be, which has a maximum to average concentration ratio of 140, caused by the segregation of zirconium cladding waste, the ratios are all well under 100 and frequently under 10.

The second and third columns of Table 4.5 show the average concentrations based on the total nominal ILAW inventory and the total upper bound inventory from Table 4.3. The nominal average package concentration is determined by dividing the total nominal ILAW inventory (Table 4.2) by the total volume of waste produced (Table 2.1). The upper bound for a package or group of packages was determined by increasing the average concentration based on the total upper bound inventory by the ratio of the maximum batch concentration to the average batch concentration. An additional multiplicative factor representing the uncertainty in an individual tank inventory was then applied. This approach is shown in Table 4.5. The ratio of the

maximum batch to average batch was taken from Table 4.4. The tank uncertainty factors were roughly based on the BBI tank inventory uncertainties (Ferryman 1998). These tank-by-tank uncertainties were examined for the major components of concern to the performance assessment, and in general, a factor of 3 characterized the typical variations between the 90% confidence values and the nominal values for tanks with substantial inventories of a given component. Much larger values can be found, but these generally applied to tanks with relatively small inventories of the given component, or where discrepancies exist between the inventory used in the uncertainty studies and the BBI tank inventories used for this study. This factor was assumed to be a factor of 10 for the components that were not based on BBI data. The contract limits for ^{99}Tc, ^{90}Sr, and ^{137}Cs of 0.1, 20, and 3 Ci/m^3 can be exceeded as long as the average is maintained below these values. The 10CFR 61.55 Class C limits cannot be exceeded. The Class C limits for ^{99}Tc, ^{90}Sr, and ^{137}Cs are 3, 7000, and 4600 Ci/m^3. Other radionuclides with Class C limits are ^{129}I (0.08 Ci/m^3), ^{14}C (8 Ci/m^3, ^{63}Ni (700 Ci/m^3), ^{241}Pu (3500 nCi/g - which corresponds to 9.28 Ci/m^3 at 2.65 MT/m^3 glass density), and ^{242}Cm (20,000 nCi/g – which corresponds to 53 Ci/m^3 at 2.65 MT/m^3 glass density). The Class C limits provide the ultimate upper bounds for these isotopes for a single package or group of packages. The TRU (alpha emitting Np, Pu, Am, and Cm radionuclides with half life greater than 5 years) concentration is limited by contract to 100 nCi/g (this is also the Class C limit). There is no exception within the contract for ILAW with greater than 100 nCi/g TRU. With a glass density of 2.65 MT/m^3, the 100 nCi/g limit corresponds to 0.265 Ci/m^3. Thus, the sum of the ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{241}Am, ^{243}Am, ^{242}Cm, and ^{244}Cm curie inventory must be within this limit for every package. The upper bound for a package or group of packages is shown in the last column of Table 4.5

Table 4.4 Average and Maximum Radionuclide and Chemical Concentrations Based on Nominal Inventories

Component	Phase 1 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Phase 2 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Total average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Maximum batch concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Ratio of Maximum/ Average batch concentration
3-H	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
14-C	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
59-Ni	1.55E-03	8.64E-04	1.06E-03	4.02E-03	3.8
60-Co	4.56E-02	1.90E-02	2.64E-02	3.07E-01	11.6
63-Ni	1.51E-01	8.34E-02	1.02E-01	3.91E-01	3.8
79-Se	4.86E-03	3.38E-03	3.79E-03	6.84E-02	18.0
90-Sr	1.93E+01	3.20E+01	2.85E+01	5.43E+01	1.9
93-Zr	1.18E-02	6.44E-03	7.94E-03	3.37E-02	4.3
93m-Nb	8.20E-03	4.15E-03	5.29E-03	4.47E-02	8.5
99-Tc[a]	4.55E-02	4.08E-02	4.21E-02	9.96E-02	2.4
106-Ru	5.30E-03	5.79E-03	5.65E-03	2.59E-01	45.8
113m-Cd	7.21E-02	4.20E-02	5.04E-02	2.14E-01	4.3
125-Sb	9.32E-01	9.39E-02	3.29E-01	6.50E+00	19.7
126-Sn	4.74E-03	1.87E-03	2.67E-03	1.04E-02	3.9
129-I	2.52E-04	9.52E-05	1.39E-04	1.81E-03	13.0
134-Cs	1.25E+00	2.90E-02	3.73E-01	1.35E+01	36.2
137-Cs	4.30E+00	6.33E+00	5.76E+00	7.80E+00	1.4
151-Sm	8.03E+00	3.72E+00	4.93E+00	2.42E+01	4.9
152-Eu	3.01E-03	1.53E-03	1.94E-03	4.21E-02	21.7
154-Eu	2.36E-01	2.39E-01	2.38E-01	6.13E+00	25.7
155-Eu	3.30E-01	1.49E-01	1.99E-01	7.36E+00	36.9
226-Ra	5.95E-03	6.76E-03	6.53E-03	2.82E-01	43.2
227-Ac	6.45E-07	2.81E-07	3.83E-07	1.76E-06	4.6
228-Ra	2.75E-04	1.84E-04	2.10E-04	1.07E-03	5.1
229-Th	3.75E-06	1.53E-06	2.15E-06	1.14E-05	5.3
231-Pa	3.40E-06	1.64E-06	2.13E-06	1.03E-05	4.8
232-Th	1.56E-05	5.16E-06	8.09E-06	5.97E-05	7.4
232-U	2.08E-04	2.23E-04	2.19E-04	1.64E-03	7.5
233-U	7.89E-04	8.41E-04	8.26E-04	6.22E-03	7.5
234-U	2.87E-04	2.75E-04	2.79E-04	1.95E-03	7.0
235-U	1.17E-05	1.11E-05	1.13E-05	7.97E-05	7.1
236-U	1.21E-05	7.81E-06	9.03E-06	3.68E-05	4.1
237-Np	1.01E-03	3.19E-04	5.13E-04	1.78E-03	3.5
238-Pu	9.90E-04	5.48E-04	6.72E-04	2.69E-03	4.0
238-U	2.98E-04	3.09E-04	3.06E-04	2.02E-03	6.6
239-Pu	1.99E-02	1.90E-02	1.93E-02	9.50E-02	4.9
240-Pu	3.61E-03	3.21E-03	3.32E-03	1.34E-02	4.0
241-Am	1.04E-01	5.48E-02	6.85E-02	1.69E+00	24.6
241-Pu	6.61E-02	3.73E-02	4.53E-02	1.98E-01	4.4

Component	Phase 1 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Phase 2 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Total average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Maximum batch concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Ratio of Maximum/ Average batch concentration
242-Cm	2.37E-04	4.13E-04	3.64E-04	1.16E-02	31.7
242-Pu	4.68E-07	2.12E-07	2.84E-07	1.69E-06	6.0
243-Am	1.22E-05	1.31E-06	4.36E-06	9.01E-05	20.7
243-Cm	6.21E-05	3.49E-05	4.26E-05	5.18E-04	12.2
244-Cm	1.15E-03	4.36E-04	6.36E-04	6.77E-03	10.6
Ag+	2.01E-03	1.66E-04	6.83E-04	5.68E-03	8.3
Al(OH)4-	7.95E+00	4.36E+01	3.36E+01	2.51E+02	7.5
Al+3	3.24E+01	2.30E+01	2.56E+01	8.65E+01	3.4
As+5	9.85E-05	1.17E-04	1.12E-04	7.42E-03	66.5
B+3	1.14E-02	1.31E-03	4.14E-03	5.20E-02	12.6
Ba+2	1.59E-04	1.01E-04	1.17E-04	7.24E-03	61.6
Be+2	0.00E+00	5.40E-06	3.89E-06	5.48E-04	141.0
Bi+3	8.13E-03	8.44E-02	6.30E-02	1.72E+00	27.3
Ca+2	1.50E-01	3.62E-01	3.03E-01	3.27E+00	10.8
Cd+2	9.13E-04	1.98E-04	3.98E-04	5.13E-03	12.9
Ce+3	2.44E-03	1.95E-02	1.47E-02	3.89E-01	26.4
Cl-	6.26E+00	5.75E+00	5.89E+00	1.55E+01	2.6
CN-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Co+3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
CO3-2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Cr(OH)4-	5.61E-01	3.35E+00	2.56E+00	3.14E+01	12.2
Cr(TOTAL)	1.39E+00	1.87E+00	1.73E+00	1.27E+01	7.3
Cs+	1.98E+00	2.18E-01	7.13E-01	1.81E+01	25.3
Cu+2	1.43E-05	8.67E-07	4.63E-06	2.54E-05	5.5
F-	5.06E+00	6.76E+00	6.28E+00	2.75E+01	4.4
Fe+3	1.66E-01	3.29E-01	2.83E-01	2.86E+00	10.1
H+	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
H2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Hg+2	5.61E-04	1.47E-03	1.22E-03	3.38E-02	27.8
K+	1.12E+01	2.95E+00	5.27E+00	2.08E+01	4.0
La+3	8.85E-03	9.90E-04	3.20E-03	2.99E-02	9.3
Li+	6.59E-04	8.40E-06	1.91E-04	2.47E-04	1.3
Mg+2	4.26E-03	8.39E-04	1.80E-03	6.43E-02	35.7
Mn+4	1.32E-01	6.97E-02	8.71E-02	4.20E-01	4.8
Mo+6	1.35E-02	1.93E-04	3.93E-03	1.32E-02	3.4
Na+	2.84E+02	3.89E+02	3.60E+02	3.93E+02	1.1
NH3	5.08E+00	1.53E+00	2.53E+00	4.24E+01	16.8
Ni+2	1.73E-01	2.00E-01	1.93E-01	2.96E+00	15.4
NO2-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
NO3-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
OH(BOUND)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A

Component	Phase 1 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Phase 2 average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Total average concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Maximum batch concentration (Ci/m^3 for radionuclides, kg/m^3 for chemicals)	Ratio of Maximum/ Average batch concentration
OH-	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Pb+2	8.00E-02	3.76E-02	4.95E-02	2.73E-01	5.5
PO4-3	6.14E+00	4.30E+01	3.26E+01	2.28E+02	7.0
Rh+3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Ru+3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Sb+5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Se+6	9.67E-06	9.12E-07	3.37E-06	2.96E-05	8.8
Si+4	8.54E-01	3.36E+00	2.66E+00	2.29E+01	8.6
SO4-2	1.12E+01	2.55E+01	2.15E+01	9.12E+01	4.3
Sr+2	3.02E-03	1.82E-02	1.39E-02	1.29E-01	9.3
Tc+7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Te+6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Th+4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Ti+4	3.12E-04	9.10E-06	9.42E-05	1.15E-03	12.2
Tl+3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
TOC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
U(TOTAL)	1.67E-01	8.72E-02	1.10E-01	2.16E+00	19.7
V+5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
W+6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	N/A
Zn+2	3.21E-02	4.86E-03	1.25E-02	1.19E-01	9.5
Zr+4	1.46E-01	5.10E-02	7.76E-02	7.03E-01	9.0

a) Concentrations are for ILAW glass based on glass density of 2.65 MT/m^3.

Table 4.5 Package Upper Bound Concentrations

Component	Nominal average package concentration (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Upper bound average package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Ratio of Maximum batch/ Average batch	Tank Inventory Uncertainty Factor	Maximum Upper Bound Package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)
3-H	0.00E+00	1.55E-01	NA	3.0	4.66E-01
14-C	0.00E+00	2.77E-02	NA	NA	8.00E+00
59-Ni	1.06E-03	5.42E-03	3.8	3.0	6.20E-02
60-Co	2.64E-02	1.26E-01	11.6	3.0	4.39E+00
63-Ni	1.02E-01	5.34E-01	3.8	NA	7.00E+02[a]
79-Se	3.79E-03	5.89E-03	18.0	3.0	3.19E-01
90-Sr	2.85E+01	3.70E+01	1.9	NA	7.00E+03[a]
93-Zr	7.94E-03	2.61E-02	4.3	3.0	3.32E-01
93m-Nb	5.29E-03	1.60E-02	8.5	3.0	4.05E-01
99-Tc	3.66E-02	4.21E-02	2.4	NA	3.00E+00[a]
106-Ru	5.65E-03	8.01E-01	45.8	3.0	1.10E+02
113m-Cd	5.04E-02	1.05E-01	4.3	3.0	1.34E+00
125-Sb	3.29E-01	1.56E+00	19.7	3.0	9.23E+01
126-Sn	2.67E-03	7.31E-03	3.9	3.0	8.53E-02
129-I	1.39E-04	6.37E-04	13.0	NA	8.00E-02[a]
134-Cs	3.73E-01	3.09E-03	36.2	3.0	3.36E-01
137-Cs	5.76E+00	7.49E+00	1.4	NA	4.60E+03[a]
151-Sm	4.93E+00	1.65E+01	4.9	3.0	2.43E+02
152-Eu	1.94E-03	9.16E-03	21.7	3.0	5.96E-01
154-Eu	2.38E-01	1.16E+00	25.7	3.0	8.92E+01
155-Eu	1.99E-01	1.11E+00	36.9	3.0	1.23E+02
226-Ra	6.53E-03	7.22E-03	43.2	3.0	9.36E-01
227-Ac	3.83E-07	5.53E-04	4.6	3.0	7.63E-03
228-Ra	2.10E-04	4.90E-04	5.1	3.0	7.49E-03
229-Th	2.15E-06	1.14E-05	5.3	3.0	1.82E-04
231-Pa	2.13E-06	9.68E-04	4.8	3.0	1.40E-02
232-Th	8.09E-06	2.79E-05	7.4	3.0	6.17E-04
232-U	2.19E-04	9.42E-04	7.5	3.0	2.11E-02
233-U	8.26E-04	3.62E-03	7.5	3.0	8.18E-02
234-U	2.79E-04	2.16E-03	7.0	3.0	4.54E-02
235-U	1.13E-05	9.26E-05	7.1	3.0	1.96E-03
236-U	9.03E-06	7.85E-05	4.1	3.0	9.60E-04
237-Np	5.13E-04	1.90E-03	3.5	NA	1.46E-03[a]
238-Pu	6.72E-04	2.49E-03	4.0	NA	1.91E-03[a]
238-U	3.06E-04	2.08E-03	6.6	3.0	4.12E-02
239-Pu	1.93E-02	7.14E-02	4.9	NA	5.49E-02[a]
240-Pu	3.32E-03	1.23E-02	4.0	NA	9.47E-03[a]
241-Am	6.85E-02	2.54E-01	24.6	NA	1.95E-01[a]
241-Pu	4.53E-02	1.05E+00	4.4	NA	9.28E+00[a]
242-Cm	3.64E-04	1.09E-03	31.7	NA	5.30E+01[a]

Component	Nominal average package concentration (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Upper bound average package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Ratio of Maximum batch/ Average batch	Tank Inventory Uncertainty Factor	Maximum Upper Bound Package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)
242-Pu	2.84E-07	1.05E-06	6.0	NA	8.09E-07 [a]
243-Am	4.36E-06	1.61E-05	20.7	NA	1.24E-05 [a]
243-Cm	4.26E-05	1.58E-04	12.2	NA	1.21E-04 [a]
244-Cm	6.36E-04	2.36E-03	10.6	NA	1.81E-03 [a]
Ag+	6.83E-04	1.91E-02	8.3	10.0	1.59E+00
Al(OH)4-	3.36E+01	6.85E+01	7.5	3.0	1.53E+03
Al+3	2.56E+01	5.23E+01	3.4	3.0	5.29E+02
As+5	1.12E-04	2.63E-04	66.5	10.0	1.75E-01
B+3	4.14E-03	8.27E-02	12.6	10.0	1.04E+01
Ba+2	1.17E-04	2.15E-02	61.6	10.0	1.32E+01
Be+2	3.89E-06	1.38E-03	141.0	10.0	1.94E+00
Bi+3	6.30E-02	3.99E+00	27.3	3.0	3.27E+02
Ca+2	3.03E-01	2.02E+00	10.8	3.0	6.54E+01
Cd+2	3.98E-04	5.29E-03	12.9	10.0	6.81E-01
Ce+3	1.47E-02	3.00E+00	26.4	10.0	7.93E+02
Cl-	5.89E+00	5.93E+00	2.6	3.0	4.67E+01
CN-	0.00E+00	6.88E-01	NA	3.0	2.06E+00
CO3-2	0.00E+00	5.98E+01	NA	3.0	1.79E+02
Cr(OH)4-	2.56E+00	6.29E+00	12.2	3.0	2.31E+02
Cr(TOTAL)	1.73E+00	4.25E+00	7.3	3.0	9.37E+01
Cs+	7.13E-01	7.45E-01	25.3	3.0	5.67E+01
Cu+2	4.63E-06	3.99E-03	5.5	10.0	2.19E-01
F-	6.28E+00	7.60E+00	4.4	3.0	9.97E+01
Fe+3	2.83E-01	8.84E+00	10.1	3.0	2.68E+02
H2O	0.00E+00	5.50E+02	NA	3.0	1.65E+03
Hg+2	1.22E-03	1.33E-02	27.8	3.0	1.11E+00
K+	5.27E+00	5.53E+00	4.0	3.0	6.57E+01
La+3	3.20E-03	3.25E-01	9.3	3.0	9.10E+00
Li+	1.91E-04	3.85E-04	1.3	10.0	4.98E-03
Mg+2	1.80E-03	4.27E-02	35.7	10.0	1.53E+01
Mn+4	8.71E-02	1.24E+00	4.8	3.0	1.79E+01
Mo+6	3.93E-03	1.66E-02	3.4	10.0	5.58E-01
Na+	3.60E+02	3.10E+02	1.1	3.0	1.01E+03
NH3	2.53E+00	3.17E+00	16.8	3.0	9.51E+00
Ni+2	1.93E-01	1.14E+00	15.4	3.0	5.25E+01
NO2-	0.00E+00	7.99E+01	1.0	3.0	2.40E+02
NO3-	0.00E+00	3.32E+02	NA	3.0	9.96E+02
OH(BOUND)	0.00E+00	1.34E+02	NA	3.0	4.01E+02
OH-	0.00E+00	2.32E+01	NA	3.0	6.95E+01
Pb+2	4.95E-02	5.31E-01	5.5	3.0	8.77E+00
PO4-3	3.26E+01	3.52E+01	7.0	3.0	7.36E+02

Component	Nominal average package concentration (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Upper bound average package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)	Ratio of Maximum batch/ Average batch	Tank Inventory Uncertainty Factor	Maximum Upper Bound Package (Ci/m^3 for radionuclides and kg/m^3 for chemicals)
Rh+3	0.00E+00	6.56E-04	NA	10.0	6.56E-03
Ru+3	0.00E+00	1.53E-05	NA	10.0	1.53E-04
Se+6	3.37E-06	7.73E-06	8.8	10.0	6.80E-04
Si+4	2.66E+00	5.95E+00	8.6	3.0	1.54E+02
SO4-2	2.15E+01	2.47E+01	4.3	3.0	3.16E+02
Sr+2	1.39E-02	2.88E-01	9.3	3.0	8.01E+00
Te+6	0.00E+00	3.84E-03	NA	10.0	3.84E-02
Th+4	0.00E+00	1.62E-01	NA	3.0	4.86E-01
Ti+4	9.42E-05	3.29E-03	12.2	10.0	4.00E-01
Tl+3	0.00E+00	3.21E-01	NA	10.0	3.21E+00
TOC	0.00E+00	1.26E+01	NA	3.0	3.79E+01
U(TOTAL)	1.10E-01	4.82E-01	19.7	3.0	2.85E+01
V+5	0.00E+00	2.13E-04	NA	10.0	2.13E-03
W+6	0.00E+00	2.01E-01	NA	10.0	2.01E+00
Zn+2	1.25E-02	3.66E-02	9.5	10.0	3.48E+00
Zr+4	7.76E-02	2.94E+00	9.0	3.0	7.98E+01

a) Class C Limits

4.3 HAZARDOUS CHEMICALS

The ILAW packages must meet the land disposal restriction (LDR) treatment standards for compliance with the Washington State Dangerous Waste Regulations contained in Chapter 173-303 of the Washington Administrative Code (WAC). The LDR regulations are found in 40 CFR 268 and WAC173-303-140. The privatization regulatory Data Quality Objectives (DQO) (Wiemers 1998) identified a set of regulatory constituents plausible to be in the tank waste and which might be considered during permitting activities in support of the treatment facility. The TWRS-P Project Dangerous Waste Permit Application (BNFL 1999) compared these constituents to the "Universal Treatment Standards" (40 CFR 268.48) and provided a list of components and LDR treatment standards. These LDR treatment standards provide an upper bound concentration for acceptability of the ILAW product. These maximum concentrations were multiplied by the glass mass produced in Phase 1 and Phase 2 from Table 2.1, along with a safety factor of 1.3 to allow for uncertainty in the total glass mass, to provide bounding inventories of trace hazardous organic chemicals in the ILAW product. These are summarized in Table 4.6 for Phase 1, Phase 2, and total ILAW inventories. The 1,160,000 kg total inventory of organic chemicals is a little more than half of the total 2,000,000 kg tank inventory of TOC.

Table 4.6 Bounding Limits for Organic Chemicals in ILAW Packages

Organic Compounds	LDR Treatment Standard (mg/kg)	Upper Bound Organic ILAW Inventory (MT)		
		Phase 1	Phase 2	Total
1,1,1-trichlorethane	6	9.17E-01	2.35E+00	3.27E+00
1,1,2-trichloro-1,2,2-trifluoroethane	30	4.59E+00	1.18E+01	1.63E+01
1,1,2-trichloroethane	6	9.17E-01	2.35E+00	3.27E+00
1,1-dichloroethylene	6	9.17E-01	2.35E+00	3.27E+00
1,2-dichloroethane	6	9.17E-01	2.35E+00	3.27E+00
acetone	160	2.45E+01	6.27E+01	8.71E+01
benzene	10	1.53E+00	3.92E+00	5.45E+00
carbon tetrachloride	6	9.17E-01	2.35E+00	3.27E+00
chlorobenzene	6	9.17E-01	2.35E+00	3.27E+00
chloroform	6	9.17E-01	2.35E+00	3.27E+00
ethyl acetate	33	5.05E+00	1.29E+01	1.80E+01
ethyl benzene	10	1.53E+00	3.92E+00	5.45E+00
hexachorobutadiene	5.6	8.56E-01	2.19E+00	3.05E+00
methyl ethyl ketone	36	5.50E+00	1.41E+01	1.96E+01
methyl isobutyl ketone	33	5.05E+00	1.29E+01	1.80E+01
methylene chloride	30	4.59E+00	1.18E+01	1.63E+01
n-butyl alcohol	2.6	3.98E-01	1.02E+00	1.42E+00
nitrobenzene	14	2.14E+00	5.49E+00	7.63E+00
o-dichlorobenzene	6	9.17E-01	2.35E+00	3.27E+00
pyridine	16	2.45E+00	6.27E+00	8.71E+00
tetrachloroethylene	6	9.17E-01	2.35E+00	3.27E+00
toluene	10	1.53E+00	3.92E+00	5.45E+00
trichloroethylene	6	9.17E-01	2.35E+00	3.27E+00
trichloromonofluoromethane	30	4.59E+00	1.18E+01	1.63E+01
vinyl chloride	6	9.17E-01	2.35E+00	3.27E+00
xylenes-mixed isomers	30	4.59E+00	1.18E+01	1.63E+01
1,1,2,2-tetrachloroethane	6	9.17E-01	2.35E+00	3.27E+00
1,1-dichloroethane	6	9.17E-01	2.35E+00	3.27E+00
1,2,4-trichlorobenzene	19	2.90E+00	7.44E+00	1.03E+01
1,2-dichloropropane	18	2.75E+00	7.05E+00	9.80E+00
1,3-dichlorobenzene	6	9.17E-01	2.35E+00	3.27E+00
1,4-dichlorobenzene	6	9.17E-01	2.35E+00	3.27E+00
1,4-dioxane	170	2.60E+01	6.66E+01	9.26E+01
2-sec-butyl-4,6-dinitrophenol	2.5	3.82E-01	9.79E-01	1.36E+00
3-chloropropene	30	4.59E+00	1.18E+01	1.63E+01
acetonitrile	38	5.81E+00	1.49E+01	2.07E+01
acetophenone	9.7	1.48E+00	3.80E+00	5.28E+00
acrylonitrile	84	1.28E+01	3.29E+01	4.58E+01
aldrin	0.066	1.01E-02	2.59E-02	3.59E-02
benzo(a)pyrene	3.4	5.20E-01	1.33E+00	1.85E+00
chloroethane	6	9.17E-01	2.35E+00	3.27E+00
cis-1,3-dichoropropene	18	2.75E+00	7.05E+00	9.80E+00
cyanide	590	9.02E+01	2.31E+02	3.21E+02
dibenzo(a,h)anthracene	8.2	1.25E+00	3.21E+00	4.47E+00

Organic Compounds	LDR Treatment Standard (mg/kg)	Upper Bound Organic ILAW Inventory (MT)		
		Phase 1	Phase 2	Total
dichlorodifluoromethane	7.2	1.10E+00	2.82E+00	3.92E+00
dieldrin	0.13	1.99E-02	5.09E-02	7.08E-02
dimethylnitrosamine	2.3	3.52E-01	9.01E-01	1.25E+00
diphenylamine	13	1.99E+00	5.09E+00	7.08E+00
endrin	0.13	1.99E-02	5.09E-02	7.08E-02
ethylene dibromide	15	2.29E+00	5.88E+00	8.17E+00
heptachlor	0.066	1.01E-02	2.59E-02	3.59E-02
hexachlorobenzene	10	1.53E+00	3.92E+00	5.45E+00
hexachlorocyclohexane alpha bhc	0.066	1.01E-02	2.59E-02	3.59E-02
hexachlorocyclohexane beta bhc	0.066	1.01E-02	2.59E-02	3.59E-02
isodrin	0.066	1.01E-02	2.59E-02	3.59E-02
lindane (all isomers)	0.066	1.01E-02	2.59E-02	3.59E-02
methacrylonitrile	84	1.28E+01	3.29E+01	4.58E+01
methyl bromide	15	2.29E+00	5.88E+00	8.17E+00
methyl chloride	30	4.59E+00	1.18E+01	1.63E+01
p-dinitrobenzene	2.3	3.52E-01	9.01E-01	1.25E+00
pentachloronitrobenzene	4.8	7.34E-01	1.88E+00	2.61E+00
pentachlorophenol	7.4	1.13E+00	2.90E+00	4.03E+00
phenol	6.2	9.48E-01	2.43E+00	3.38E+00
polychlorinated biphenyls (PCB)	10	1.53E+00	3.92E+00	5.45E+00
propionitrile	360	5.50E+01	1.41E+02	1.96E+02
toxaphene	2.6	3.98E-01	1.02E+00	1.42E+00
trans-1,3-dichloropropene	18	2.75E+00	7.05E+00	9.80E+00
triethylamine	0.081	1.24E-02	3.17E-02	4.41E-02
Total		3.25E+02	8.33E+02	1.16E+03

5.0 CONCLUSIONS

Nominal and bounding inventories for radionuclides, tank chemicals, and organic chemicals for the Phase 1, Phase 2, and total ILAW processing have been generated. Uncertainties in the nominal ILAW inventory were addressed qualitatively using engineering judgement for selected components. Nominal and bounding concentrations for ILAW packages have also been generated. The bounding values and uncertainties were based on qualitative considerations and conservative assumptions since consistent quantitative uncertainty information on the tank inventories, separation factors, and process losses are not available at this time.

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Appendix A

Phase 1 and Phase 2 ILAW Inventory by Batch

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Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by_LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1	3/19/07	2007	279.5	0.32	0.00E+00	0.00E+00	2.95E+00	1.64E+01	2.64E+02	8.68E+00	3.90E+04	2.72E+00	3.41E+00	9.22E+01	2.18E-07	9.60E+01	5.34E+00	5.69E+00	2.98E-01
BATCH-2	4/2/07	194	27.9	0.33	0.00E+00	0.00E+00	5.44E-01	7.48E-01	4.88E+01	2.40E+00	1.94E+03	9.81E-01	3.30E-01	1.64E+01	4.66E-04	1.18E+00	1.12E+00	3.16E-01	5.50E-03
BATCH-3	8/19/07	194	27.9	0.33	0.00E+00	0.00E+00	5.44E-01	7.48E-01	4.88E+01	2.40E+00	1.94E+03	9.81E-01	3.30E-01	1.64E+01	4.66E-04	1.18E+00	1.12E+00	3.16E-01	5.50E-03
BATCH-4	12/28/07	1687	234.7	0.32	0.00E+00	0.00E+00	2.56E+00	4.82E+00	2.28E+02	4.70E+00	5.67E+03	2.47E+01	9.28E+00	1.06E+02	1.90E-06	7.18E+01	1.30E+01	7.77E+00	1.38E-01
BATCH-5	1/5/08	256	36.7	0.33	0.00E+00	0.00E+00	5.80E-01	8.32E-01	5.16E+01	2.51E+00	4.76E+03	1.01E+00	3.53E-01	1.75E+01	2.34E-04	2.24E+00	9.20E-01	3.85E-01	9.25E-03
BATCH-6	5/20/08	256	36.7	0.33	0.00E+00	0.00E+00	5.80E-01	8.32E-01	5.16E+01	2.51E+00	4.76E+03	1.01E+00	3.53E-01	1.75E+01	2.34E-04	2.24E+00	9.20E-01	3.85E-01	9.25E-03
BATCH-7	8/24/08	1747	242.9	0.32	0.00E+00	0.00E+00	2.64E+00	4.15E+00	2.34E+02	4.79E+00	5.41E+02	2.60E+01	9.27E+00	1.10E+02	1.01E-06	7.04E+01	1.06E+01	8.10E+00	1.40E-01
BATCH-8	9/16/08	224	32.1	0.33	0.00E+00	0.00E+00	5.82E-01	7.70E-01	5.18E+01	2.49E+00	3.19E+03	1.21E+00	4.09E-01	1.78E+01	2.34E-04	2.22E+00	9.80E-01	4.14E-01	8.25E-03
BATCH-9	12/31/08	46	6.6	0.33	0.00E+00	0.00E+00	6.30E-02	1.44E-01	5.57E+00	1.96E-01	9.23E+02	2.75E-01	1.09E-01	2.16E+00	1.06E-05	1.14E+00	1.50E-01	1.13E-01	3.00E-03
BATCH-10	2/6/09	335	48.1	0.33	0.00E+00	0.00E+00	2.89E-01	8.36E-01	2.55E+01	2.76E+00	5.94E+03	2.00E+00	9.00E-01	3.34E+01	3.03E-04	4.75E+00	1.06E+00	1.98E+00	2.40E-02
BATCH-11	4/28/09	1637	226.2	0.32	0.00E+00	0.00E+00	7.98E-01	3.77E+01	7.07E+01	6.76E+00	3.15E+04	4.89E+00	2.64E+00	6.24E+01	2.03E-08	2.06E+01	2.54E+00	1.80E+00	2.27E-01
BATCH-12	5/31/09	333	47.7	0.33	0.00E+00	0.00E+00	2.73E-01	1.12E+00	2.41E+01	2.76E+00	5.58E+03	1.95E+00	8.82E-01	3.31E+01	3.04E-04	4.27E+00	1.04E+00	1.94E+00	2.40E-02
BATCH-13	9/21/09	333	47.7	0.33	0.00E+00	0.00E+00	2.73E-01	1.12E+00	2.41E+01	2.76E+00	5.58E+03	1.95E+00	8.82E-01	3.31E+01	3.04E-04	4.27E+00	1.04E+00	1.94E+00	2.40E-02
BATCH-14	12/17/09	1702	235.6	0.32	0.00E+00	0.00E+00	7.18E-01	4.17E+01	6.38E+01	7.16E+00	3.28E+04	4.46E+00	2.56E+00	6.33E+01	3.01E-09	1.83E+01	2.46E+00	1.57E+00	2.41E-01
BATCH-15	1/12/10	334	47.9	0.33	0.00E+00	0.00E+00	2.72E-01	1.03E+00	2.38E+01	2.77E+00	5.59E+03	1.93E+00	8.35E-01	3.32E+01	1.53E-04	4.05E+00	8.06E-01	1.93E+00	2.43E-02
BATCH-16	5/6/10	334	34.8	0.24	0.00E+00	0.00E+00	2.72E-01	1.03E+00	2.38E+01	2.77E+00	5.59E+03	1.93E+00	8.35E-01	3.32E+01	1.53E-04	4.05E+00	8.06E-01	1.93E+00	2.43E-02
BATCH-17	7/6/10	1661	167.9	0.23	0.00E+00	0.00E+00	5.03E+00	1.94E+00	4.40E+02	9.14E+00	5.74E+03	4.81E+01	1.56E+01	1.60E+02	4.24E-07	1.18E+02	1.11E+01	1.51E+01	8.84E-01
BATCH-18	8/27/10	335	34.9	0.24	0.00E+00	0.00E+00	2.70E-01	1.09E+00	2.37E+01	2.78E+00	5.72E+03	1.92E+00	8.31E-01	3.34E+01	1.53E-04	4.01E+00	8.03E-01	1.93E+00	2.45E-02
BATCH-19	12/19/10	335	34.9	0.24	0.00E+00	0.00E+00	2.70E-01	1.09E+00	2.37E+01	2.78E+00	5.72E+03	1.92E+00	8.31E-01	3.34E+01	1.53E-04	4.01E+00	8.03E-01	1.93E+00	2.45E-02
BATCH-20	12/25/10	1708	172.6	0.23	0.00E+00	0.00E+00	5.30E+00	8.20E-01	4.64E+02	9.44E+00	2.70E+03	5.08E+01	1.65E+01	1.65E+02	4.50E-07	1.24E+02	1.17E+01	1.59E+01	9.29E-01
BATCH-21	4/8/11	245	25.6	0.24	0.00E+00	0.00E+00	2.07E-01	7.17E-01	1.80E+01	1.99E+00	4.07E+03	1.51E+00	6.07E-01	2.44E+01	5.40E-05	3.08E+00	4.70E-01	1.41E+00	2.03E-02
BATCH-22	6/20/11	1367	137.3	0.23	0.00E+00	0.00E+00	9.22E-01	1.44E+00	7.99E+01	5.32E+00	1.35E+04	6.14E+00	2.52E+00	1.31E+02	1.43E-08	1.79E+01	1.36E+00	2.04E+00	1.83E-01
BATCH-23	7/1/11	282	29.5	0.24	0.00E+00	0.00E+00	2.38E-01	1.02E+00	2.07E+01	8.42E-01	5.65E+03	1.81E+00	5.99E-01	2.81E+01	5.38E-05	4.31E+00	2.29E+00	7.54E-01	2.38E-02
BATCH-24	11/7/11	1005	98.1	0.23	0.00E+00	0.00E+00	4.72E-01	1.68E+00	4.10E+01	3.76E+00	8.77E+03	2.64E+00	1.31E+00	9.37E+01	1.50E-09	9.04E+00	6.81E-01	9.17E-01	1.17E-01
BATCH-25	1/12/12	282	29.4	0.24	0.00E+00	0.00E+00	2.36E-01	8.72E-01	2.03E+01	8.41E-01	5.65E+03	1.79E+00	5.62E-01	2.81E+01	2.71E-05	4.06E+00	1.78E+00	7.46E-01	2.35E-02
BATCH-26	2/18/12	1769	179.0	0.23	0.00E+00	0.00E+00	3.21E+00	1.52E+00	2.76E+02	4.95E+00	2.56E+03	2.54E+01	7.51E+00	1.71E+02	9.37E-08	5.51E+01	4.07E+00	8.04E+00	8.66E-01
BATCH-27	7/26/12	283	29.5	0.24	0.00E+00	0.00E+00	2.34E-01	8.61E-01	2.02E+01	8.42E-01	5.65E+03	1.77E+00	5.57E-01	2.82E+01	2.71E-05	4.02E+00	1.78E+00	7.41E-01	2.33E-02
BATCH-28	8/20/12	2146	217.9	0.23	0.00E+00	0.00E+00	3.93E+00	1.83E+00	3.38E+02	5.76E+00	2.53E+03	3.09E+01	9.08E+00	2.08E+02	1.17E-07	6.65E+01	4.98E+00	9.75E+00	1.08E+00
BATCH-29	2/6/13	282	29.5	0.24	0.00E+00	0.00E+00	2.37E-01	7.31E-01	2.02E+01	8.35E-01	5.65E+03	1.78E+00	5.32E-01	2.81E+01	1.36E-05	3.85E+00	1.39E+00	7.45E-02	2.45E-02
BATCH-30	3/28/13	1986	200.8	0.23	0.00E+00	0.00E+00	3.00E-03	2.83E+01	3.45E+01	4.35E+01	1.00E-02	1.30E-02	6.32E+00	1.16E-04	1.34E-05	1.50E-02	2.54E+02	0.00E+00	1.20E+00
BATCH-31	8/20/13	276	28.8	0.24	0.00E+00	0.00E+00	2.40E-01	6.72E-01	2.05E+01	8.12E-01	5.53E+03	1.83E+00	5.40E-01	2.75E+01	1.36E-05	3.89E+00	1.40E+00	7.58E-01	2.95E-02
BATCH-32	10/15/13	1512	152.4	0.23	0.00E+00	0.00E+00	3.05E+00	5.37E+00	2.61E+02	5.61E+00	1.58E+03	3.01E+01	8.36E+00	1.46E+02	5.44E-08	6.18E+01	4.25E+00	9.50E+00	1.21E+00
BATCH-33	2/27/14	176	18.3	0.24	0.00E+00	0.00E+00	1.59E-01	3.83E-01	1.35E+01	5.18E-01	3.52E+03	1.24E+00	3.46E-01	1.75E+01	4.05E-06	2.52E+00	6.60E-01	4.99E-01	2.28E-02
BATCH-34	3/21/14	1638	165.5	0.23	0.00E+00	0.00E+00	3.32E+00	5.31E+00	2.82E+02	6.16E+00	1.67E+03	3.30E+01	8.71E+00	1.58E+02	3.00E-08	6.46E+01	3.65E+00	1.04E+01	1.34E+00
BATCH-35	6/25/14	244	25.5	0.24	0.00E+00	0.00E+00	3.50E-01	4.37E-01	2.96E+01	1.29E+00	4.89E+03	2.13E+00	5.62E-01	2.43E+01	6.95E-07	4.37E+00	1.62E-01	1.15E+00	2.58E-02
BATCH-36	9/6/14	1515	151.9	0.23	0.00E+00	0.00E+00	2.53E+00	3.07E+00	2.13E+02	3.56E+00	2.91E+04	1.92E+01	5.05E+00	1.45E+02	6.20E-06	3.86E+01	1.35E+00	8.30E+00	1.75E-01
BATCH-37	9/11/14	244	25.5	0.24	0.00E+00	0.00E+00	3.51E-01	4.37E-01	2.96E+01	1.29E+00	4.88E+03	2.13E+00	5.64E-01	2.43E+01	6.98E-07	4.38E+00	1.63E-01	1.15E+00	2.60E-02
BATCH-38	11/29/14	244	25.5	0.24	0.00E+00	0.00E+00	3.51E-01	4.37E-01	2.96E+01	1.29E+00	4.88E+03	2.13E+00	5.64E-01	2.43E+01	6.98E-07	4.38E+00	1.63E-01	1.15E+00	2.60E-02
BATCH-39	2/9/15	1830	184.7	0.23	0.00E+00	0.00E+00	2.07E+00	2.11E+00	1.74E+02	3.89E+00	3.34E+04	1.55E+01	3.54E+00	1.76E+02	1.20E-05	4.97E+01	1.39E+00	1.28E+01	2.46E-01
BATCH-40	2/16/15	244	25.5	0.24	0.00E+00	0.00E+00	3.52E-01	3.82E-01	2.95E+01	1.28E+00	4.89E+03	2.13E+00	5.35E-01	2.44E+01	3.56E-07	4.18E+00	1.26E-01	1.15E+00	2.53E-02
BATCH-41	5/6/15	244	25.5	0.24	0.00E+00	0.00E+00	3.52E-01	3.82E-01	2.95E+01	1.28E+00	4.89E+03	2.13E+00	5.35E-01	2.44E+01	3.56E-07	4.18E+00	1.26E-01	1.15E+00	2.53E-02
BATCH-42	7/23/15	244	25.5	0.24	0.00E+00	0.00E+00	3.52E-01	3.82E-01	2.95E+01	1.28E+00	4.89E+03	2.13E+00	5.35E-01	2.44E+01	3.56E-07	4.18E+00	1.26E-01	1.15E+00	2.53E-02
BATCH-43	8/18/15	1827	184.4	0.23	0.00E+00	0.00E+00	2.04E+00	2.07E+00	1.71E+02	3.87E+00	3.18E+04	1.52E+01	3.46E+00	1.76E+02	1.22E-05	4.98E+01	1.39E+00	1.29E+01	2.47E-01
BATCH-44	10/8/15	192	20.1	0.24	0.00E+00	0.00E+00	2.75E-01	3.01E-01	2.30E+01	9.85E-01	3.85E+03	1.69E+00	4.24E-01	1.92E+01	2.88E-07	3.34E+00	1.02E-01	9.08E-01	2.13E-02
BATCH-45	12/9/15	241	25.1	0.24	0.00E+00	0.00E+00	3.30E-01	3.65E-01	2.77E+01	1.30E+00	4.81E+03	2.04E+00	5.17E-01	2.40E+01	3.25E-07	4.06E+00	2.78E-01	1.14E+00	2.50E-02
BATCH-46	2/22/16	1616	162.2	0.23	0.00E+00	0.00E+00	3.50E+00	3.53E+00	2.91E+02	4.89E+00	3.11E+04	2.75E+01	6.50E+00	1.55E+02	2.59E-07	5.16E+01	1.26E+00	8.83E+00	1.94E-01
BATCH-47	2/25/16	241	25.2	0.24	0.00E+00	0.00E+00	3.29E-01	3.18E-01	2.74E+01	1.30E+00	4.83E+03	2.03E+00	4.87E-01	2.41E+01	1.72E-07	3.88E+00	2.16E-01	1.14E+00	2.40E-02
BATCH-48	5/14/16	241	25.2	0.24	0.00E+00	0.00E+00	3.29E-01	3.18E-01	2.74E+01	1.30E+00	4.83E+03	2.03E+00	4.87E-01	2.41E+01	1.72E-07	3.88E+00	2.16E-01	1.14E+00	2.40E-02
BATCH-49	7/31/16	241	25.2	0.24	0.00E+00	0.00E+00	3.29E-01	3.18E-01	2.74E+01	1.30E+00	4.83E+03	2.03E+00	4.87E-01	2.41E+01	1.72E-07	3.88E+00	2.16E-01	1.14E+00	2.40E-02

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1	3/19/07	2007	279.5	0.32	1.55E-03	5.84E+03	1.06E+02	2.20E-02	2.21E+00	4.22E-01	1.47E-04	5.55E-06	1.49E-01	2.52E-04	6.11E-04	1.00E-03	1.70E-02	3.80E-02	1.60E-02
BATCH-2	4/22/07	194	27.9	0.33	4.18E-04	5.83E+02	2.37E+02	2.00E-01	1.33E+01	5.04E+00	4.00E+00	1.35E-05	8.12E-04	7.35E-05	2.40E-04	2.42E-04	1.20E-02	5.50E-02	4.50E-02
BATCH-3	8/19/07	194	27.9	0.33	4.13E-04	5.83E+02	2.37E+02	2.00E-01	1.33E+01	5.04E+00	4.00E+00	1.35E-05	8.12E-04	7.35E-05	2.40E-04	2.42E-04	1.20E-02	5.50E-02	4.50E-02
BATCH-4	12/28/07	1687	234.7	0.32	3.61E-03	4.91E+03	1.61E+04	3.33E+00	5.65E+01	1.59E+02	2.08E-04	8.41E-04	1.23E-01	1.10E-02	6.00E-03	4.90E-02	7.10E-02	3.08E-01	9.00E-02
BATCH-5	1/5/08	256	36.7	0.33	3.10E-04	7.67E+02	2.36E+02	1.91E-01	1.23E+01	4.39E+00	3.99E+00	1.32E-05	2.00E-03	7.65E-05	2.47E-04	2.56E-04	1.20E-02	5.50E-02	4.50E-02
BATCH-6	5/20/08	256	36.7	0.33	3.10E-04	7.67E+02	2.36E+02	1.91E-01	1.23E+01	4.39E+00	3.99E+00	1.32E-05	2.00E-03	7.65E-05	2.47E-04	2.56E-04	1.20E-02	5.50E-02	4.50E-02
BATCH-7	8/24/08	1747	242.9	0.32	2.72E-03	5.08E+03	1.69E+04	3.35E+00	5.48E+01	1.47E+02	2.17E-04	8.62E-04	1.14E-01	1.10E-02	6.00E-03	5.10E-02	7.20E-02	3.17E-01	9.40E-02
BATCH-8	9/16/08	224	32.1	0.33	3.25E-04	6.71E+02	3.76E+02	2.18E-01	1.27E+01	5.60E+00	3.99E+00	2.03E-05	2.00E-03	1.68E-04	2.93E-04	6.74E-04	1.30E-02	5.80E-02	4.60E-02
BATCH-9	12/31/08	46	6.6	0.33	4.13E-05	1.38E+02	1.51E+02	3.60E-02	1.02E+00	1.41E+00	1.80E-01	7.75E-06	2.00E-03	9.74E-05	6.40E-05	4.42E-04	1.00E-03	5.00E-03	3.00E-03
BATCH-10	2/6/09	335	48.1	0.33	4.54E-04	1.01E+03	1.03E+03	2.75E-01	1.99E+01	8.18E+00	1.23E+01	5.37E-05	5.00E-03	4.31E-04	4.42E-04	2.00E-03	4.40E-02	1.99E-01	9.30E-02
BATCH-11	4/28/09	1637	226.2	0.32	7.33E-04	4.73E+03	6.26E+02	1.19E-01	1.93E+00	4.75E+00	6.30E-05	3.12E-05	3.10E-02	5.02E-04	3.00E-03	2.00E-03	5.00E-03	2.20E-02	6.00E-03
BATCH-12	5/31/09	333	47.7	0.33	4.49E-04	9.98E+02	9.80E+02	2.67E-01	1.98E+01	7.83E+00	1.23E+01	5.13E-05	4.00E-03	4.00E-04	4.47E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-13	9/21/09	333	47.7	0.33	4.49E-04	9.98E+02	9.80E+02	2.67E-01	1.98E+01	7.83E+00	1.23E+01	5.13E-05	4.00E-03	4.00E-04	4.47E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-14	12/17/09	1702	235.6	0.32	7.28E-04	4.93E+03	9.75E+01	1.80E-02	2.96E-01	7.40E-01	5.87E-05	4.85E-06	2.70E-02	1.54E-04	3.00E-03	7.06E-04	3.00E-03	1.30E-02	3.00E-03
BATCH-15	1/12/10	334	47.9	0.33	3.20E-04	1.00E+03	9.59E+02	2.51E-01	1.82E+01	6.72E+00	1.23E+01	4.91E-05	4.00E-03	3.91E-04	4.47E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-16	5/6/10	334	34.8	0.24	3.20E-04	1.00E+03	9.59E+02	2.51E-01	1.82E+01	6.72E+00	1.23E+01	4.91E-05	4.00E-03	3.91E-04	4.47E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-17	7/6/10	1661	167.9	0.23	2.27E-03	4.83E+03	3.08E+04	5.40E+00	3.17E+01	4.06E+01	4.12E-04	2.00E-03	1.76E-01	2.10E-02	1.10E-02	9.60E-02	4.40E-02	2.00E-01	4.70E-02
BATCH-18	8/27/10	335	34.9	0.24	3.20E-04	1.00E+03	9.44E+02	2.48E-01	1.82E+01	6.63E+00	1.23E+01	4.84E-05	4.00E-03	3.81E-04	4.46E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-19	12/19/10	335	34.9	0.24	3.20E-04	1.00E+03	9.44E+02	2.48E-01	1.82E+01	6.63E+00	1.23E+01	4.84E-05	4.00E-03	3.81E-04	4.46E-04	2.00E-03	4.40E-02	1.98E-01	9.30E-02
BATCH-20	12/25/10	1708	172.6	0.23	2.38E-03	4.96E+03	3.27E+04	5.72E+00	3.30E+01	4.29E+01	4.35E-04	2.00E-03	1.86E-01	2.20E-02	1.20E-02	1.01E-01	4.50E-02	2.04E-01	4.60E-02
BATCH-21	4/8/11	245	25.6	0.24	1.65E-04	7.36E+02	7.59E+02	1.83E-01	1.19E+01	4.20E+00	8.65E+00	3.78E-05	3.00E-03	3.38E-04	3.54E-04	1.00E-03	3.00E-02	1.40E-01	6.50E-02
BATCH-22	6/20/11	1367	137.3	0.23	1.96E-04	3.95E+03	2.10E+03	3.40E-01	1.54E+01	3.57E+00	7.09E-05	1.06E-04	1.50E-02	1.00E-03	3.00E-03	4.00E-03	5.90E-02	2.67E-01	8.10E-02
BATCH-23	7/1/11	282	29.5	0.24	2.76E-03	8.47E+02	1.11E+03	1.78E-01	1.41E+01	4.88E+00	7.19E+00	5.56E-05	3.00E-03	4.39E-04	4.61E-04	2.00E-03	4.20E-02	1.95E-01	1.09E-01
BATCH-24	11/7/11	1005	98.1	0.23	7.23E-05	2.82E+03	2.69E+02	4.10E-02	3.39E+00	5.23E-01	3.63E-05	1.36E-05	7.00E-03	1.10E-04	2.00E-03	3.69E-04	1.10E-02	5.30E-02	1.80E-02
BATCH-25	1/12/12	282	29.4	0.24	1.97E-03	8.47E+02	1.09E+03	1.66E-01	1.30E+01	4.21E+00	7.19E+00	5.31E-05	3.00E-03	4.27E-04	4.57E-04	2.00E-03	4.20E-02	1.96E-01	1.09E-01
BATCH-26	2/18/12	1769	179.0	0.23	9.60E-04	5.15E+03	1.61E+04	2.68E+00	5.71E+01	9.07E+01	2.45E-04	8.46E-04	7.00E-02	1.00E-02	4.40E-02	4.60E-02	2.08E-01	7.30E-02	
BATCH-27	7/26/12	283	29.5	0.24	1.97E-03	8.48E+02	1.07E+03	1.64E-01	1.30E+01	4.19E+00	7.19E+00	5.25E-05	3.00E-03	4.17E-04	4.54E-04	2.00E-03	4.20E-02	1.96E-01	1.09E-01
BATCH-28	8/20/12	2146	217.9	0.23	1.20E-03	6.27E+03	1.97E+04	3.28E+00	7.28E+01	1.16E+02	2.99E-04	1.00E-03	8.50E-02	1.30E-02	7.00E-03	5.30E-02	5.70E-02	2.57E-01	9.10E-02
BATCH-29	2/6/13	282	29.5	0.24	1.41E-03	8.47E+02	1.08E+03	1.58E-01	1.21E+01	3.79E+00	7.19E+00	5.16E-05	3.00E-03	4.24E-04	4.55E-04	2.00E-03	4.20E-02	1.96E-01	1.09E-01
BATCH-30	3/28/13	1986	200.8	0.23	4.19E-01	1.00E-03	1.86E+00	1.45E+00	1.35E+02	5.04E+01	1.47E-06	3.06E-08	1.41E-11	3.55E-08	2.07E-07	4.88E-10	1.00E-03	5.00E-03	2.31E-01
BATCH-31	8/20/13	276	28.8	0.24	1.41E-03	8.29E+02	1.12E+03	1.64E-01	1.23E+01	4.15E+00	7.19E+00	5.40E-05	3.00E-03	4.48E-04	4.57E-04	2.00E-03	4.30E-02	2.00E-01	1.12E-01
BATCH-32	10/15/13	1512	152.4	0.23	9.29E-04	4.38E+03	1.90E+04	2.88E+00	4.50E+01	6.40E+01	2.67E-04	9.25E-04	7.70E-02	1.30E-02	7.00E-03	5.30E-02	1.94E-01	8.91E-01	5.16E-01
BATCH-33	2/27/14	176	18.3	0.24	5.99E-04	5.28E+02	7.53E+02	1.06E-01	6.94E+00	2.42E+00	4.26E+00	3.55E-05	2.00E-03	3.30E-04	3.10E-04	1.00E-03	2.60E-02	1.21E-01	6.80E-02
BATCH-34	3/21/14	1638	165.5	0.23	7.69E-04	4.76E+03	2.07E+04	2.99E+00	4.48E+01	5.99E+01	2.92E-04	9.81E-04	7.60E-02	1.40E-02	8.00E-03	5.90E-02	2.16E-01	1.00E+00	5.84E-01
BATCH-35	6/25/14	244	25.5	0.24	1.55E-05	7.33E+02	1.29E+03	1.82E-01	1.30E+01	2.21E+00	9.28E-01	6.11E-05	3.00E-03	5.22E-04	2.00E-03	2.00E-03	5.70E-02	2.65E-01	1.15E-01
BATCH-36	9/6/14	1515	151.9	0.23	9.29E-05	4.37E+03	1.18E+04	1.62E+00	1.31E+02	1.75E+01	8.60E+00	5.58E-04	2.10E-02	4.00E-03	5.00E-03	1.30E-02	5.80E-01	2.70E+00	1.17E+00
BATCH-37	9/11/14	244	25.5	0.24	1.55E-05	7.33E+02	1.30E+03	1.83E-01	1.31E+01	2.21E+00	9.32E-01	6.14E-05	3.00E-03	5.24E-04	2.00E-03	5.80E-02	2.67E-01	1.16E-01	
BATCH-38	11/29/14	244	25.5	0.24	1.55E-05	7.33E+02	1.30E+03	1.83E-01	1.31E+01	2.21E+00	9.32E-01	6.14E-05	3.00E-03	5.24E-04	2.00E-03	5.80E-02	2.67E-01	1.16E-01	
BATCH-39	2/9/15	1830	184.7	0.23	2.32E-04	5.31E+03	7.05E+03	9.41E-01	7.52E+01	1.72E+01	3.31E+01	3.22E-04	3.20E-02	3.00E-03	3.00E-03	1.30E-02	2.62E-01	1.23E+00	4.40E-01
BATCH-40	2/16/15	244	25.5	0.24	1.03E-05	7.33E+02	1.29E+03	1.74E-01	1.22E+01	1.90E+00	9.45E-01	5.95E-05	2.00E-03	5.18E-04	2.00E-03	2.00E-03	5.80E-02	2.71E-01	1.18E-01
BATCH-41	5/6/15	244	25.5	0.24	1.03E-05	7.33E+02	1.29E+03	1.74E-01	1.22E+01	1.90E+00	9.45E-01	5.95E-05	2.00E-03	5.18E-04	2.00E-03	2.00E-03	5.80E-02	2.71E-01	1.18E-01
BATCH-42	7/23/15	244	25.5	0.24	1.03E-05	7.33E+02	1.29E+03	1.74E-01	1.22E+01	1.90E+00	9.45E-01	5.95E-05	2.00E-03	5.18E-04	2.00E-03	2.00E-03	5.80E-02	2.71E-01	1.18E-01
BATCH-43	8/18/15	1827	184.4	0.23	2.37E-04	5.30E+03	6.82E+03	9.11E-01	7.29E+01	1.72E+01	3.37E+01	3.11E-04	3.20E-02	3.00E-03	3.00E-03	1.30E-02	2.49E-01	1.17E+00	4.10E-01
BATCH-44	10/8/15	192	20.1	0.24	1.03E-05	5.77E+02	1.02E+03	1.37E-01	9.41E+00	1.55E+00	7.67E-01	4.70E-05	2.00E-03	4.18E-04	1.00E-03	1.00E-03	4.40E-02	2.08E-01	9.00E-02
BATCH-45	12/9/15	241	25.1	0.24	3.97E-04	7.22E+02	1.24E+03	1.70E-01	1.22E+01	1.95E+00	8.60E-01	5.72E-05	2.00E-03	4.96E-04	2.00E-03	2.00E-03	5.60E-02	2.63E-01	1.14E-01
BATCH-46	2/22/16	1616	162.2	0.23	8.78E-05	4.66E+03	1.66E+04	2.20E+00	1.70E+02	1.84E+01	1.40E+00	7.32E-04	2.90E-02	6.00E-03	7.00E-03	2.20E-02	9.55E-01	4.53E+00	1.23E+00
BATCH-47	2/25/16	241	25.2	0.24	2.84E-04	7.24E+02	1.22E+03	1.60E-01	1.13E+01	1.67E+00	9.08E-01	5.48E-05	2.00E-03	4.87E-04	2.00E-03	2.00E-03	5.60E-02	2.63E-01	1.14E-01
BATCH-48	5/14/16	241	25.2	0.24	2.84E-04	7.24E+02	1.22E+03	1.60E-01	1.13E+01	1.67E+00	9.08E-01	5.48E-05	2.00E-03	4.87E-04	2.00E-03	2.00E-03	5.60E-02	2.63E-01	1.14E-01
BATCH-49	7/31/16	241	25.2	0.24	2.84E-04	7.24E+02	1.22E+03	1.60E-01	1.13E+01	1.67E+00	9.08E-01	5.48E-05	2.00E-03	4.87E-04	2.00E-03	2.00E-03	5.60E-02	2.63E-01	1.14E-01

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1	3/19/07	2007	279.5	0.32	6.38E-04	8.40E-04	3.20E-02	2.24E-01	1.50E-02	1.14E+02	1.32E+00	1.49E+03	9.71E+00	3.66E-11	9.51E-05	2.00E-03	1.00E-03	1.00E-02	1.09E-04
BATCH-2	4/2/07	194	27.9	0.33	2.00E-03	3.00E-03	6.00E-02	9.14E-01	3.90E-02	1.95E+01	4.05E+00	9.20E+00	3.65E+01	6.77E-12	5.18E-04	1.86E-04	1.50E-02	1.69E-01	1.00E-03
BATCH-3	8/19/07	194	27.9	0.33	2.00E-03	3.00E-03	6.00E-02	9.14E-01	3.90E-02	1.95E+01	4.05E+00	9.20E+00	3.65E+01	6.77E-12	5.18E-04	1.85E-04	1.50E-02	1.69E-01	1.00E-03
BATCH-4	12/28/07	1687	234.7	0.32	4.00E-03	5.00E-03	1.61E-01	1.58E-01	7.30E-02	2.84E+00	2.43E-01	3.44E+01	7.77E+00	9.33E-11	6.75E-05	1.00E-03	1.14E-01	2.27E+00	1.68E-01
BATCH-5	1/5/08	256	36.7	0.33	2.00E-03	3.00E-03	6.10E-02	9.09E-01	3.90E-02	2.09E+01	4.06E+00	2.74E+01	3.49E+01	1.53E-12	5.19E-04	2.13E-04	1.50E-02	1.63E-01	1.00E-03
BATCH-6	5/20/08	256	36.7	0.33	2.00E-03	3.00E-03	6.10E-02	9.09E-01	3.90E-02	2.09E+01	4.06E+00	2.74E+01	3.49E+01	1.53E-12	5.19E-04	2.13E-04	1.50E-02	1.63E-01	1.00E-03
BATCH-7	8/24/08	1747	242.9	0.32	4.00E-03	5.00E-03	1.68E-01	1.59E-01	7.50E-02	4.02E+01	2.13E+01	3.51E+00	7.55E+00	2.07E-11	6.84E-05	1.00E-03	1.18E-01	2.32E+00	1.78E-01
BATCH-8	9/16/08	224	32.1	0.33	2.00E-03	3.00E-03	6.20E-02	9.09E-01	4.00E-02	2.01E+01	4.06E+00	1.74E+01	3.49E+01	1.65E-12	5.19E-04	2.09E-04	1.60E-02	1.82E-01	3.00E-03
BATCH-9	12/31/08	46	6.6	0.33	1.14E-04	1.74E-04	4.00E-03	4.40E-02	2.00E-03	1.52E+00	1.92E-01	8.65E+00	1.69E+00	2.80E-13	2.45E-05	3.18E-05	2.00E-03	2.70E-02	2.00E-03
BATCH-10	2/6/09	335	48.1	0.33	4.00E-03	4.00E-03	1.65E-01	3.18E-01	8.90E-02	5.98E+00	1.08E+00	6.28E+01	6.25E+00	7.02E-13	2.82E-04	4.00E-03	3.70E-02	3.56E-01	3.00E-03
BATCH-11	4/28/09	1637	226.2	0.32	2.32E-04	2.79E-04	9.00E-03	1.77E-01	5.00E-03	1.19E+01	1.78E-01	2.40E+02	1.37E+00	2.69E-12	1.46E-05	4.46E-04	4.00E-03	6.11E-01	7.00E-03
BATCH-12	5/31/09	333	47.7	0.33	4.00E-03	4.00E-03	1.65E-01	3.18E-01	8.90E-02	5.48E+00	1.08E+00	5.71E+01	6.20E+00	7.05E-13	2.81E-04	4.00E-03	3.70E-02	3.55E-01	3.00E-03
BATCH-13	9/21/09	333	47.7	0.33	4.00E-03	4.00E-03	1.65E-01	3.18E-01	8.90E-02	5.48E+00	1.08E+00	5.71E+01	6.20E+00	7.05E-13	2.81E-04	4.00E-03	3.70E-02	3.55E-01	3.00E-03
BATCH-14	12/17/09	1702	235.6	0.32	1.11E-04	1.09E-04	3.00E-03	1.86E-01	2.00E-03	1.02E+01	1.56E-01	2.28E+02	1.03E+00	2.81E-12	1.13E-05	3.90E-04	7.34E-04	6.04E-01	1.00E-03
BATCH-15	1/12/10	334	47.9	0.33	4.00E-03	4.00E-03	1.65E-01	3.15E-01	8.90E-02	5.50E+00	1.08E+00	5.74E+01	5.90E+00	1.50E-13	2.81E-04	4.00E-03	3.60E-02	3.41E-01	3.00E-03
BATCH-16	5/6/10	334	34.8	0.24	4.00E-03	4.00E-03	1.65E-01	3.15E-01	8.90E-02	5.50E+00	1.08E+00	5.74E+01	5.90E+00	1.50E-13	2.81E-04	4.00E-03	3.60E-02	3.41E-01	3.00E-03
BATCH-17	7/6/10	1661	167.9	0.23	2.00E-03	2.00E-03	1.20E-01	1.06E-01	4.00E-02	7.68E-01	1.75E-01	8.90E+00	3.69E+00	2.15E-13	5.78E-05	2.31E-04	3.80E-02	2.20E-01	1.91E-01
BATCH-18	8/27/10	335	34.9	0.24	4.00E-03	4.00E-03	1.64E-01	3.15E-01	8.90E-02	5.50E+00	1.08E+00	5.76E+01	5.90E+00	1.50E-13	2.81E-04	4.00E-03	3.60E-02	3.40E-01	2.00E-03
BATCH-19	12/19/10	335	34.9	0.24	4.00E-03	4.00E-03	1.64E-01	3.15E-01	8.90E-02	5.50E+00	1.08E+00	5.76E+01	5.90E+00	1.50E-13	2.81E-04	4.00E-03	3.60E-02	3.40E-01	2.00E-03
BATCH-20	12/25/10	1708	172.6	0.23	2.00E-03	2.00E-03	1.23E-01	9.20E-02	3.90E-02	2.20E-01	1.18E-01	7.09E-01	3.73E+00	2.00E-13	4.05E-05	2.25E-04	3.90E-02	1.90E-01	2.03E-01
BATCH-21	4/8/11	245	25.6	0.24	3.00E-03	3.00E-03	1.16E-01	2.20E-01	6.30E-02	3.88E+00	7.56E-01	4.08E+01	3.96E+00	2.28E-14	1.97E-04	3.00E-03	2.50E-02	2.32E-01	2.00E-03
BATCH-22	6/20/11	1367	137.3	0.23	3.00E-03	3.00E-03	1.07E-01	1.29E-01	9.20E-02	5.23E+00	8.92E-01	1.51E+01	4.37E+00	3.36E-13	5.43E-05	3.79E-04	7.00E-03	5.20E-02	6.00E-03
BATCH-23	7/1/11	282	29.5	0.24	4.00E-03	6.00E-03	1.48E-01	4.67E-01	1.03E-01	7.46E+00	1.74E+00	3.01E+01	9.81E+00	1.01E-13	5.12E-04	2.00E-03	4.50E-02	5.65E-01	4.00E-03
BATCH-24	11/7/11	1005	98.1	0.23	7.29E-04	5.54E-04	3.00E-02	9.30E-02	2.00E-02	2.16E+00	4.14E-01	1.69E+01	1.20E+00	2.25E-13	1.13E-04	1.88E-04	1.10E-02	1.60E-01	2.38E-04
BATCH-25	1/12/12	282	29.4	0.24	4.00E-03	6.00E-03	1.48E-01	4.64E-01	1.03E-01	7.46E+00	1.74E+00	2.99E+01	9.35E+00	2.16E-14	5.12E-04	2.00E-03	4.30E-02	5.43E-01	4.00E-03
BATCH-26	2/18/12	1769	179.0	0.23	3.00E-03	4.00E-03	1.14E+01	1.98E-01	5.70E-02	4.01E+00	4.30E-02	9.14E+00	7.90E+00	1.66E-14	9.46E-05	6.05E-04	3.00E-03	2.10E-02	6.00E-03
BATCH-27	7/26/12	283	29.5	0.24	4.00E-03	6.00E-03	1.48E-01	4.64E-01	1.03E-01	7.46E+00	1.74E+00	2.98E+01	9.35E+00	2.17E-14	5.12E-04	2.00E-03	4.30E-02	5.42E-01	4.00E-03
BATCH-28	8/20/12	2146	217.9	0.23	4.00E-03	5.00E-03	1.48E+01	2.46E-01	7.10E-02	5.03E+00	1.80E-02	1.05E+01	1.00E+01	1.73E-14	1.12E-04	7.61E-04	2.00E-03	8.00E-03	1.66E-04
BATCH-29	2/6/13	282	29.5	0.24	4.00E-03	6.00E-03	1.76E-01	4.60E-01	1.03E-01	7.45E+00	1.74E+00	2.95E+01	8.92E+00	4.58E-15	5.12E-04	2.00E-03	4.20E-02	5.21E-01	3.00E-03
BATCH-30	3/28/13	1986	200.8	0.23	9.00E-03	1.90E-02	7.22E-08	5.34E+00	1.59E-01	4.06E-06	1.02E+01	1.34E-04	1.50E+02	5.06E-13	3.00E-03	4.56E-01	3.39E-01	6.51E+00	0.00E+00
BATCH-31	8/20/13	276	28.8	0.24	4.00E-03	6.00E-03	2.05E-01	4.72E-01	1.05E-01	7.42E+00	1.77E+00	2.86E+01	9.50E+00	4.56E-15	5.17E-04	2.00E-03	4.20E-02	5.23E-01	3.00E-03
BATCH-32	10/15/13	1512	152.4	0.23	2.00E-02	3.60E-02	1.88E+00	2.11E+00	3.84E-01	3.13E+00	6.58E+00	2.35E+01	9.82E+01	7.06E-15	9.38E-04	2.00E-03	5.90E-02	1.08E+00	7.33E-06
BATCH-33	2/27/14	176	18.3	0.24	3.00E-03	4.00E-03	1.45E-01	2.83E-01	6.30E-02	4.42E+00	1.07E+00	1.72E+01	5.61E+00	5.82E-16	3.09E-04	9.39E-04	2.50E-02	3.02E-01	2.00E-03
BATCH-34	3/21/14	1638	165.5	0.23	2.20E-02	4.10E-02	1.54E+00	2.38E+00	4.34E-01	3.82E+00	7.49E+00	2.64E+01	1.06E+02	1.68E-15	1.00E-03	2.00E-03	6.50E-02	1.19E+00	5.12E-07
BATCH-35	6/25/14	244	25.5	0.24	5.00E-03	5.00E-03	1.48E-01	2.44E-01	1.15E-01	6.12E+00	1.18E+00	8.21E+00	8.24E+00	7.22E-16	1.16E-04	2.69E-04	4.00E-03	4.50E-02	5.55E-04
BATCH-36	9/6/14	1515	151.9	0.23	4.70E-02	5.40E-02	1.06E+00	2.18E+00	1.18E+00	5.69E+01	1.08E+01	6.89E+01	7.42E+01	5.17E-15	1.00E-03	2.00E-03	3.10E-02	2.68E-01	1.00E-03
BATCH-37	9/11/14	244	25.5	0.24	5.00E-03	5.00E-03	1.45E-01	2.46E-01	1.16E-01	6.14E+00	1.19E+00	8.19E+00	8.34E+00	7.25E-16	1.18E-04	2.71E-04	4.00E-03	4.60E-02	5.12E-04
BATCH-38	11/29/14	244	25.5	0.24	5.00E-03	5.00E-03	1.45E-01	2.46E-01	1.16E-01	6.14E+00	1.19E+00	8.19E+00	8.34E+00	7.25E-16	1.18E-04	2.71E-04	4.00E-03	4.60E-02	5.12E-04
BATCH-39	2/9/15	1830	184.7	0.23	1.80E-02	1.50E-02	1.11E+00	1.07E+00	4.76E-01	2.67E+01	4.55E+00	5.34E+01	1.75E+01	4.92E-16	5.12E-04	9.48E-04	7.20E-02	5.59E-01	3.00E-03
BATCH-40	2/16/15	244	25.5	0.24	5.00E-03	5.00E-03	1.42E-01	2.46E-01	1.18E-01	6.23E+00	1.21E+00	8.24E+00	8.01E+00	1.55E-16	1.19E-04	2.73E-04	4.00E-03	4.40E-02	4.88E-04
BATCH-41	5/6/15	244	25.5	0.24	5.00E-03	5.00E-03	1.42E-01	2.46E-01	1.18E-01	6.23E+00	1.21E+00	8.24E+00	8.01E+00	1.55E-16	1.19E-04	2.73E-04	4.00E-03	4.40E-02	4.88E-04
BATCH-42	7/23/15	244	25.5	0.24	5.00E-03	5.00E-03	1.42E-01	2.46E-01	1.18E-01	6.23E+00	1.21E+00	8.24E+00	8.01E+00	1.55E-16	1.19E-04	2.73E-04	4.00E-03	4.40E-02	4.88E-04
BATCH-43	8/18/15	1827	184.4	0.23	1.70E-02	1.40E-02	1.10E+00	1.02E+00	4.46E-01	2.54E+01	4.29E+00	5.24E+01	1.54E+01	4.66E-16	4.90E-04	8.93E-04	7.30E-02	5.66E-01	3.00E-03
BATCH-44	10/8/15	192	20.1	0.24	4.00E-03	4.00E-03	1.16E-01	1.90E-01	9.00E-02	4.75E+00	9.25E-01	6.40E+00	6.17E+00	1.19E-16	9.13E-05	2.10E-04	3.00E-03	3.50E-02	4.20E-04
BATCH-45	12/9/15	241	25.1	0.24	5.00E-03	5.00E-03	1.37E-01	2.16E-01	1.14E-01	5.54E+00	1.06E+00	1.06E+01	7.07E+00	1.55E-16	1.01E-04	1.00E-03	4.00E-03	4.00E-02	4.17E-04
BATCH-46	2/22/16	1616	162.2	0.23	5.00E-02	3.90E-02	1.47E+00	1.97E+00	1.46E+00	7.46E+01	1.28E+01	6.83E+01	5.32E+01	3.70E-16	8.54E-04	3.00E-03	1.90E-02	1.78E-01	1.53E-04
BATCH-47	2/25/16	241	25.2	0.24	5.00E-03	5.00E-03	1.34E-01	2.14E-01	1.14E-01	5.56E+00	1.06E+00	1.06E+01	6.69E+00	3.28E-17	1.01E-04	1.00E-03	4.00E-03	3.90E-02	3.92E-04
BATCH-48	5/14/16	241	25.2	0.24	5.00E-03	5.00E-03	1.34E-01	2.14E-01	1.14E-01	5.56E+00	1.06E+00	1.06E+01	6.69E+00	3.28E-17	1.01E-04	1.00E-03	4.00E-03	3.90E-02	3.92E-04
BATCH-49	7/31/16	241	25.2	0.24	5.00E-03	5.00E-03	1.34E-01	2.14E-01	1.14E-01	5.56E+00	1.06E+00	1.06E+01	6.69E+00	3.28E-17	1.01E-04	1.00E-03	4.00E-03	3.90E-02	3.92E-04

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Losses				0.32	0.00E+00	1.18E+02	3.10E-06	0.00E+00	2.61E-04	0.00E+00	0.00E+00	3.91E+01	1.00E-03	1.42E-15	1.63E+02	0.00E+00	0.00E+00	7.80E+00	1.05E-03
BATCH-1	3/19/07	2007	279.5	0.33	1.94E+02	3.56E+01	1.00E-03	1.96E-01	7.71E-04	0.00E+00	2.00E-03	6.96E-01	1.00E-03	4.00E-03	1.98E+01	0.00E+00	3.81E+00	1.80E+00	6.36E-02
BATCH-2	4/2/07	194	27.9	0.33	1.94E+02	3.56E+01	1.00E-03	1.96E-01	7.71E-04	0.00E+00	2.00E-03	6.96E-01	1.00E-03	4.00E-03	1.98E+01	0.00E+00	3.81E+00	1.80E+00	6.36E-02
BATCH-3	8/19/07	194	27.9	0.32	0.00E+00	4.67E+03	6.62E-08	0.00E+00	5.56E-06	0.00E+00	3.34E-01	2.59E+00	3.04E-05	4.49E-16	3.86E+02	0.00E+00	0.00E+00	4.97E+01	3.91E-03
BATCH-4	12/28/07	1687	234.7	0.33	2.10E+02	3.61E+01	1.00E-03	1.96E-01	7.74E-04	0.00E+00	2.00E-03	1.18E+00	1.00E-03	4.00E-03	2.18E+01	0.00E+00	4.16E+00	1.84E+00	6.36E-02
BATCH-5	1/5/08	256	36.7	0.33	2.10E+02	3.61E+01	1.00E-03	1.96E-01	7.74E-04	0.00E+00	2.00E-03	1.18E+00	1.00E-03	4.00E-03	2.18E+01	0.00E+00	4.16E+00	1.84E+00	6.36E-02
BATCH-6	5/20/08	256	36.7	0.32	0.00E+00	4.94E+03	1.75E-09	0.00E+00	1.47E-07	0.00E+00	3.54E-01	1.88E+00	8.03E-07	1.19E-17	4.05E+02	0.00E+00	0.00E+00	5.25E+01	4.12E-03
BATCH-7	8/24/08	1747	242.9	0.33	2.21E+02	6.11E+01	1.00E-03	1.96E-01	7.72E-04	0.00E+00	5.00E-03	9.46E-01	1.00E-03	4.00E-03	2.41E+01	0.00E+00	4.22E+00	2.07E+00	6.36E-02
BATCH-8	9/16/08	224	32.1	0.33	4.90E+01	1.37E+01	6.01E-05	9.00E-03	3.63E-05	0.00E+00	3.00E-03	2.81E-01	6.50E-05	2.03E-04	5.15E+00	0.00E+00	7.50E-01	1.88E-01	2.91E-03
BATCH-9	12/31/08	46	6.6	0.33	1.67E+02	1.30E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	5.00E-03	2.10E+00	7.00E-03	1.00E-02	4.80E+01	0.00E+00	1.55E+01	4.42E+00	1.32E-01
BATCH-10	2/6/09	335	48.1	0.32	0.00E+00	1.05E+03	7.79E-08	0.00E+00	6.55E-06	0.00E+00	1.30E-02	1.84E+01	3.58E-05	3.60E-17	1.89E+02	0.00E+00	0.00E+00	1.12E+01	8.52E-04
BATCH-11	4/28/09	1637	226.2	0.33	1.54E+02	1.28E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	4.00E-03	2.08E+00	7.00E-03	1.00E-02	4.77E+01	0.00E+00	1.52E+01	4.43E+00	1.32E-01
BATCH-12	5/31/09	333	47.7	0.33	1.54E+02	1.28E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	4.00E-03	2.08E+00	7.00E-03	1.00E-02	4.77E+01	0.00E+00	1.52E+01	4.43E+00	1.32E-01
BATCH-13	9/21/09	333	47.7	0.32	0.00E+00	9.93E+02	2.64E-09	0.00E+00	2.22E-07	0.00E+00	2.00E-03	1.95E+01	1.21E-06	3.24E-18	1.93E+02	0.00E+00	0.00E+00	1.04E+01	7.74E-04
BATCH-14	12/17/09	1702	235.6	0.33	1.54E+02	1.26E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	3.00E-03	2.11E+00	7.00E-03	1.00E-02	4.77E+01	0.00E+00	1.53E+01	4.41E+00	1.32E-01
BATCH-15	1/12/10	334	47.9	0.24	1.54E+02	1.26E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	3.00E-03	2.11E+00	7.00E-03	1.00E-02	4.77E+01	0.00E+00	1.53E+01	4.41E+00	1.32E-01
BATCH-16	5/6/10	334	34.8	0.24	1.54E+02	1.26E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	3.00E-03	2.11E+00	7.00E-03	1.00E-02	4.77E+01	0.00E+00	1.52E+01	4.43E+00	1.32E-01
BATCH-17	7/6/10	1661	167.9	0.23	0.00E+00	5.01E+03	8.57E-11	7.99E+00	7.20E-09	0.00E+00	3.26E-01	4.14E+00	3.93E-08	1.53E-04	5.30E+02	0.00E+00	0.00E+00	3.31E+01	1.22E-02
BATCH-18	8/27/10	335	34.9	0.24	1.54E+02	1.24E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	3.00E-03	2.14E+00	7.00E-03	1.00E-02	4.76E+01	0.00E+00	1.54E+01	4.38E+00	1.32E-01
BATCH-19	12/19/10	335	34.9	0.24	1.54E+02	1.24E+02	3.00E-03	2.73E-01	2.00E-03	0.00E+00	3.00E-03	2.14E+00	7.00E-03	1.00E-02	4.76E+01	0.00E+00	1.54E+01	4.38E+00	1.32E-01
BATCH-20	12/25/10	1708	172.6	0.23	0.00E+00	5.28E+03	2.49E-12	8.47E+00	2.09E-10	0.00E+00	3.46E-01	3.73E+00	1.14E-09	4.44E-06	5.54E+02	0.00E+00	0.00E+00	3.44E+01	1.77E-03
BATCH-21	4/8/11	245	25.6	0.24	1.17E+02	9.87E+01	2.00E-03	2.17E-01	1.00E-03	0.00E+00	3.00E-03	1.57E+00	5.00E-03	7.00E-03	3.55E+01	0.00E+00	1.18E+01	3.15E+00	9.28E-02
BATCH-22	6/20/11	1367	137.3	0.23	0.00E+00	1.68E+03	3.07E-04	2.46E-01	8.25E-04	0.00E+00	1.00E-02	7.41E+00	1.70E-02	5.00E-03	4.80E+02	0.00E+00	0.00E+00	8.80E+01	1.19E-04
BATCH-23	7/1/11	282	29.5	0.24	1.65E+02	1.34E+02	2.00E-03	3.62E-01	1.00E-03	0.00E+00	8.00E-03	1.12E+00	2.00E-03	1.00E-02	4.37E+01	0.00E+00	1.47E+01	5.98E+00	2.42E-01
BATCH-24	11/7/11	1005	98.1	0.23	0.00E+00	1.13E+03	1.06E-05	4.60E-02	2.85E-05	0.00E+00	6.37E-04	5.93E+00	5.73E-04	9.77E-04	3.40E+02	0.00E+00	0.00E+00	6.33E+01	5.79E-02
BATCH-25	1/12/12	282	29.4	0.24	1.64E+02	1.34E+02	2.00E-03	3.58E-01	1.00E-03	0.00E+00	8.00E-03	1.12E+00	2.00E-03	1.00E-02	4.41E+01	0.00E+00	1.50E+01	6.07E+00	2.42E-01
BATCH-26	2/18/12	1769	179.0	0.23	0.00E+00	3.70E+03	6.74E-07	9.15E+00	1.81E-06	0.00E+00	1.00E-02	4.73E+00	3.30E-02	6.21E-05	3.48E+02	0.00E+00	0.00E+00	2.58E+01	4.84E-03
BATCH-27	7/26/12	283	29.5	0.24	1.64E+02	1.34E+02	2.00E-03	3.56E-01	1.00E-03	0.00E+00	8.00E-03	1.12E+00	2.00E-03	1.00E-02	4.45E+01	0.00E+00	1.52E+01	6.16E+00	2.42E-01
BATCH-28	8/20/12	2146	217.9	0.23	0.00E+00	4.51E+03	1.85E-08	1.16E+01	4.97E-08	0.00E+00	2.83E-04	5.52E+00	4.30E-02	1.71E-06	4.03E+02	0.00E+00	0.00E+00	2.71E+01	1.55E-03
BATCH-29	2/6/13	282	29.5	0.24	1.65E+02	1.35E+02	2.00E-03	3.72E-01	1.00E-03	0.00E+00	8.00E-03	1.10E+00	2.00E-03	1.00E-02	4.44E+01	0.00E+00	1.52E+01	6.14E+00	2.42E-01
BATCH-30	3/28/13	1986	200.8	0.23	0.00E+00	1.05E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+00	0.00E+00	0.00E+00	1.72E+01	0.00E+00	2.51E+01	8.49E+01	6.36E-03
BATCH-31	8/20/13	276	28.8	0.24	1.64E+02	1.32E+02	2.00E-03	3.69E-01	1.00E-03	0.00E+00	6.00E-03	9.71E-01	2.00E-03	1.00E-02	4.32E+01	0.00E+00	1.36E+01	6.00E+00	2.42E-01
BATCH-32	10/15/13	1512	152.4	0.23	0.00E+00	2.14E+03	1.66E-06	4.21E-01	4.46E-06	0.00E+00	1.06E-05	9.02E-01	2.00E-03	2.45E-05	2.79E+02	0.00E+00	0.00E+00	8.70E+00	1.02E-03
BATCH-33	2/27/14	176	18.3	0.24	1.05E+02	8.91E+01	1.00E-03	2.39E-01	8.24E-04	0.00E+00	4.00E-03	6.24E-01	1.00E-03	6.00E-03	2.76E+01	0.00E+00	8.64E+00	3.66E+00	1.43E-01
BATCH-34	3/21/14	1638	165.5	0.23	0.00E+00	2.25E+03	5.18E-08	1.40E-02	1.39E-07	0.00E+00	1.71E-01	1.54E+00	5.11E-05	9.72E-06	3.03E+02	0.00E+00	0.00E+00	9.44E+00	1.72E-03
BATCH-35	6/25/14	244	25.5	0.24	2.54E+02	9.04E+01	8.00E-05	6.20E-02	2.76E-04	0.00E+00	9.25E-04	7.27E-01	2.00E-03	5.00E-03	3.45E+01	0.00E+00	7.67E+00	3.60E+00	8.75E-03
BATCH-36	9/6/14	1515	151.9	0.23	0.00E+00	1.53E+03	4.47E-04	1.35E-01	3.00E-03	0.00E+00	7.00E-03	3.13E+00	2.10E-02	5.30E-02	2.99E+02	0.00E+00	0.00E+00	7.05E+01	7.28E-02
BATCH-37	9/11/14	244	25.5	0.24	2.53E+02	8.97E+01	8.02E-05	5.60E-02	2.77E-04	0.00E+00	1.00E-03	7.29E-01	2.00E-03	5.00E-03	3.45E+01	0.00E+00	7.59E+00	3.60E+00	8.79E-03
BATCH-38	11/29/14	244	25.5	0.24	2.53E+02	8.97E+01	8.02E-05	5.60E-02	2.77E-04	0.00E+00	1.00E-03	7.29E-01	2.00E-03	5.00E-03	3.45E+01	0.00E+00	7.59E+00	3.60E+00	8.79E-03
BATCH-39	2/9/15	1830	184.7	0.23	0.00E+00	1.09E+03	8.00E-03	1.29E+00	7.00E-03	0.00E+00	1.00E-03	2.08E+00	5.50E-02	3.00E-02	2.36E+02	0.00E+00	0.00E+00	3.65E+01	1.53E-01
BATCH-40	2/16/15	244	25.5	0.24	2.53E+02	8.92E+01	8.09E-05	5.30E-02	2.82E-04	0.00E+00	1.00E-03	7.32E-01	2.00E-03	5.00E-03	3.46E+01	0.00E+00	7.59E+00	3.63E+00	8.90E-03
BATCH-41	5/6/15	244	25.5	0.24	2.53E+02	8.92E+01	8.09E-05	5.30E-02	2.82E-04	0.00E+00	1.00E-03	7.32E-01	2.00E-03	5.00E-03	3.46E+01	0.00E+00	7.59E+00	3.63E+00	8.90E-03
BATCH-42	7/23/15	244	25.5	0.24	2.53E+02	8.92E+01	8.09E-05	5.30E-02	2.82E-04	0.00E+00	1.00E-03	7.32E-01	2.00E-03	5.00E-03	3.46E+01	0.00E+00	7.59E+00	3.63E+00	8.90E-03
BATCH-43	8/18/15	1827	184.4	0.23	0.00E+00	1.07E+03	8.00E-03	1.32E+00	7.00E-03	0.00E+00	2.00E-03	2.03E+00	5.60E-02	2.90E-02	2.32E+02	0.00E+00	0.00E+00	3.50E+01	1.55E-01
BATCH-44	10/8/15	192	20.1	0.24	1.94E+02	7.17E+01	7.39E-05	4.80E-02	2.23E-04	0.00E+00	1.00E-03	5.78E-01	2.00E-03	4.00E-03	2.71E+01	0.00E+00	6.04E+00	2.82E+00	6.97E-03
BATCH-45	12/9/15	241	25.1	0.24	2.50E+02	8.51E+01	5.50E-05	4.60E-02	2.62E-04	0.00E+00	1.00E-03	7.05E-01	2.00E-03	5.00E-03	3.31E+01	0.00E+00	7.60E+00	3.60E+00	7.13E-03
BATCH-46	2/22/16	1616	162.2	0.23	0.00E+00	2.07E+03	2.65E-04	4.60E-02	3.34E-04	0.00E+00	5.00E-03	4.04E-01	3.00E-03	1.00E-01	2.96E+02	0.00E+00	0.00E+00	8.79E+01	1.03E-02
BATCH-47	2/25/16	241	25.2	0.24	2.49E+02	8.39E+01	6.71E-05	4.40E-02	2.72E-04	0.00E+00	9.60E-04	7.02E-01	2.00E-03	5.00E-03	3.30E+01	0.00E+00	7.69E+00	3.60E+00	7.35E-03
BATCH-48	5/14/16	241	25.2	0.24	2.49E+02	8.39E+01	6.71E-05	4.40E-02	2.72E-04	0.00E+00	9.60E-04	7.02E-01	2.00E-03	5.00E-03	3.30E+01	0.00E+00	7.69E+00	3.60E+00	7.35E-03
BATCH-49	7/31/16	241	25.2	0.24	2.49E+02	8.39E+01	6.71E-05	4.40E-02	2.72E-04	0.00E+00	9.60E-04	7.02E-01	2.00E-03	5.00E-03	3.30E+01	0.00E+00	7.69E+00	3.60E+00	7.35E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1	3/19/07	2007	279.5	0.32	1.90E-04	8.18E+01	6.82E+01	0.00E+00	0.00E+00	6.00E-04	1.36E+02	6.48E-05	0.00E+00	3.68E-04	2.36E+01	2.00E-03	2.32E+04	0.00E+00	2.34E-01
BATCH-2	4/2/07	194	27.9	0.33	5.44E-04	1.92E+02	8.30E-01	0.00E+00	0.00E+00	1.80E-03	4.15E+01	2.00E-03	2.50E-02	3.30E-02	2.50E-02	2.00E-03	2.66E+03	0.00E+00	2.14E-01
BATCH-3	8/19/07	194	27.9	0.33	5.44E-04	1.92E+02	8.30E-01	0.00E+00	0.00E+00	1.80E-03	4.15E+01	2.00E-03	2.50E-02	3.30E-02	2.50E-02	2.00E-03	2.66E+03	0.00E+00	2.14E-01
BATCH-4	12/28/07	1687	234.7	0.32	4.06E-06	5.84E+01	2.06E+00	0.00E+00	0.00E+00	1.42E-05	2.75E+02	4.38E-01	1.73E+00	7.85E-06	1.72E+00	8.57E-01	2.24E+04	0.00E+00	9.88E-01
BATCH-5	1/5/08	256	36.7	0.33	5.46E-04	1.93E+02	1.76E+00	0.00E+00	0.00E+00	1.80E-03	4.31E+01	2.00E-03	2.50E-02	3.30E-02	3.13E-01	2.00E-03	3.04E+03	0.00E+00	4.99E-01
BATCH-6	5/20/08	256	36.7	0.33	5.46E-04	1.93E+02	1.76E+00	0.00E+00	0.00E+00	1.80E-03	4.31E+01	2.00E-03	2.50E-02	3.30E-02	3.13E-01	2.00E-03	3.04E+03	0.00E+00	5.31E-01
BATCH-7	8/24/08	1747	242.9	0.32	1.07E-07	6.00E+01	6.76E-01	0.00E+00	0.00E+00	3.75E-07	2.88E+02	4.64E-01	1.83E+00	2.08E-07	1.30E+00	9.08E-01	2.32E+04	0.00E+00	3.47E-01
BATCH-8	9/16/08	224	32.1	0.33	5.45E-04	1.93E+02	1.31E+00	0.00E+00	0.00E+00	1.80E-03	4.46E+01	6.00E-03	4.10E-02	3.30E-02	1.66E-01	9.00E-03	3.06E+03	0.00E+00	1.43E-01
BATCH-9	12/31/08	46	6.6	0.33	2.56E-05	9.63E+00	4.39E-01	0.00E+00	0.00E+00	8.40E-05	5.00E+00	4.00E-03	1.60E-02	1.00E-03	1.42E-01	8.00E-03	5.49E+02	0.00E+00	1.43E-01
BATCH-10	2/6/09	335	48.1	0.33	4.81E-05	2.26E+02	1.11E+00	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.40E-02	1.90E-02	6.90E-02	2.44E-01	1.00E-02	3.99E+03	0.00E+00	3.31E-01
BATCH-11	4/28/09	1637	226.2	0.32	4.78E-06	1.58E+02	3.15E+00	0.00E+00	0.00E+00	1.67E-05	1.67E+02	1.70E-02	6.80E-02	9.25E-06	1.77E+00	3.40E-02	1.88E+04	0.00E+00	1.04E+01
BATCH-12	5/31/09	333	47.7	0.33	4.72E-05	2.27E+02	7.66E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.30E-02	1.40E-02	6.90E-02	1.31E-01	7.00E-03	3.95E+03	0.00E+00	3.04E-01
BATCH-13	9/21/09	333	47.7	0.33	4.72E-05	2.27E+02	7.66E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.30E-02	1.40E-02	6.90E-02	1.31E-01	7.00E-03	3.95E+03	0.00E+00	3.04E-01
BATCH-14	12/17/09	1702	235.6	0.32	1.62E-07	1.73E+02	1.64E+00	0.00E+00	0.00E+00	5.66E-07	1.73E+02	3.00E-03	1.10E-02	3.14E-07	1.29E+00	5.00E-03	1.95E+04	0.00E+00	1.10E+01
BATCH-15	1/12/10	334	47.9	0.33	4.72E-05	2.28E+02	7.69E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.20E-02	1.30E-02	6.90E-02	1.32E-01	6.00E-03	3.97E+03	0.00E+00	3.20E-01
BATCH-16	5/6/10	334	34.8	0.24	4.72E-05	2.28E+02	7.69E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.20E-02	1.30E-02	6.90E-02	1.32E-01	6.00E-03	3.97E+03	0.00E+00	3.20E-01
BATCH-17	7/6/10	1661	167.9	0.23	5.26E-09	9.98E+01	1.05E+00	0.00E+00	0.00E+00	8.00E-04	2.97E+02	2.08E-01	1.00E-03	1.02E-08	1.00E+00	1.17E+00	2.20E+04	0.00E+00	7.91E-01
BATCH-18	8/27/10	335	34.9	0.24	4.71E-05	2.28E+02	7.67E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.20E-02	1.10E-02	6.90E-02	1.31E-01	6.00E-03	3.98E+03	0.00E+00	3.35E-01
BATCH-19	12/19/10	335	34.9	0.24	4.71E-05	2.28E+02	7.67E-01	0.00E+00	0.00E+00	4.00E-04	1.20E+02	1.20E-02	1.10E-02	6.90E-02	1.31E-01	6.00E-03	3.98E+03	0.00E+00	3.35E-01
BATCH-20	12/25/10	1708	172.6	0.23	1.53E-10	9.97E+01	1.06E+00	0.00E+00	0.00E+00	8.00E-04	3.09E+02	2.21E-01	3.21E-05	2.96E-10	1.01E+00	1.24E+00	2.26E+04	0.00E+00	4.65E-01
BATCH-21	4/8/11	245	25.6	0.24	3.31E-05	1.60E+02	5.49E-01	0.00E+00	0.00E+00	2.00E-04	8.57E+01	9.00E-03	9.00E-03	4.80E-02	9.80E-02	8.00E-03	2.92E+03	0.00E+00	2.53E-01
BATCH-22	6/20/11	1367	137.3	0.23	1.93E-06	1.22E+02	9.95E+00	0.00E+00	0.00E+00	6.00E-04	1.65E+02	6.00E-03	6.00E-03	2.00E-03	8.05E-01	3.60E-02	1.80E+04	0.00E+00	2.95E+01
BATCH-23	7/1/11	282	29.5	0.24	1.65E-05	3.49E+02	2.54E-01	0.00E+00	0.00E+00	1.00E-03	7.67E+01	7.00E-03	1.40E-02	5.90E-02	2.34E-01	1.60E-02	3.62E+03	0.00E+00	4.09E-01
BATCH-24	11/7/11	1005	98.1	0.23	6.66E-08	8.81E+01	7.35E+00	0.00E+00	0.00E+00	4.00E-04	1.05E+02	2.97E-04	4.81E-04	5.87E-05	3.50E-01	1.00E-03	1.29E+04	0.00E+00	2.21E+01
BATCH-25	1/12/12	282	29.4	0.24	1.65E-05	3.49E+02	2.70E-01	0.00E+00	0.00E+00	1.00E-03	7.67E+01	6.00E-03	1.40E-02	5.90E-02	2.33E-01	1.50E-02	3.62E+03	0.00E+00	4.60E-01
BATCH-26	2/18/12	1769	179.0	0.23	4.23E-09	8.99E+01	2.19E+00	0.00E+00	0.00E+00	4.88E-05	4.89E+02	5.38E-01	3.05E-05	3.73E-06	3.22E-01	3.70E-02	2.35E+04	0.00E+00	1.92E+00
BATCH-27	7/26/12	283	29.5	0.24	1.65E-05	3.49E+02	2.85E-01	0.00E+00	0.00E+00	1.00E-03	7.67E+01	6.00E-03	1.40E-02	5.90E-02	2.32E-01	1.50E-02	3.62E+03	0.00E+00	5.05E-01
BATCH-28	8/20/12	2146	217.9	0.23	1.16E-10	1.06E+02	2.21E+00	0.00E+00	0.00E+00	1.34E-06	6.15E+02	6.90E-01	8.39E-07	1.02E-07	3.51E-01	1.00E-03	2.86E+04	0.00E+00	6.94E-01
BATCH-29	2/6/13	282	29.5	0.24	1.65E-05	3.49E+02	2.80E-01	0.00E+00	0.00E+00	1.00E-03	7.73E+01	7.00E-03	1.30E-02	5.90E-02	2.30E-01	1.40E-02	3.62E+03	0.00E+00	4.81E-01
BATCH-30	3/28/13	1986	200.8	0.23	0.00E+00	4.56E+02	4.24E+00	0.00E+00	0.00E+00	5.93E+02	2.40E-02	0.00E+00	0.00E+00	0.00E+00	7.00E-03	0.00E+00	2.63E+04	0.00E+00	9.00E-03
BATCH-31	8/20/13	276	28.8	0.24	1.65E-05	3.48E+02	2.50E-01	0.00E+00	0.00E+00	1.00E-03	8.58E+01	7.00E-03	1.10E-02	7.50E-02	2.40E-01	1.40E-02	3.54E+03	0.00E+00	3.83E-01
BATCH-32	10/15/13	1512	152.4	0.23	1.04E-08	1.03E+02	9.60E-01	0.00E+00	0.00E+00	2.99E-06	1.61E+03	2.50E-02	3.34E-05	2.69E+00	3.56E+00	7.50E-01	2.00E+04	0.00E+00	7.90E-01
BATCH-33	2/27/14	176	18.3	0.24	9.75E-06	2.07E+02	1.64E-01	0.00E+00	0.00E+00	6.00E-04	5.60E+01	5.00E-03	7.00E-03	5.10E-02	1.54E-01	1.10E-02	2.25E+03	0.00E+00	2.56E-01
BATCH-34	3/21/14	1638	165.5	0.23	3.25E-10	1.13E+02	1.03E+00	0.00E+00	0.00E+00	3.84E-06	1.80E+03	7.84E-04	3.96E-06	3.07E+00	4.03E+00	8.54E-01	2.17E+04	0.00E+00	9.29E-01
BATCH-35	6/25/14	244	25.5	0.24	1.53E-04	1.86E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.46E+01	3.00E-03	4.00E-03	2.10E-02	6.75E-01	9.00E-03	2.91E+03	0.00E+00	4.77E-01
BATCH-36	9/6/14	1515	151.9	0.23	1.00E-03	6.84E+02	9.15E-01	0.00E+00	0.00E+00	9.60E-03	4.71E+02	3.00E-03	2.40E-02	1.13E-01	6.91E+00	4.20E-02	1.73E+04	0.00E+00	2.90E+00
BATCH-37	9/11/14	244	25.5	0.24	1.54E-04	1.87E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.56E+01	3.00E-03	4.00E-03	2.20E-02	6.80E-01	9.00E-03	2.90E+03	0.00E+00	4.72E-01
BATCH-38	11/29/14	244	25.5	0.24	1.54E-04	1.87E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.56E+01	3.00E-03	4.00E-03	2.20E-02	6.80E-01	9.00E-03	2.90E+03	0.00E+00	4.72E-01
BATCH-39	2/9/15	1830	184.7	0.23	7.92E-04	6.30E+02	3.21E-01	0.00E+00	0.00E+00	4.40E-03	1.01E+03	1.00E-03	5.90E-02	2.54E-01	2.32E+00	6.00E-03	2.11E+04	0.00E+00	4.72E-01
BATCH-40	2/16/15	244	25.5	0.24	1.56E-04	1.88E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.52E+01	2.00E-03	4.00E-03	2.10E-02	6.89E-01	8.00E-03	2.91E+03	0.00E+00	4.72E-01
BATCH-41	5/6/15	244	25.5	0.24	1.56E-04	1.88E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.52E+01	2.00E-03	4.00E-03	2.10E-02	6.89E-01	8.00E-03	2.91E+03	0.00E+00	4.72E-01
BATCH-42	7/23/15	244	25.5	0.24	1.56E-04	1.88E+02	5.16E-01	0.00E+00	0.00E+00	1.20E-03	5.52E+01	2.00E-03	4.00E-03	2.10E-02	6.89E-01	8.00E-03	2.91E+03	0.00E+00	3.80E-01
BATCH-43	8/18/15	1827	184.4	0.23	7.62E-04	6.23E+02	2.96E-01	0.00E+00	0.00E+00	4.20E-03	1.02E+03	1.00E-03	5.90E-02	2.57E-01	2.13E+00	4.00E-03	2.10E-04	0.00E+00	3.65E-01
BATCH-44	10/8/15	192	20.1	0.24	1.19E-04	1.43E+02	3.95E-01	0.00E+00	0.00E+00	1.00E-03	4.53E+01	2.00E-03	3.00E-03	1.90E-02	5.28E-01	7.00E-03	2.29E+03	0.00E+00	4.57E-01
BATCH-45	12/9/15	241	25.1	0.24	1.38E-04	1.85E+02	5.11E-01	0.00E+00	0.00E+00	1.20E-03	5.41E+01	2.00E-03	3.00E-03	1.90E-02	6.68E-01	8.00E-03	2.86E+03	0.00E+00	4.57E-01
BATCH-46	2/22/16	1616	162.2	0.23	1.02E-04	1.59E+02	1.73E+01	0.00E+00	0.00E+00	1.22E-02	1.83E+02	1.81E-04	3.00E-03	1.00E-02	7.96E+00	7.77E-04	1.85E+04	0.00E+00	1.49E+00
BATCH-47	2/25/16	241	25.2	0.24	1.38E-04	1.86E+02	5.09E-01	0.00E+00	0.00E+00	1.20E-03	5.43E+01	2.00E-03	3.00E-03	1.70E-02	6.67E-01	7.00E-03	2.87E+03	0.00E+00	4.52E-01
BATCH-48	5/14/16	241	25.2	0.24	1.38E-04	1.86E+02	5.09E-01	0.00E+00	0.00E+00	1.20E-03	5.43E+01	2.00E-03	3.00E-03	1.70E-02	6.67E-01	7.00E-03	2.87E+03	0.00E+00	4.52E-01
BATCH-49	7/31/16	241	25.2	0.24	1.38E-04	1.86E+02	5.09E-01	0.00E+00	0.00E+00	1.20E-03	5.43E+01	2.00E-03	3.00E-03	1.70E-02	6.67E-01	7.00E-03	2.87E+03	0.00E+00	4.52E-01

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	0.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1	3/19/07	2007	279.5	0.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.55E+00	3.30E+01	4.90E-06	5.15E+01	2.84E+02	1.40E-02	2.36E-04	0.00E+00	0.00E+00	4.65E-04	3.00E-02
BATCH-2	4/2/07	194	27.9	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	3.36E+01	7.48E-05	9.16E+01	3.00E+01	5.00E-03	6.02E-11	0.00E+00	9.75E-01	7.00E-02	2.55E+00
BATCH-3	8/19/07	194	27.9	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	3.36E+01	7.48E-05	9.16E+01	3.00E+01	5.00E-03	6.02E-11	0.00E+00	9.75E-01	7.00E-02	2.55E+00
BATCH-4	12/28/07	1687	234.7	0.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.65E-01	7.86E+01	1.05E-07	2.06E+01	1.52E+02	1.53E-01	5.04E-06	0.00E+00	4.36E-05	2.21E-01	5.51E-01
BATCH-5	1/5/08	256	36.7	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.80E-02	3.57E+01	7.48E-05	9.38E+01	3.36E+01	5.00E-03	2.88E-06	0.00E+00	9.74E-01	7.00E-02	2.55E+00
BATCH-6	5/20/08	256	36.7	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.80E-02	3.57E+01	7.48E-05	9.38E+01	3.36E+01	5.00E-03	2.88E-06	0.00E+00	9.74E-01	7.00E-02	2.55E+00
BATCH-7	8/24/08	1747	242.9	0.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E-01	8.24E+01	2.77E-09	2.07E+01	1.55E+02	1.62E-01	1.33E-07	0.00E+00	4.62E-05	2.34E-01	5.83E-01
BATCH-8	9/16/08	224	32.1	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.30E-02	3.58E+01	7.48E-05	9.36E+01	3.31E+01	6.00E-03	1.31E-06	0.00E+00	9.74E-01	7.20E-02	2.55E+00
BATCH-9	12/31/08	46	6.6	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	3.71E+00	3.41E-06	6.26E+00	4.45E+00	2.00E-03	1.30E-06	0.00E+00	4.40E-02	5.00E-03	1.20E-01
BATCH-10	2/6/09	335	48.1	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-01	2.73E+01	1.53E-04	1.02E+01	4.15E+01	7.00E-03	1.30E-06	0.00E+00	1.66E-01	1.42E-01	2.58E+00
BATCH-11	4/28/09	1637	226.2	0.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-01	8.43E+01	1.23E-07	5.39E+00	2.51E+02	1.40E-02	5.93E-06	0.00E+00	1.24E+00	9.00E-03	1.37E-01
BATCH-12	5/31/09	333	47.7	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.69E+01	1.53E-04	9.55E+00	4.20E+01	6.00E-03	9.91E-08	0.00E+00	1.77E-01	1.42E-01	2.58E+00
BATCH-13	9/21/09	333	47.7	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.69E+01	1.53E-04	9.55E+00	4.20E+01	6.00E-03	9.91E-08	0.00E+00	1.77E-01	1.42E-01	2.58E+00
BATCH-14	12/17/09	1702	235.6	0.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.22E-01	9.05E+01	4.18E-09	3.89E+00	2.67E+02	9.00E-03	2.01E-07	0.00E+00	1.39E+00	1.00E-03	1.32E-01
BATCH-15	1/12/10	334	47.9	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.69E+01	1.53E-04	9.52E+00	4.22E+01	6.00E-03	1.02E-07	0.00E+00	1.79E-01	1.42E-01	2.58E+00
BATCH-16	5/6/10	334	34.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.69E+01	1.53E-04	9.52E+00	4.22E+01	6.00E-03	1.02E-07	0.00E+00	1.79E-01	1.42E-01	2.58E+00
BATCH-17	7/6/10	1661	167.9	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E-01	9.11E+01	1.35E-10	9.79E+00	9.49E+01	8.10E-02	6.53E-09	0.00E+00	4.50E-02	5.52E-01	3.43E-01
BATCH-18	8/27/10	335	34.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.70E+01	1.53E-04	9.44E+00	4.25E+01	6.00E-03	8.31E-08	0.00E+00	1.82E-01	1.41E-01	2.58E+00
BATCH-19	12/19/10	335	34.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-01	2.70E+01	1.53E-04	9.44E+00	4.25E+01	6.00E-03	8.31E-08	0.00E+00	1.82E-01	1.41E-01	2.58E+00
BATCH-20	12/25/10	1708	172.6	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-01	9.30E+01	3.94E-12	1.02E+01	9.12E+01	8.60E-02	1.90E-10	0.00E+00	1.00E-03	5.86E-01	3.59E-01
BATCH-21	4/8/11	245	25.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	1.98E+01	1.08E-04	7.03E+00	3.07E+01	5.00E-03	6.76E-08	0.00E+00	1.30E-01	1.01E-01	1.81E+00
BATCH-22	6/20/11	1367	137.3	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-01	1.33E+02	7.49E-10	3.10E+01	9.12E+01	4.00E-03	3.61E-08	0.00E+00	9.60E-02	1.09E+00	7.20E-02
BATCH-23	7/1/11	282	29.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.09E+01	1.35E-04	1.20E+01	3.67E+01	1.10E-02	5.61E-08	0.00E+00	1.43E-01	1.32E-01	4.52E+00
BATCH-24	11/7/11	1005	98.1	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.88E-01	9.60E+01	2.59E-11	2.27E+01	6.39E+01	9.46E-04	1.25E-09	0.00E+00	1.03E-01	7.91E-01	3.90E-02
BATCH-25	1/12/12	282	29.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.11E+01	1.35E-04	1.20E+01	3.66E+01	1.10E-02	5.06E-08	0.00E+00	1.43E-01	1.34E-01	4.52E+00
BATCH-26	2/18/12	1769	179.0	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.11E-01	5.01E+01	1.64E-12	3.27E+01	5.60E+01	1.73E-01	7.92E-11	0.00E+00	2.97E-01	1.80E-01	4.52E+00
BATCH-27	7/26/12	283	29.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.13E+01	1.35E-04	1.20E+01	3.66E+01	1.10E-02	4.70E-08	0.00E+00	7.00E-03	1.36E-01	4.52E+00
BATCH-28	8/20/12	2146	217.9	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+00	5.38E+01	4.52E-14	4.03E+01	6.40E+01	2.21E-01	2.18E-12	0.00E+00	1.42E-01	2.99E-01	2.17E-01
BATCH-29	2/6/13	282	29.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.11E+01	1.35E-04	1.20E+01	3.63E+01	1.10E-02	3.99E-08	0.00E+00	1.41E-01	1.35E-01	4.52E+00
BATCH-30	3/28/13	1986	200.8	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.84E+01	0.00E+00	1.14E+02	1.01E+03	3.46E+01	1.10E-02	7.50E-04	0.00E+00	1.85E+01	0.00E+00	8.00E-03
BATCH-31	8/20/13	276	28.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	2.98E+01	1.38E-04	1.15E+01	3.46E+01	1.10E-02	7.50E-04	0.00E+00	1.36E-01	1.68E-01	4.52E+00
BATCH-32	10/15/13	1512	152.4	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.19E-01	3.75E+01	4.75E-04	2.29E+01	2.95E+01	8.00E-03	1.24E-01	0.00E+00	5.27E-04	6.05E+00	8.77E-01
BATCH-33	2/27/14	176	18.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	1.83E+01	8.27E-05	7.16E+00	2.12E+01	7.00E-03	7.50E-04	0.00E+00	8.20E-02	1.16E-01	2.68E+00
BATCH-34	3/21/14	1638	165.5	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+00	4.13E+01	5.40E-04	2.45E+01	3.14E+01	7.00E-02	1.41E-01	0.00E+00	2.00E-03	6.88E+00	9.90E-01
BATCH-35	6/25/14	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-01	8.32E-06	1.58E+01	2.47E+01	2.60E-02	9.87E-04	0.00E+00	4.80E-02	5.50E-02	1.97E-01
BATCH-36	9/6/14	1515	151.9	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.71E-01	1.09E+02	4.91E-05	2.09E+01	2.04E+02	4.00E-03	6.00E-03	0.00E+00	1.82E-01	3.23E-01	1.17E+00
BATCH-37	9/11/14	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	1.62E+01	8.68E-06	1.58E+01	2.47E+01	2.60E-02	1.00E-03	0.00E+00	4.70E-02	5.90E-02	1.98E-01
BATCH-38	11/29/14	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	1.62E+01	8.68E-06	1.58E+01	2.47E+01	2.60E-02	1.00E-03	0.00E+00	4.70E-02	5.90E-02	1.98E-01
BATCH-39	2/9/15	1830	184.7	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.63E-01	1.10E+02	8.96E-04	1.12E+01	1.54E+02	4.00E-03	9.19E-04	0.00E+00	4.34E-01	5.53E-01	3.04E-01
BATCH-40	2/16/15	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	1.63E+01	8.48E-06	1.58E+01	2.49E+01	2.60E-02	1.00E-03	0.00E+00	4.70E-02	5.60E-02	1.99E-01
BATCH-41	5/6/15	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	1.63E+01	8.48E-06	1.58E+01	2.49E+01	2.60E-02	1.00E-03	0.00E+00	4.70E-02	5.60E-02	1.99E-01
BATCH-42	7/23/15	244	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	1.63E+01	8.48E-06	1.58E+01	2.49E+01	2.60E-02	1.00E-03	0.00E+00	4.70E-02	5.60E-02	1.99E-01
BATCH-43	8/18/15	1827	184.4	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-01	1.09E+02	9.00E-04	1.08E+01	1.51E+02	4.00E-03	7.19E-04	0.00E+00	4.40E-01	5.57E-01	2.69E-01
BATCH-44	10/8/15	192	20.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	1.26E+01	8.33E-06	1.20E+01	1.92E+01	1.90E-02	8.97E-04	0.00E+00	3.70E-02	5.00E-02	1.52E-01
BATCH-45	12/9/15	241	25.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.50E-02	1.51E+01	7.39E-06	1.37E+01	2.59E+01	2.60E-02	9.25E-04	0.00E+00	1.02E-01	5.00E-02	1.24E-01
BATCH-46	2/22/16	1616	162.2	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.88E-01	1.77E+02	2.82E-05	6.83E+00	1.84E+02	2.00E-03	8.83E-05	0.00E+00	5.20E-02	3.50E-02	5.57E-01
BATCH-47	2/25/16	241	25.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	1.52E+01	8.45E-06	1.36E+01	2.60E+01	2.60E-02	8.47E-04	0.00E+00	1.02E-01	4.70E-02	1.23E-01
BATCH-48	5/14/16	241	25.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	1.52E+01	8.45E-06	1.36E+01	2.60E+01	2.60E-02	8.47E-04	0.00E+00	1.02E-01	4.70E-02	1.23E-01
BATCH-49	7/31/16	241	25.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	1.52E+01	8.45E-06	1.36E+01	2.60E+01	2.60E-02	8.47E-04	0.00E+00	1.02E-01	4.70E-02	1.23E-01

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-50	8/6/16	1629	163.5	0.23	0.00E+00	0.00E+00	3.55E+00	3.59E+00	2.95E+02	4.97E+00	3.13E+04	2.80E+04	6.61E+00	1.56E+02	2.19E-07	5.25E+01	1.29E+00	8.91E+00	1.98E-01
BATCH-51	10/17/16	242	25.2	0.24	0.00E+00	0.00E+00	3.31E-01	3.18E-01	2.75E+01	1.30E+00	4.84E+00	2.04E+03	4.89E-01	2.41E+01	1.72E-07	3.89E+00	2.16E-01	1.15E+00	2.38E-02
BATCH-52	1/4/17	242	25.2	0.24	0.00E+00	0.00E+00	3.31E-01	2.79E-01	2.73E+01	1.30E+00	4.84E+00	2.04E+03	4.65E-01	2.41E+01	8.62E-08	3.71E+00	1.68E-01	1.15E+00	2.38E-02
BATCH-53	1/20/17	1676	168.4	0.23	0.00E+00	0.00E+00	4.12E+00	3.41E+00	3.39E+02	5.77E+00	3.23E+04	3.11E+04	7.00E+00	1.61E+02	7.43E-07	5.52E+01	9.94E-01	1.18E+01	2.24E-01
BATCH-54	3/23/17	237	24.7	0.24	0.00E+00	0.00E+00	3.25E-01	2.74E-01	2.68E+01	1.27E+00	4.73E+03	2.00E+03	4.57E-01	2.36E+01	8.39E-08	3.65E+00	1.64E-01	1.12E+00	2.33E-02
BATCH-55	6/13/17	358	37.4	0.24	0.00E+00	0.00E+00	5.89E-01	9.59E-01	4.87E+01	1.03E+00	7.17E+03	4.32E+03	9.98E-01	3.57E+01	2.05E-07	7.78E+00	2.24E-01	1.41E+00	8.70E-02
BATCH-56	7/12/17	1681	168.9	0.23	0.00E+00	0.00E+00	4.21E+00	3.49E+00	3.47E+02	5.87E+00	3.24E+04	3.18E+04	7.16E+00	1.61E+02	6.72E-07	5.58E+01	1.01E+00	1.18E+01	2.25E-01
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	0.00E+00	0.00E+00	5.90E-01	9.60E-01	4.88E+01	1.03E+00	7.17E+03	4.33E+03	1.00E+00	3.57E+01	2.05E-07	7.80E+00	2.24E-01	1.41E+00	8.68E-02
BATCH-58	12/25/17	358	37.4	0.24	0.00E+00	0.00E+00	5.90E-01	9.60E-01	4.88E+01	1.03E+00	7.17E+03	4.33E+03	1.00E+00	3.57E+01	2.05E-07	7.80E+00	2.24E-01	1.41E+00	8.68E-02
BATCH-59	1/2/18	353	36.8	0.24	0.00E+00	0.00E+00	9.52E-01	1.02E+00	7.83E+01	1.66E+00	7.05E+03	9.10E+03	1.93E+00	3.51E+01	2.91E-10	1.61E+01	2.88E-01	2.79E+00	6.90E-02
BATCH-60	2/1/18	353	36.8	0.24	0.00E+00	0.00E+00	9.52E-01	1.02E+00	7.83E+01	1.66E+00	7.05E+03	9.10E+03	1.93E+00	3.51E+01	2.91E-10	1.61E+01	2.88E-01	2.79E+00	6.90E-02
BATCH-61	2/8/18	352	36.7	0.24	0.00E+00	0.00E+00	9.50E-01	1.01E+00	7.82E+01	1.66E+00	7.04E+03	9.09E+03	1.92E+00	3.51E+01	2.91E-10	1.61E+01	2.88E-01	2.79E+00	6.90E-02
BATCH-62	3/10/18	351	36.7	0.24	0.00E+00	0.00E+00	9.48E-01	1.01E+00	7.80E+01	1.65E+00	7.03E+03	9.07E+03	1.92E+00	3.50E+01	2.90E-10	1.61E+01	2.87E-01	2.78E+00	6.90E-02
BATCH-63	3/17/18	343	35.8	0.24	0.00E+00	0.00E+00	1.15E+00	9.64E-01	9.42E+01	1.65E+00	6.86E+03	9.65E+03	2.06E+00	3.42E+01	3.27E-10	1.64E+01	2.62E-01	2.97E+00	6.55E-02
BATCH-64	4/15/18	343	35.8	0.24	0.00E+00	0.00E+00	1.15E+00	9.63E-01	9.45E+01	1.65E+00	6.86E+03	9.66E+03	2.06E+00	3.42E+01	3.28E-10	1.64E+01	2.61E-01	2.98E+00	6.53E-02
BATCH-65	4/22/18	343	35.8	0.24	0.00E+00	0.00E+00	1.15E+00	9.63E-01	9.44E+01	1.64E+00	6.85E+03	9.65E+03	2.06E+00	3.41E+01	3.27E-10	1.64E+01	2.61E-01	2.97E+00	6.53E-02
BATCH-66	5/21/18	343	35.7	0.24	0.00E+00	0.00E+00	1.15E+00	9.62E-01	9.43E+01	1.64E+00	6.85E+03	9.64E+03	2.06E+00	3.41E+01	3.27E-10	1.64E+01	2.61E-01	2.97E+00	6.53E-02
BATCH-67	5/28/18	342	35.7	0.24	0.00E+00	0.00E+00	1.15E+00	9.60E-01	9.42E+01	1.64E+00	6.84E+03	9.63E+03	2.06E+00	3.41E+01	3.27E-10	1.63E+01	2.61E-01	2.97E+00	6.50E-02
BATCH-68	6/26/18	324	33.8	0.24	0.00E+00	0.00E+00	5.43E-01	7.97E-01	4.45E+01	9.47E-01	6.48E+03	3.93E+03	8.63E-01	3.23E+01	9.79E-08	6.72E+00	1.60E-01	1.26E+00	7.63E-02
BATCH-69	7/3/18	286	29.8	0.24	0.00E+00	0.00E+00	1.01E+00	1.50E+00	8.29E+01	1.07E+00	5.72E+03	8.48E+03	1.81E+00	2.85E+01	2.78E-10	1.45E+01	2.30E-01	2.61E+00	5.88E-02
BATCH-70	7/30/18	198	20.7	0.24	0.00E+00	0.00E+00	7.96E-01	2.36E+00	6.53E+01	1.61E-01	8.45E+02	6.68E+03	1.42E+00	1.97E+01	2.03E-10	1.15E+01	1.81E-01	2.06E+00	4.88E-02
BATCH-71	8/2/18	198	20.6	0.24	0.00E+00	0.00E+00	7.95E-01	2.36E+00	6.52E+01	1.61E-01	8.44E+02	6.67E+03	1.42E+00	1.97E+01	2.02E-10	1.15E+01	1.81E-01	2.06E+00	4.88E-02
BATCH-72	8/20/18	198	20.6	0.24	0.00E+00	0.00E+00	7.95E-01	2.36E+00	6.52E+01	1.61E-01	8.43E+02	6.67E+03	1.42E+00	1.97E+01	2.02E-10	1.15E+01	1.81E-01	2.06E+00	4.88E-02
BATCH-73	8/22/18	198	20.6	0.24	0.00E+00	0.00E+00	7.94E-01	2.36E+00	6.52E+01	1.61E-01	8.42E+02	6.65E+03	1.42E+00	1.96E+01	2.02E-10	1.15E+01	1.81E-01	2.05E+00	4.85E-02
BATCH-74	9/10/18	197	20.6	0.24	0.00E+00	0.00E+00	7.92E-01	2.35E+00	6.50E+01	1.61E-01	4.13E-01	3.99E+03	4.32E-01	1.99E+01	4.88E-11	4.25E+00	5.50E-02	5.54E-01	2.55E-02
BATCH-75	9/12/18	200	20.8	0.24	0.00E+00	0.00E+00	2.47E-01	4.97E-01	2.02E+01	9.47E-01	6.48E+03	2.05E+03	8.63E-01	3.23E+01	9.79E-08	6.72E+00	1.60E-01	1.26E+00	7.63E-02
BATCH-76	10/1/18	324	33.8	0.24	0.00E+00	0.00E+00	5.43E-01	7.97E-01	4.45E+01	9.47E-01	6.48E+03	3.93E+03	8.63E-01	3.23E+01	9.79E-08	6.72E+00	1.60E-01	1.26E+00	7.63E-02
BATCH-77	10/3/18	199	20.8	0.24	0.00E+00	0.00E+00	1.14E-01	4.80E-02	9.32E+00	4.73E-01	3.98E+03	9.31E+01	1.93E-01	1.98E+01	1.16E-11	2.49E+00	2.40E-02	1.90E-01	2.00E-02
BATCH-78	10/24/18	199	20.8	0.24	0.00E+00	0.00E+00	1.14E-01	4.70E-02	9.32E+00	4.72E-01	3.98E+03	9.30E+01	1.93E-01	1.98E+01	1.16E-11	2.49E+00	2.40E-02	1.90E-01	2.00E-02
BATCH-79	11/4/18	199	20.8	0.24	0.00E+00	0.00E+00	1.14E-01	4.70E-02	9.31E+00	4.72E-01	3.98E+03	9.30E+01	1.93E-01	1.98E+01	1.16E-11	2.48E+00	2.40E-02	1.89E-01	2.00E-02
BATCH-80	11/14/18	199	20.7	0.24	0.00E+00	0.00E+00	1.14E-01	4.70E-02	9.30E+00	4.71E-01	3.97E+03	9.29E+01	1.93E-01	1.98E+01	1.16E-11	2.48E+00	2.40E-02	1.89E-01	2.00E-02
BATCH-81	11/25/18	184	19.2	0.24	0.00E+00	0.00E+00	9.80E-02	4.60E-02	8.02E+00	4.32E-01	3.67E+03	8.15E+01	1.61E-01	1.83E+01	1.92E-08	2.24E+00	2.20E-02	1.65E-01	1.75E-02
BATCH-82	12/5/18	163	17.0	0.24	0.00E+00	0.00E+00	5.50E-02	4.80E-02	4.51E+00	3.69E-01	3.26E+03	5.27E+01	6.90E-02	1.52E+01	1.03E-07	1.73E+00	2.10E-02	1.00E-01	1.08E-02
BATCH-83	12/14/18	157	16.4	0.24	0.00E+00	0.00E+00	5.30E-02	4.60E-02	4.35E+00	3.56E-01	3.14E+03	5.08E+01	6.70E-02	1.46E+01	9.91E-08	1.67E+00	2.00E-02	9.70E-02	1.05E-02
BATCH-84	12/22/18	104	10.8	0.24	0.00E+00	0.00E+00	1.74E-01	2.55E-01	1.43E+01	3.03E-01	2.07E+03	1.26E+01	2.76E-01	1.03E+01	3.13E-08	2.15E+00	5.10E-02	4.02E-01	2.45E-02
BATCH-85	12/31/18	157	16.4	0.24	0.00E+00	0.00E+00	5.30E-02	4.60E-02	4.34E+00	3.56E-01	3.14E+03	5.07E+01	6.70E-02	1.46E+01	9.90E-08	1.67E+00	2.00E-02	9.70E-02	1.05E-02
BATCH-86	1/2/19	157	16.4	0.24	0.00E+00	0.00E+00	5.30E-02	4.00E-02	4.31E+00	3.56E-01	3.14E+03	5.07E+01	6.30E-02	1.46E+01	4.98E-08	1.59E+00	1.60E-02	9.70E-02	1.05E-02
BATCH-87	1/16/19	157	16.4	0.24	0.00E+00	0.00E+00	5.30E-02	4.00E-02	4.31E+00	3.55E-01	3.13E+03	5.07E+01	6.30E-02	1.46E+01	4.98E-08	1.59E+00	1.60E-02	9.70E-02	1.05E-02
BATCH-88	1/19/19	146	15.2	0.24	0.00E+00	0.00E+00	4.90E-02	3.70E-02	4.00E+00	3.29E-01	2.91E+03	4.71E+01	5.90E-02	1.36E+01	4.62E-08	1.48E+00	1.40E-02	9.00E-02	9.75E-03
BATCH-89	2/2/19	201	21.0	0.24	0.00E+00	0.00E+00	5.13E-01	3.46E-01	4.16E+01	1.00E+00	4.02E+03	4.02E+03	8.17E-01	2.00E+01	3.40E-08	6.67E+00	8.20E-02	1.32E+00	3.18E-02
BATCH-90	2/3/19	273	28.5	0.24	0.00E+00	0.00E+00	9.47E-01	6.36E-01	7.68E+01	1.67E+00	5.46E+03	7.36E+03	1.52E+00	2.72E+01	2.95E-08	1.17E+01	1.45E-01	2.46E+00	5.33E-02
BATCH-91	2/23/19	273	28.5	0.24	0.00E+00	0.00E+00	9.47E-01	6.36E-01	7.68E+01	1.67E+00	5.46E+03	7.35E+03	1.52E+00	2.72E+01	2.95E-08	1.17E+01	1.45E-01	2.46E+00	5.33E-02
BATCH-92	3/4/19	322	33.5	0.24	0.00E+00	0.00E+00	5.40E-01	7.01E-01	4.40E+01	8.65E-01	6.43E+03	3.91E+03	8.13E-01	3.20E+01	4.48E-08	6.40E+00	1.33E-01	1.20E+00	7.60E-02
BATCH-93	3/24/19	273	28.5	0.24	0.00E+00	0.00E+00	9.46E-01	6.36E-01	7.68E+01	1.67E+00	5.46E+03	7.35E+03	1.52E+00	2.72E+01	2.95E-08	1.17E+01	1.45E-01	2.46E+00	5.33E-02
BATCH-94	4/7/19	273	28.5	0.24	0.00E+00	0.00E+00	9.46E-01	6.35E-01	7.67E+01	1.67E+00	5.46E+03	7.35E+03	1.52E+00	2.72E+01	2.95E-08	1.17E+01	1.45E-01	2.46E+00	5.33E-02
BATCH-95	4/21/19	254	26.5	0.24	0.00E+00	0.00E+00	8.80E-01	5.91E-01	7.13E+01	1.55E+00	5.08E+03	6.83E+03	1.42E+00	2.53E+01	2.74E-08	1.08E+01	1.35E-01	2.29E+00	4.95E-02
BATCH-96	5/5/19	245	25.5	0.24	0.00E+00	0.00E+00	8.47E-01	5.69E-01	6.87E+01	1.49E+00	4.89E+03	6.58E+03	1.36E+00	2.43E+01	2.64E-08	1.04E+01	1.30E-01	2.20E+00	4.75E-02
BATCH-97	5/18/19	272	28.3	0.24	0.00E+00	0.00E+00	9.42E-01	6.33E-01	7.64E+01	1.66E+00	5.43E+03	7.32E+03	1.52E+00	2.71E+01	2.94E-08	1.16E+01	1.45E-01	2.45E+00	5.30E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-50	8/6/16	1629	163.5	0.23	9.29E-05	4.70E+03	1.69E+04	2.24E+00	1.73E+02	1.88E+01	1.18E+00	7.43E-04	3.00E-02	7.00E-03	7.00E-03	2.30E-02	9.73E-01	4.61E+00	1.23E+00
BATCH-51	10/17/16	242	25.2	0.24	2.84E-04	7.25E+02	1.22E+03	1.61E-01	1.15E+01	1.67E+00	9.03E-01	5.51E-05	2.00E-03	4.86E-04	2.00E-03	2.00E-03	5.60E-02	2.67E-01	1.15E-01
BATCH-52	1/4/17	242	25.2	0.24	2.01E-04	7.25E+02	1.21E+03	1.53E-01	1.06E+01	1.45E+00	9.03E-01	5.34E-05	2.00E-03	4.86E-04	2.00E-03	2.00E-03	5.60E-02	2.67E-01	1.15E-01
BATCH-53	1/20/17	1676	168.4	0.23	2.58E-05	4.84E+03	1.86E+04	2.26E+00	1.78E+02	1.75E+01	8.08E+00	8.14E-04	2.40E-02	6.00E-03	8.00E-03	1.80E-02	1.00E+00	4.79E+00	1.48E+00
BATCH-54	3/23/17	237	24.7	0.24	1.96E-04	7.10E+02	1.19E+03	1.50E-01	1.04E+01	1.42E+00	8.79E-01	5.25E-05	2.00E-03	4.78E-04	2.00E-03	2.00E-03	5.50E-02	2.64E-01	1.13E-01
BATCH-55	6/13/17	358	37.4	0.24	2.58E-05	1.08E+03	2.56E+03	3.23E-01	2.51E+01	2.94E+00	6.15E-01	1.10E-04	5.00E-03	1.00E-03	1.00E-03	4.00E-03	1.37E-01	6.55E-01	2.22E-01
BATCH-56	7/12/17	1681	168.9	0.23	2.58E-05	4.86E+03	1.91E+04	2.32E+00	1.82E+02	1.78E+01	7.31E+00	8.36E-04	2.40E-02	6.00E-03	8.00E-03	1.80E-02	1.03E+00	4.94E+00	1.52E+00
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	1.35E-04	1.08E+03	2.57E+03	3.24E-01	2.52E+01	2.94E+00	6.17E-01	1.11E-04	5.00E-03	1.00E-03	1.00E-03	4.00E-03	1.38E-01	6.57E-01	2.23E-01
BATCH-58	12/25/17	358	37.4	0.24	1.35E-04	1.08E+03	2.57E+03	3.24E-01	2.52E+01	2.94E+00	6.17E-01	1.11E-04	5.00E-03	1.00E-03	1.00E-03	4.00E-03	1.38E-01	6.57E-01	2.23E-01
BATCH-59	1/2/18	353	36.8	0.24	2.70E-05	1.06E+03	5.40E+03	7.40E-01	5.38E+01	5.24E+00	7.78E-05	2.03E-04	1.60E-02	4.00E-03	2.00E-03	2.10E-02	4.53E-01	2.19E+00	3.55E-01
BATCH-60	2/1/18	353	36.8	0.24	2.70E-05	1.06E+03	5.40E+03	7.40E-01	5.38E+01	5.24E+00	6.94E-05	2.03E-04	1.60E-02	4.00E-03	2.00E-03	2.10E-02	4.52E-01	2.19E+00	3.54E-01
BATCH-61	2/8/18	352	36.7	0.24	2.70E-05	1.05E+03	5.39E+03	7.39E-01	5.37E+01	5.23E+00	6.93E-05	2.03E-04	1.60E-02	4.00E-03	2.00E-03	2.10E-02	4.52E-01	2.19E+00	3.54E-01
BATCH-62	3/10/18	351	36.7	0.24	2.70E-05	1.05E+03	5.38E+03	7.38E-01	5.36E+01	5.22E+00	6.91E-05	2.02E-04	1.60E-02	4.00E-03	2.00E-03	2.10E-02	4.51E-01	2.19E+00	3.54E-01
BATCH-63	3/17/18	343	35.8	0.24	1.35E-04	1.03E+03	5.75E+03	7.20E-01	5.04E+01	4.99E+00	2.69E-04	2.35E-04	1.00E-02	3.00E-03	2.00E-03	1.20E-02	3.39E-01	1.64E+00	3.91E-01
BATCH-64	4/15/18	343	35.8	0.24	1.35E-04	1.03E+03	5.76E+03	7.19E-01	5.04E+01	4.99E+00	2.73E-04	2.36E-04	1.00E-02	3.00E-03	2.00E-03	1.10E-02	3.36E-01	1.62E+00	3.92E-01
BATCH-65	4/22/18	343	35.8	0.24	1.35E-04	1.03E+03	5.75E+03	7.19E-01	5.03E+01	4.98E+00	2.73E-04	2.35E-04	1.00E-02	3.00E-03	2.00E-03	1.10E-02	3.36E-01	1.62E+00	3.91E-01
BATCH-66	5/21/18	343	35.7	0.24	1.35E-04	1.03E+03	5.75E+03	7.18E-01	5.03E+01	4.98E+00	2.72E-04	2.35E-04	1.00E-02	3.00E-03	2.00E-03	1.10E-02	3.36E-01	1.62E+00	3.91E-01
BATCH-67	5/28/18	342	35.7	0.24	1.35E-04	1.03E+03	5.74E+03	7.17E-01	5.02E+01	4.97E+00	2.72E-04	2.35E-04	1.00E-02	3.00E-03	2.00E-03	1.10E-02	3.35E-01	1.62E+00	3.91E-01
BATCH-68	6/26/18	324	33.8	0.24	8.09E-05	9.72E+02	2.32E+03	2.80E-01	2.23E+01	2.21E+00	5.05E-01	9.73E-05	4.00E-03	8.97E-04	1.00E-03	3.00E-03	1.31E-01	6.33E-01	2.14E-01
BATCH-69	7/3/18	286	29.8	0.24	8.09E-05	8.58E+02	5.05E+03	6.32E-01	4.50E+01	4.41E+00	1.88E-04	2.05E-04	9.00E-03	3.00E-03	2.00E-03	1.10E-02	2.06E-01	9.97E-01	2.41E-01
BATCH-70	7/30/18	198	20.7	0.24	2.17E-05	5.94E+02	3.96E+03	4.99E-01	3.70E+01	3.54E+00	5.47E-05	1.59E-04	8.00E-03	2.00E-03	2.00E-03	1.00E-02	1.00E-03	7.00E-03	2.00E-03
BATCH-71	8/2/18	198	20.6	0.24	2.16E-05	5.94E+02	3.96E+03	4.99E-01	3.70E+01	3.54E+00	5.46E-05	1.59E-04	8.00E-03	2.00E-03	2.00E-03	1.00E-02	1.00E-03	7.00E-03	2.00E-03
BATCH-72	8/20/18	198	20.6	0.24	2.16E-05	5.93E+02	3.95E+03	4.98E-01	3.69E+01	3.54E+00	5.46E-05	1.59E-04	8.00E-03	2.00E-03	2.00E-03	1.00E-02	1.00E-03	7.00E-03	2.00E-03
BATCH-73	8/22/18	198	20.6	0.24	2.16E-05	5.93E+02	3.95E+03	4.98E-01	3.69E+01	3.53E+00	5.45E-05	1.59E-04	8.00E-03	2.00E-03	2.00E-03	1.00E-02	1.00E-03	7.00E-03	2.00E-03
BATCH-74	9/10/18	197	20.6	0.24	2.16E-05	5.91E+02	3.94E+03	4.97E-01	3.68E+01	7.37E+00	5.44E-05	1.58E-04	8.00E-03	2.00E-03	2.00E-03	1.00E-02	1.00E-03	7.00E-03	2.00E-03
BATCH-75	9/12/18	200	20.8	0.24	1.05E-05	5.99E+02	8.90E+02	1.12E-01	7.37E+00	7.54E-01	1.93E-05	3.59E-05	3.00E-03	5.66E-04	5.91E-04	2.00E-03	1.10E-02	8.00E-03	2.00E-03
BATCH-76	10/1/18	324	33.8	0.24	8.09E-05	9.72E+02	2.32E+03	2.80E-01	2.23E+01	2.21E+00	5.05E-01	9.73E-05	4.00E-03	8.97E-04	1.00E-03	3.00E-03	1.31E-01	6.33E-01	2.14E-01
BATCH-77	10/3/18	199	20.8	0.24	7.78E-06	5.98E+02	1.49E+02	1.90E-02	2.32E-01	8.20E-02	1.06E-05	6.15E-06	1.00E-03	1.36E-04	3.45E-04	5.49E-04	2.00E-03	1.10E-02	9.00E-03
BATCH-78	10/24/18	199	20.8	0.24	7.78E-06	5.97E+02	1.49E+02	1.90E-02	2.32E-01	8.20E-02	1.06E-05	6.15E-06	1.00E-03	1.36E-04	3.45E-04	5.49E-04	2.00E-03	1.10E-02	9.00E-03
BATCH-79	11/4/18	199	20.8	0.24	7.77E-06	5.97E+02	1.49E+02	1.90E-02	2.32E-01	8.10E-02	1.06E-05	6.14E-06	1.00E-03	1.36E-04	3.44E-04	5.48E-04	2.00E-03	1.10E-02	9.00E-03
BATCH-80	11/14/18	199	20.7	0.24	7.76E-06	5.96E+02	1.49E+02	1.90E-02	2.32E-01	8.10E-02	1.06E-05	6.14E-06	1.00E-03	1.36E-04	2.87E-04	4.58E-04	3.00E-03	1.40E-02	1.10E-02
BATCH-81	11/25/18	184	19.2	0.24	1.06E-05	5.51E+02	1.32E+02	1.70E-02	3.67E-01	1.15E-01	3.15E-01	5.47E-06	1.00E-03	1.16E-04	2.87E-04	4.58E-04	3.00E-03	1.40E-02	2.10E-02
BATCH-82	12/5/18	163	17.0	0.24	2.48E-05	4.88E+02	9.11E+01	1.10E-02	9.99E-01	2.79E-01	1.68E+00	3.89E-06	6.59E-04	6.04E-05	1.18E-04	1.85E-04	5.00E-03	2.70E-02	2.10E-02
BATCH-83	12/14/18	157	16.4	0.24	2.39E-05	4.71E+02	8.76E+01	1.10E-02	9.61E-01	2.69E-01	1.62E+00	3.73E-06	6.35E-04	5.81E-05	1.13E-04	1.77E-04	5.00E-03	2.60E-02	2.00E-02
BATCH-84	12/22/18	104	10.8	0.24	2.70E-05	3.11E+02	7.41E+02	8.90E-02	7.15E+00	7.06E-01	1.62E-01	3.11E-05	1.00E-03	2.87E-04	4.47E-04	9.42E-04	4.20E-02	2.03E-01	6.80E-02
BATCH-85	12/31/18	157	16.4	0.24	2.39E-05	4.71E+02	8.75E+01	1.10E-02	9.60E-01	2.69E-01	1.62E+00	3.73E-06	6.34E-04	5.80E-05	1.13E-04	1.77E-04	5.00E-03	2.60E-02	2.00E-02
BATCH-86	1/2/19	157	16.4	0.24	1.70E-05	4.71E+02	8.68E+01	1.00E-02	8.85E-01	2.33E-01	1.62E+00	3.61E-06	5.72E-04	5.80E-05	1.13E-04	1.77E-04	5.00E-03	2.60E-02	2.00E-02
BATCH-87	1/16/19	157	16.4	0.24	1.70E-05	4.70E+02	8.67E+01	1.00E-02	8.85E-01	2.33E-01	1.62E+00	3.61E-06	5.71E-04	5.79E-05	1.13E-04	1.77E-04	5.00E-03	2.60E-02	2.00E-02
BATCH-88	1/19/19	146	15.2	0.24	1.58E-05	4.37E+02	8.06E+01	1.00E-02	8.22E-01	2.17E-01	1.51E+00	3.35E-06	5.31E-04	5.38E-05	1.05E-04	1.64E-04	5.00E-03	2.40E-02	1.90E-02
BATCH-89	2/2/19	201	21.0	0.24	2.67E-05	6.03E+02	2.28E+03	2.51E-01	1.85E+01	1.71E+00	1.27E+00	9.42E-05	3.00E-03	8.03E-04	9.89E-04	3.00E-03	1.14E-01	5.58E-01	1.80E-01
BATCH-90	2/23/19	273	28.5	0.24	2.70E-05	8.20E+02	4.32E+03	4.75E-01	3.48E+01	3.10E+00	1.27E+00	1.78E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.16E-01	1.05E+00	3.30E-01
BATCH-91	2/23/19	273	28.5	0.24	2.70E-05	8.19E+02	4.32E+03	4.75E-01	3.48E+01	3.10E+00	1.27E+00	1.78E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.16E-01	1.05E+00	3.30E-01
BATCH-92	3/4/19	322	33.5	0.24	1.08E-04	9.65E+02	2.30E+03	2.63E-01	2.05E+01	1.90E+00	2.76E-01	9.42E-05	3.00E-03	8.94E-04	1.00E-03	3.00E-03	1.30E-01	6.33E-01	2.14E-01
BATCH-93	3/24/19	273	28.5	0.24	2.70E-05	8.19E+02	4.31E+03	4.75E-01	3.48E+01	3.10E+00	1.27E+00	1.78E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.15E-01	1.05E+00	3.30E-01
BATCH-94	4/7/19	273	28.5	0.24	2.70E-05	8.19E+02	4.31E+03	4.75E-01	3.48E+01	3.10E+00	1.27E+00	1.78E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.15E-01	1.05E+00	3.30E-01
BATCH-95	4/21/19	254	26.5	0.24	2.70E-05	7.61E+02	4.01E+03	4.41E-01	3.23E+01	2.88E+00	1.18E+00	1.66E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.00E-01	9.77E-01	3.07E-01
BATCH-96	5/5/19	245	25.5	0.24	2.70E-05	7.33E+02	3.86E+03	4.25E-01	3.11E+01	2.78E+00	1.13E+00	1.59E-04	4.00E-03	1.00E-03	2.00E-03	5.00E-03	1.93E-01	9.41E-01	2.95E-01
BATCH-97	5/18/19	272	28.3	0.24	2.70E-05	8.15E+02	4.29E+03	4.73E-01	3.46E+01	3.09E+00	1.26E+00	1.77E-04	5.00E-03	1.00E-03	2.00E-03	5.00E-03	2.14E-01	1.05E+00	3.29E-01

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with ofgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-50	8/6/16	1629	163.5	0.23	5.00E-02	3.90E-02	1.50E+00	1.97E+00	1.47E+00	7.55E+01	1.29E+01	8.94E+01	5.29E+01	3.77E-16	8.52E-04	3.00E-03	1.90E-02	1.78E-01	1.11E-04
BATCH-51	10/17/16	242	25.2	0.24	5.00E-03	5.00E-03	1.34E-01	2.15E-01	1.16E-01	5.63E+00	1.07E+00	1.06E+01	6.71E+00	3.32E-17	1.01E-04	1.00E-03	4.00E-03	3.80E-02	3.79E-04
BATCH-52	1/4/17	242	25.2	0.24	5.00E-03	5.00E-03	1.34E-01	2.13E-01	1.16E-01	5.63E+00	1.07E+00	1.06E+01	6.39E+00	7.01E-18	1.01E-04	1.00E-03	3.00E-03	3.70E-02	3.79E-04
BATCH-53	1/20/17	1676	168.4	0.23	6.00E-02	4.70E-02	1.67E+00	2.25E+00	1.69E+00	8.68E+01	1.47E+01	1.09E+02	5.73E+01	8.75E-17	1.00E-03	4.00E-03	3.10E-02	2.28E-01	9.21E-04
BATCH-54	3/23/17	237	24.7	0.24	5.00E-03	5.00E-03	1.31E-01	2.09E-01	1.14E-01	5.55E+00	1.06E+00	1.04E+01	6.26E+00	6.90E-18	9.94E-05	1.00E-03	3.00E-03	3.60E-02	3.66E-04
BATCH-55	6/13/17	358	37.4	0.24	9.00E-03	9.00E-03	2.56E-01	4.77E-01	2.42E-01	1.38E+01	2.72E+00	2.45E+01	1.83E+01	2.80E-17	2.55E-04	2.00E-03	5.20E-02	8.75E-01	3.22E-04
BATCH-56	7/12/17	1681	168.9	0.23	6.20E-02	4.90E-02	1.70E+00	2.31E+00	1.74E+00	8.93E+01	1.52E+01	1.11E+02	5.90E+01	9.01E-17	1.00E-03	4.00E-03	3.00E-02	2.20E-01	8.74E-04
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	9.00E-03	9.00E-03	2.56E-01	4.78E-01	2.43E-01	1.39E+01	2.72E+00	2.46E+01	1.83E+01	2.80E-17	2.55E-04	2.00E-03	5.20E-02	8.74E-01	3.14E-04
BATCH-58	12/25/17	358	37.4	0.24	9.00E-03	9.00E-03	2.56E-01	4.78E-01	2.43E-01	1.39E+01	2.72E+00	2.46E+01	1.83E+01	2.80E-17	2.55E-04	2.00E-03	5.20E-02	8.74E-01	3.14E-04
BATCH-59	1/2/18	353	36.8	0.24	1.40E-02	1.10E-02	5.01E-01	6.11E-01	4.93E-01	2.48E+01	4.28E+00	3.12E+01	1.62E+01	5.66E-18	2.80E-04	1.00E-03	4.00E-03	2.50E-02	1.88E-04
BATCH-60	2/1/18	353	36.8	0.24	1.40E-02	1.10E-02	5.01E-01	6.11E-01	4.92E-01	2.48E+01	4.28E+00	3.12E+01	1.62E+01	5.66E-18	2.80E-04	1.00E-03	4.00E-03	2.50E-02	1.88E-04
BATCH-61	2/8/18	352	36.7	0.24	1.40E-02	1.10E-02	5.00E-01	6.11E-01	4.92E-01	2.48E+01	4.27E+00	3.12E+01	1.62E+01	5.64E-18	2.79E-04	1.00E-03	4.00E-03	2.50E-02	1.87E-04
BATCH-62	3/10/18	351	36.7	0.24	1.40E-02	1.10E-02	4.99E-01	6.09E-01	4.91E-01	2.47E+01	4.26E+00	3.11E+01	1.62E+01	5.64E-18	2.79E-04	1.00E-03	4.00E-03	2.50E-02	1.87E-04
BATCH-63	3/17/18	343	35.8	0.24	1.60E-02	1.20E-02	5.08E-01	6.53E-01	4.84E-01	2.49E+01	4.25E+00	2.92E+01	1.60E+01	5.68E-18	2.78E-04	1.00E-03	6.00E-03	6.30E-02	3.85E-06
BATCH-64	4/15/18	343	35.8	0.24	1.60E-02	1.20E-02	5.09E-01	6.54E-01	4.84E-01	2.49E+01	4.25E+00	2.92E+01	1.60E+01	5.67E-18	2.78E-04	1.00E-03	6.00E-03	6.30E-02	7.83E-08
BATCH-65	4/22/18	343	35.8	0.24	1.60E-02	1.20E-02	5.08E-01	6.54E-01	4.84E-01	2.49E+01	4.25E+00	2.92E+01	1.60E+01	5.67E-18	2.78E-04	1.00E-03	6.00E-03	6.30E-02	1.72E-07
BATCH-66	5/21/18	343	35.7	0.24	1.60E-02	1.20E-02	5.08E-01	6.53E-01	4.83E-01	2.49E+01	4.24E+00	2.91E+01	1.60E+01	5.67E-18	2.78E-04	1.00E-03	6.00E-03	6.30E-02	1.72E-07
BATCH-67	5/28/18	342	35.7	0.24	1.60E-02	1.20E-02	5.07E-01	6.52E-01	4.83E-01	2.48E+01	4.24E+00	2.91E+01	1.59E+01	5.66E-18	2.77E-04	1.00E-03	6.00E-03	6.30E-02	1.72E-07
BATCH-68	6/26/18	324	33.8	0.24	8.00E-03	8.00E-03	2.14E-01	4.52E-01	2.34E-01	1.35E+01	2.63E+00	2.36E+01	1.68E+01	5.86E-18	2.45E-04	2.00E-03	5.00E-02	8.34E-01	7.43E-05
BATCH-69	7/3/18	286	29.8	0.24	1.00E-02	8.00E-03	4.47E-01	4.03E-01	2.97E-01	1.53E+01	2.62E+00	1.81E+01	9.80E+00	3.51E-18	1.73E-04	6.76E-04	1.00E-02	4.60E-02	2.01E-05
BATCH-70	7/30/18	198	20.7	0.24	7.65E-05	5.25E-05	3.53E-01	8.00E-03	2.00E-03	1.54E-01	3.60E-02	5.07E-01	5.20E-02	9.49E-20	6.97E-06	1.31E-05	1.70E-02	1.90E-02	5.19E-05
BATCH-71	8/2/18	198	20.6	0.24	7.65E-05	5.25E-05	3.53E-01	8.00E-03	2.00E-03	1.54E-01	3.50E-02	5.07E-01	5.20E-02	9.48E-20	6.97E-06	1.31E-05	1.70E-02	1.90E-02	5.18E-05
BATCH-72	8/20/18	198	20.6	0.24	7.64E-05	5.24E-05	3.53E-01	8.00E-03	2.00E-03	1.54E-01	3.50E-02	5.07E-01	5.20E-02	9.47E-20	6.96E-06	1.31E-05	1.70E-02	1.90E-02	5.18E-05
BATCH-73	8/22/18	198	20.6	0.24	7.63E-05	5.24E-05	3.52E-01	8.00E-03	2.00E-03	1.54E-01	3.50E-02	5.06E-01	5.20E-02	9.47E-20	6.96E-06	1.31E-05	1.70E-02	1.90E-02	5.18E-05
BATCH-74	9/10/18	197	20.6	0.24	7.62E-05	5.23E-05	3.52E-01	8.00E-03	2.00E-03	1.53E-01	3.50E-02	5.05E-01	5.10E-02	9.45E-20	6.94E-06	1.31E-05	1.70E-02	1.90E-02	5.17E-05
BATCH-75	9/12/18	200	20.8	0.24	3.28E-04	1.23E-04	7.90E-02	9.10E-02	8.00E-03	1.44E+00	3.76E-01	3.01E+00	2.42E-01	6.04E-19	9.04E-05	2.12E-05	4.00E-03	1.20E-02	7.34E-04
BATCH-76	10/1/18	324	33.8	0.24	8.00E-03	8.00E-03	2.14E-01	4.52E-01	2.34E-01	1.35E+01	2.63E+00	2.36E+01	1.68E+01	5.86E-18	2.45E-04	2.00E-03	5.00E-02	8.34E-01	7.43E-05
BATCH-77	10/3/18	199	20.8	0.24	3.84E-04	1.37E-04	1.20E-02	1.11E-01	9.00E-03	1.74E+00	4.56E-01	3.60E+00	2.84E-01	7.23E-19	1.10E-04	2.28E-05	9.07E-04	1.00E-02	8.96E-04
BATCH-78	10/24/18	199	20.8	0.24	3.84E-04	1.37E-04	1.20E-02	1.11E-01	9.00E-03	1.74E+00	4.56E-01	3.60E+00	2.84E-01	7.23E-19	1.10E-04	2.28E-05	9.07E-04	1.00E-02	8.95E-04
BATCH-79	11/4/18	199	20.8	0.24	3.83E-04	1.37E-04	1.20E-02	1.11E-01	9.00E-03	1.74E+00	4.55E-01	3.59E+00	2.83E-01	7.22E-19	1.10E-04	2.28E-05	9.06E-04	1.00E-02	8.94E-04
BATCH-80	11/14/18	199	20.7	0.24	3.83E-04	1.37E-04	1.20E-02	1.10E-01	9.00E-03	1.74E+00	4.55E-01	3.59E+00	2.83E-01	7.21E-19	1.10E-04	2.28E-05	9.05E-04	1.00E-02	8.93E-04
BATCH-81	11/25/18	184	19.2	0.24	4.50E-04	3.23E-04	1.60E-02	9.70E-02	1.00E-02	1.64E+00	4.20E-01	3.33E+00	4.61E-01	6.21E-19	9.65E-05	2.22E-05	2.00E-03	1.70E-02	7.57E-04
BATCH-82	12/5/18	163	17.0	0.24	8.30E-04	1.00E-03	3.40E-02	6.40E-02	1.80E-02	1.61E+00	3.69E-01	3.02E+00	1.30E+00	3.46E-19	6.31E-05	2.49E-05	5.00E-03	4.70E-02	3.67E-04
BATCH-83	12/14/18	157	16.4	0.24	8.01E-04	1.00E-03	3.30E-02	6.20E-02	1.80E-02	1.56E+00	3.56E-01	2.91E+00	1.25E+00	3.34E-19	6.08E-05	2.40E-05	5.00E-03	4.50E-02	3.54E-04
BATCH-84	12/22/18	104	10.8	0.24	3.00E-03	3.00E-03	6.80E-02	1.45E-01	7.50E-02	4.31E+00	8.41E-01	7.55E+00	5.38E+00	1.87E-18	7.84E-05	5.49E-04	1.60E-02	2.67E-01	2.38E-05
BATCH-85	12/31/18	157	16.4	0.24	8.00E-04	1.00E-03	3.30E-02	6.20E-02	1.80E-02	1.56E+00	3.56E-01	2.91E+00	1.25E+00	3.34E-19	6.08E-05	2.40E-05	5.00E-03	4.50E-02	3.54E-04
BATCH-86	1/2/19	157	16.4	0.24	8.00E-04	1.00E-03	3.30E-02	6.10E-02	1.80E-02	1.56E+00	3.55E-01	2.91E+00	1.19E+00	7.09E-20	6.08E-05	2.39E-05	5.00E-03	4.40E-02	3.54E-04
BATCH-87	1/16/19	157	16.4	0.24	7.99E-04	1.00E-03	3.30E-02	6.10E-02	1.80E-02	1.55E+00	3.55E-01	2.90E+00	1.19E+00	7.08E-20	6.07E-05	2.39E-05	5.00E-03	4.40E-02	3.53E-04
BATCH-88	1/19/19	146	15.2	0.24	7.42E-04	1.00E-03	3.10E-02	5.70E-02	1.70E-02	1.44E+00	3.30E-01	2.70E+00	1.11E+00	6.58E-20	5.64E-05	2.22E-05	4.00E-03	4.10E-02	3.28E-04
BATCH-89	2/2/19	201	21.0	0.24	7.00E-03	6.00E-03	2.21E-01	2.78E-01	2.05E-01	1.08E+01	1.85E+00	1.76E+01	6.39E+00	4.79E-19	1.42E-04	7.51E-04	5.00E-03	4.50E-02	2.99E-04
BATCH-90	2/3/19	273	28.5	0.24	1.30E-02	1.00E-02	4.01E-01	4.90E-01	3.80E-01	1.96E+01	3.30E+00	3.17E+01	1.14E+01	8.69E-19	2.29E-04	1.00E-03	6.00E-03	5.50E-02	3.21E-04
BATCH-91	2/23/19	273	28.5	0.24	1.30E-02	1.00E-02	4.01E-01	4.90E-01	3.80E-01	1.96E+01	3.30E+00	3.17E+01	1.14E+01	8.68E-19	2.29E-04	1.00E-03	6.00E-03	5.50E-02	3.21E-04
BATCH-92	3/4/19	322	33.5	0.24	8.00E-03	8.00E-03	2.12E-01	4.53E-01	2.35E-01	1.35E+01	2.65E+00	2.24E+01	1.61E+01	1.25E-18	2.53E-04	2.00E-03	4.90E-02	8.09E-01	9.05E-05
BATCH-93	3/24/19	273	28.5	0.24	1.30E-02	1.00E-02	4.01E-01	4.90E-01	3.80E-01	1.96E+01	3.30E+00	3.17E+01	1.14E+01	8.68E-19	2.29E-04	1.00E-03	6.00E-03	5.50E-02	3.21E-04
BATCH-94	4/7/19	273	28.5	0.24	1.30E-02	1.00E-02	4.01E-01	4.89E-01	3.80E-01	1.96E+01	3.30E+00	3.17E+01	1.14E+01	8.68E-19	2.29E-04	1.00E-03	6.00E-03	5.50E-02	3.21E-04
BATCH-95	4/21/19	254	26.5	0.24	1.20E-02	9.00E-03	3.73E-01	4.55E-01	3.53E-01	1.82E+01	3.06E+00	2.94E+01	1.06E+01	8.07E-19	2.13E-04	1.00E-03	6.00E-03	5.10E-02	2.98E-04
BATCH-96	5/5/19	245	25.5	0.24	1.20E-02	9.00E-03	3.59E-01	4.38E-01	3.40E-01	1.75E+01	2.95E+00	2.83E+01	1.02E+01	7.77E-19	2.05E-04	1.00E-03	6.00E-03	4.90E-02	2.87E-04
BATCH-97	5/18/19	272	28.3	0.24	1.30E-02	1.00E-02	3.99E-01	4.87E-01	3.78E-01	1.95E+01	3.28E+00	3.15E+01	1.13E+01	8.64E-19	2.28E-04	1.00E-03	6.00E-03	5.40E-02	3.19E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-50	8/6/16	1629	163.5	0.23	0.00E+00	2.10E+03	2.73E-04	4.60E-02	2.55E-04	0.00E+00	5.00E-03	3.04E-01	3.00E-03	1.02E-01	2.97E+02	0.00E+00	0.00E+00	8.88E+01	8.21E-03
BATCH-51	10/17/16	242	25.2	0.24	2.49E+02	8.42E+01	6.61E-05	4.30E-02	2.71E-04	0.00E+00	9.26E-04	6.98E-01	2.00E-03	5.00E-03	3.31E+01	0.00E+00	7.73E+00	3.64E+00	7.32E-03
BATCH-52	1/4/17	242	25.2	0.24	2.49E+02	8.42E+01	6.61E-05	4.30E-02	2.71E-04	0.00E+00	9.26E-04	6.98E-01	2.00E-03	5.00E-03	3.31E+01	0.00E+00	7.73E+00	3.64E+00	7.32E-03
BATCH-53	1/20/17	1676	168.4	0.23	0.00E+00	1.64E+03	5.46E-04	1.07E-01	2.00E-03	0.00E+00	2.00E-03	9.93E-01	1.40E-02	1.07E-01	3.15E+02	0.00E+00	0.00E+00	1.09E+02	5.74E-02
BATCH-54	3/23/17	237	24.7	0.24	2.43E+02	8.29E+01	6.43E-05	4.10E-02	2.64E-04	0.00E+00	8.98E-04	6.80E-01	2.00E-03	5.00E-03	3.24E+01	0.00E+00	7.58E+00	3.59E+00	7.13E-03
BATCH-55	6/13/17	358	37.4	0.24	3.07E+02	2.39E+02	1.40E-04	4.40E-02	1.00E-04	0.00E+00	3.70E-02	1.70E+00	6.50E-04	1.20E-02	5.24E+01	0.00E+00	7.95E+00	9.87E+00	6.19E-03
BATCH-56	7/12/17	1681	168.9	0.23	0.00E+00	1.67E+03	3.01E-04	6.90E-02	2.00E-03	0.00E+00	2.00E-03	9.69E-01	1.30E-02	1.10E-01	3.19E+02	0.00E+00	0.00E+00	1.12E+02	5.47E-02
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	3.07E+02	2.39E+02	1.40E-04	4.30E-02	1.01E-04	0.00E+00	3.70E-02	1.70E+00	6.50E-04	1.20E-02	5.24E+01	0.00E+00	7.95E+00	9.91E+00	3.24E-02
BATCH-58	12/25/17	358	37.4	0.24	3.07E+02	2.39E+02	1.40E-04	4.30E-02	1.01E-04	0.00E+00	3.70E-02	1.70E+00	6.50E-04	1.20E-02	5.24E+01	0.00E+00	7.95E+00	9.91E+00	3.24E-02
BATCH-59	1/2/18	353	36.8	0.24	3.00E-03	8.99E+02	9.13E-04	5.02E-07	3.68E-04	5.55E-10	1.75E-07	1.40E-01	1.00E-03	1.18E-13	1.26E+02	0.00E+00	1.43E-04	2.89E+00	9.17E-04
BATCH-60	2/1/18	353	36.8	0.24	0.00E+00	8.99E+02	9.13E-04	0.00E+00	3.67E-04	0.00E+00	0.00E+00	1.40E-01	1.00E-03	1.17E-13	1.26E+02	0.00E+00	0.00E+00	2.89E+00	9.17E-04
BATCH-61	2/8/18	352	36.7	0.24	0.00E+00	8.98E+02	9.12E-04	0.00E+00	3.67E-04	0.00E+00	0.00E+00	1.40E-01	1.00E-03	1.17E-13	1.26E+02	0.00E+00	0.00E+00	2.88E+00	9.17E-04
BATCH-62	3/10/18	351	36.7	0.24	0.00E+00	8.96E+02	9.10E-04	0.00E+00	3.66E-04	0.00E+00	0.00E+00	1.39E-01	1.00E-03	1.17E-13	1.26E+02	0.00E+00	0.00E+00	2.00E+01	9.71E-04
BATCH-63	3/17/18	343	35.8	0.24	0.00E+00	6.79E+02	1.83E-05	1.08E-05	7.45E-06	0.00E+00	3.00E-03	1.70E-02	3.93E-04	1.50E-02	9.72E+01	0.00E+00	0.00E+00	2.03E+01	9.71E-04
BATCH-64	4/15/18	343	35.8	0.24	0.00E+00	6.74E+02	2.55E-08	1.10E-05	8.35E-08	0.00E+00	3.00E-03	1.40E-02	3.75E-04	1.50E-02	9.66E+01	0.00E+00	7.17E-08	2.03E+01	9.71E-04
BATCH-65	4/22/18	343	35.8	0.24	1.33E-06	6.74E+02	4.82E-07	1.10E-05	2.67E-07	2.77E-13	3.00E-03	1.40E-02	3.75E-04	1.50E-02	9.65E+01	0.00E+00	0.00E+00	2.03E+01	9.71E-04
BATCH-66	5/21/18	343	35.7	0.24	0.00E+00	6.73E+02	4.82E-07	1.10E-05	2.67E-07	0.00E+00	3.00E-03	1.40E-02	3.74E-04	1.50E-02	9.64E+01	0.00E+00	0.00E+00	2.02E+01	9.71E-04
BATCH-67	5/28/18	342	35.7	0.24	0.00E+00	6.72E+02	4.81E-07	1.10E-05	2.67E-07	0.00E+00	3.00E-03	1.40E-02	3.74E-04	1.50E-02	9.64E+01	0.00E+00	6.49E+00	9.55E+00	2.92E-02
BATCH-68	6/26/18	324	33.8	0.24	2.90E+02	2.15E+02	1.16E-04	1.10E-02	7.63E-05	0.00E+00	3.70E-02	1.59E+00	3.66E-04	1.10E-02	4.74E+01	0.00E+00	0.00E+00	1.58E+01	1.19E-03
BATCH-69	7/3/18	286	29.8	0.24	0.00E+00	5.37E+02	3.29E-04	8.62E-04	5.73E-04	4.00E-03	3.80E-02	5.89E-01	4.00E-03	1.30E-02	8.29E+01	0.00E+00	0.00E+00	8.89E+00	1.54E-03
BATCH-70	7/30/18	198	20.7	0.24	0.00E+00	3.24E+02	8.55E-04	2.00E-03	1.00E-03	1.20E-02	9.30E-02	1.51E+00	9.00E-03	6.18E+01	6.17E+01	0.00E+00	0.00E+00	8.89E+00	1.54E-03
BATCH-71	8/2/18	198	20.6	0.24	0.00E+00	3.24E+02	8.55E-04	2.00E-03	1.00E-03	1.20E-02	9.30E-02	1.51E+00	9.00E-03	9.00E-03	6.17E+01	0.00E+00	3.57E-11	8.88E+00	1.54E-03
BATCH-72	8/20/18	198	20.6	0.24	6.62E-10	3.24E+02	8.54E-04	2.00E-03	1.00E-03	1.20E-02	9.30E-02	1.51E+00	9.00E-03	6.16E+01	6.17E+01	0.00E+00	0.00E+00	8.87E+00	1.54E-03
BATCH-73	8/22/18	198	20.6	0.24	0.00E+00	3.23E+02	8.53E-04	2.00E-03	1.00E-03	1.20E-02	9.30E-02	1.51E+00	9.00E-03	6.15E+01	6.16E+01	0.00E+00	0.00E+00	8.85E+00	1.54E-03
BATCH-74	9/10/18	197	20.6	0.24	0.00E+00	3.23E+02	8.51E-04	2.00E-03	1.00E-03	1.20E-02	9.30E-02	1.50E+00	9.00E-03	6.15E+01	5.46E+01	0.00E+00	0.00E+00	6.30E+00	6.99E-03
BATCH-75	9/12/18	200	20.8	0.24	0.00E+00	2.66E+02	1.68E-04	3.10E-02	2.94E-04	2.00E-03	1.34E+00	1.30E+00	2.00E-03	1.52E-01	4.74E+01	0.00E+00	6.49E+00	9.55E+00	2.92E-02
BATCH-76	10/1/18	324	33.8	0.24	2.90E+02	2.15E+02	1.16E-04	1.10E-02	7.63E-05	0.00E+00	3.70E-02	1.59E+00	3.66E-04	1.10E-02	4.74E+01	0.00E+00	0.00E+00	5.65E+00	8.28E-03
BATCH-77	10/3/18	199	20.8	0.24	0.00E+00	2.51E+02	2.33E-06	3.80E-02	5.89E-06	5.16E-06	1.64E+00	1.24E+00	1.09E-04	1.85E-01	5.27E+01	0.00E+00	0.00E+00	5.65E+00	8.28E-03
BATCH-78	10/24/18	199	20.8	0.24	0.00E+00	2.51E+02	2.33E-06	3.80E-02	5.88E-06	5.15E-06	1.64E+00	1.24E+00	1.09E-04	1.85E-01	5.27E+01	0.00E+00	1.57E-14	5.65E+00	8.25E-03
BATCH-79	11/4/18	199	20.8	0.24	2.92E-13	2.51E+02	2.32E-06	3.80E-02	5.87E-06	5.15E-06	1.63E+00	1.24E+00	1.09E-04	1.85E-01	5.26E+01	0.00E+00	0.00E+00	5.64E+00	8.25E-03
BATCH-80	11/14/18	199	20.7	0.24	0.00E+00	2.50E+02	2.32E-06	3.80E-02	5.87E-06	5.15E-06	1.63E+00	1.24E+00	1.09E-04	1.85E-01	5.26E+01	0.00E+00	0.00E+00	5.64E+00	8.25E-03
BATCH-81	11/25/18	184	19.2	0.24	0.00E+00	2.22E+02	1.07E-04	4.00E-02	6.56E-05	4.64E-06	1.26E+00	1.06E+00	1.75E-04	1.70E-01	4.86E+01	0.00E+00	0.00E+00	4.96E+00	3.27E-02
BATCH-82	12/5/18	163	17.0	0.24	0.00E+00	1.55E+02	5.63E-04	5.60E-02	3.27E-04	1.07E-06	1.00E-02	5.80E-01	4.86E-04	1.46E-01	4.31E+01	0.00E+00	0.00E+00	3.29E+00	1.41E-01
BATCH-83	12/14/18	157	16.4	0.24	0.00E+00	1.49E+02	5.43E-04	5.40E-02	3.15E-04	2.52E-09	1.00E-02	5.59E-01	4.68E-04	1.41E-01	4.16E+01	0.00E+00	0.00E+00	3.17E+00	1.36E-01
BATCH-84	12/22/18	104	10.8	0.24	9.28E+01	6.87E+01	3.70E-05	4.00E-03	2.44E-05	0.00E+00	1.20E-02	5.09E-01	1.17E-04	4.00E-03	1.52E+01	0.00E+00	2.08E+00	3.06E+00	9.33E-03
BATCH-85	12/31/18	157	16.4	0.24	0.00E+00	1.49E+02	5.43E-04	5.40E-02	3.15E-04	2.51E-09	1.00E-02	5.59E-01	4.67E-04	1.41E-01	4.15E+01	0.00E+00	0.00E+00	3.17E+00	1.36E-01
BATCH-86	1/2/19	157	16.4	0.24	1.43E-16	1.49E+02	5.43E-04	5.40E-02	3.15E-04	2.51E-09	1.00E-02	5.59E-01	4.67E-04	1.41E-01	4.15E+01	0.00E+00	7.67E-18	3.17E+00	1.36E-01
BATCH-87	1/16/19	157	16.4	0.24	0.00E+00	1.49E+02	5.42E-04	5.40E-02	3.14E-04	2.51E-09	1.00E-02	5.58E-01	4.67E-04	1.41E-01	4.15E+01	0.00E+00	0.00E+00	3.16E+00	1.36E-01
BATCH-88	1/19/19	146	15.2	0.24	0.00E+00	1.38E+02	5.04E-04	5.00E-02	2.92E-04	2.43E-09	9.00E-03	5.19E-01	4.34E-04	1.31E-01	3.85E+01	0.00E+00	0.00E+00	2.94E+00	1.26E-01
BATCH-89	2/2/19	201	21.0	0.24	0.00E+00	2.93E+02	3.23E-04	3.30E-02	2.11E-04	5.57E-10	5.00E-03	3.52E-01	7.63E-04	6.40E-02	5.44E+01	0.00E+00	0.00E+00	1.40E+01	8.55E-02
BATCH-90	2/3/19	273	28.5	0.24	0.00E+00	4.55E+02	2.30E-04	2.50E-02	1.79E-04	1.81E-12	2.00E-03	2.74E-01	1.00E-03	2.20E-02	7.46E+01	0.00E+00	0.00E+00	2.46E+01	6.66E-02
BATCH-91	2/23/19	273	28.5	0.24	0.00E+00	4.55E+02	2.30E-04	2.50E-02	1.79E-04	1.81E-12	2.00E-03	2.74E-01	1.00E-03	2.20E-02	7.46E+01	0.00E+00	0.00E+00	2.46E+01	6.66E-02
BATCH-92	3/4/19	322	33.5	0.24	2.90E+02	2.14E+02	9.16E-05	1.20E-02	5.43E-05	0.00E+00	3.70E-02	1.55E+00	1.53E-04	1.10E-02	4.70E+01	0.00E+00	6.33E+00	9.61E+00	4.90E-02
BATCH-93	3/24/19	273	28.5	0.24	1.03E-19	4.54E+02	2.30E-04	2.50E-02	1.79E-04	1.81E-12	2.00E-03	2.74E-01	1.00E-03	2.20E-02	7.46E+01	0.00E+00	5.52E-21	2.46E+01	6.66E-02
BATCH-94	4/7/19	273	28.5	0.24	0.00E+00	4.54E+02	2.30E-04	2.50E-02	1.79E-04	1.80E-12	2.00E-03	2.74E-01	1.00E-03	2.20E-02	7.46E+01	0.00E+00	0.00E+00	2.46E+01	6.65E-02
BATCH-95	4/21/19	254	26.5	0.24	0.00E+00	4.22E+02	2.13E-04	2.30E-02	1.66E-04	1.88E-12	2.00E-03	2.55E-01	1.00E-03	2.00E-02	6.93E+01	0.00E+00	0.00E+00	2.28E+01	6.19E-02
BATCH-96	5/5/19	245	25.5	0.24	0.00E+00	4.07E+02	2.05E-04	2.20E-02	1.60E-04	4.46E-13	2.00E-03	2.45E-01	1.00E-03	1.90E-02	6.67E+01	0.00E+00	0.00E+00	2.20E+01	5.95E-02
BATCH-97	5/18/19	272	28.3	0.24	0.00E+00	4.52E+02	2.28E-04	2.50E-02	1.78E-04	1.30E-15	2.00E-03	2.72E-01	1.00E-03	2.10E-02	7.42E+01	0.00E+00	0.00E+00	2.45E+01	6.62E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-50	8/6/16	1629	163.5	0.23	5.05E-05	1.40E+02	1.46E-01	0.00E+00	0.00E+00	1.24E-02	1.76E+02	5.87E-05	3.00E-03	1.00E-02	8.03E+00	3.03E-04	1.86E+04	0.00E+00	1.44E+00
BATCH-51	10/17/16	242	25.2	0.24	1.38E-04	1.86E+02	5.08E-01	0.00E+00	0.00E+00	1.20E-03	5.37E+01	2.00E-03	3.00E-03	1.60E-02	6.73E-01	7.00E-03	2.88E+03	0.00E+00	4.51E-01
BATCH-52	1/4/17	242	25.2	0.24	1.38E-04	1.86E+02	5.08E-01	0.00E+00	0.00E+00	1.20E-03	5.37E+01	2.00E-03	3.00E-03	1.60E-02	6.73E-01	7.00E-03	2.88E+03	0.00E+00	4.51E-01
BATCH-53	1/20/17	1676	168.4	0.23	9.16E-04	1.51E+02	1.07E+00	0.00E+00	0.00E+00	1.70E-02	2.33E+02	5.93E-04	1.80E-02	1.60E-02	1.20E+01	8.00E-03	1.92E+04	0.00E+00	3.47E+00
BATCH-54	3/23/17	237	24.7	0.24	1.35E-04	1.81E+02	4.95E-01	0.00E+00	0.00E+00	1.20E-03	5.23E+01	2.00E-03	3.00E-03	1.60E-02	6.62E-01	7.00E-03	2.81E+03	0.00E+00	4.40E-01
BATCH-55	6/13/17	358	37.4	0.24	7.59E-06	2.47E+02	4.35E-01	0.00E+00	0.00E+00	9.40E-03	5.86E+01	3.00E-03	1.00E-03	1.80E-02	8.40E-01	5.00E-03	4.26E+03	0.00E+00	6.32E-01
BATCH-56	7/12/17	1681	168.9	0.23	9.28E-04	1.37E+02	1.10E+00	0.00E+00	0.00E+00	1.74E-02	2.09E+02	5.86E-04	1.70E-02	8.00E-03	1.24E+01	8.00E-03	1.93E+04	0.00E+00	3.59E+00
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	8.07E-06	2.47E+02	4.35E-01	0.00E+00	0.00E+00	9.40E-03	5.83E+01	3.00E-03	1.00E-03	1.80E-02	8.47E-01	5.00E-03	4.26E+03	0.00E+00	6.33E-01
BATCH-58	12/25/17	358	37.4	0.24	8.07E-06	2.47E+02	4.35E-01	0.00E+00	0.00E+00	9.40E-03	5.83E+01	3.00E-03	1.00E-03	1.80E-02	8.47E-01	5.00E-03	4.26E+03	0.00E+00	6.33E-01
BATCH-59	1/2/18	353	36.8	0.24	1.51E-06	1.27E+01	5.00E-03	0.00E+00	0.00E+00	5.55E-07	9.35E+01	2.69E-08	5.00E-03	5.20E-02	1.99E-05	5.34E-08	6.03E+03	0.00E+00	2.50E-02
BATCH-60	2/1/18	353	36.8	0.24	1.51E-06	1.27E+01	5.00E-03	0.00E+00	0.00E+00	5.49E-07	9.35E+01	0.00E+00	5.00E-03	5.20E-02	1.81E-05	0.00E+00	6.03E+03	0.00E+00	2.50E-02
BATCH-61	2/8/18	352	36.7	0.24	1.51E-06	1.27E+01	5.00E-03	0.00E+00	0.00E+00	5.49E-07	9.32E+01	0.00E+00	5.00E-03	5.10E-02	1.80E-05	0.00E+00	6.02E+03	0.00E+00	2.50E-02
BATCH-62	3/10/18	351	36.7	0.24	1.50E-06	1.26E+01	5.00E-03	0.00E+00	0.00E+00	5.47E-07	9.32E+01	0.00E+00	5.00E-03	5.10E-02	1.80E-05	0.00E+00	6.01E+03	0.00E+00	2.50E-02
BATCH-63	3/17/18	343	35.8	0.24	9.53E-08	3.83E+01	5.00E-03	0.00E+00	0.00E+00	5.60E-03	6.90E+01	9.68E-08	1.00E-04	2.00E-03	1.00E+00	2.87E-07	5.87E+03	0.00E+00	5.99E-01
BATCH-64	4/15/18	343	35.8	0.24	6.64E-08	3.88E+01	5.00E-03	0.00E+00	0.00E+00	5.60E-03	6.85E+01	9.87E-08	2.42E-06	1.00E-03	1.02E+00	2.93E-07	5.86E+03	0.00E+00	6.11E-01
BATCH-65	4/22/18	343	35.8	0.24	6.71E-08	3.88E+01	5.00E-03	0.00E+00	0.00E+00	5.60E-03	6.85E+01	9.86E-08	4.86E-06	1.00E-03	1.02E+00	2.93E-07	5.86E+03	0.00E+00	6.10E-01
BATCH-66	5/21/18	343	35.7	0.24	6.71E-08	3.87E+01	5.00E-03	0.00E+00	0.00E+00	5.60E-03	6.84E+01	9.85E-08	4.86E-06	1.00E-03	1.02E+00	2.92E-07	5.85E+03	0.00E+00	6.09E-01
BATCH-67	5/28/18	342	35.7	0.24	6.70E-08	3.87E+01	5.00E-03	0.00E+00	0.00E+00	5.60E-03	6.83E+01	9.84E-08	4.85E-06	1.00E-03	1.02E+00	2.92E-07	5.85E+03	0.00E+00	6.09E-01
BATCH-68	6/26/18	324	33.8	0.24	2.95E-06	2.43E+02	4.04E-01	0.00E+00	0.00E+00	9.40E-03	4.45E+01	8.86E-04	2.03E-04	3.00E-03	7.85E-01	9.36E-05	3.85E+03	0.00E+00	5.83E-01
BATCH-69	7/3/18	286	29.8	0.24	4.14E-08	2.78E+01	3.90E-02	0.00E+00	0.00E+00	3.60E-03	5.15E+01	4.00E-03	3.99E-06	6.78E-04	9.09E-01	1.22E-04	4.89E+03	0.00E+00	5.14E-01
BATCH-70	7/30/18	198	20.7	0.24	4.74E-11	1.07E+01	9.40E-02	0.00E+00	0.00E+00	1.99E-04	2.48E+01	9.00E-03	2.56E-07	1.03E-06	7.42E-01	3.17E-04	3.38E+03	0.00E+00	3.66E-01
BATCH-71	8/2/18	198	20.6	0.24	3.30E-11	1.06E+01	9.40E-02	0.00E+00	0.00E+00	1.99E-04	2.48E+01	9.00E-03	2.07E-07	5.30E-07	7.42E-01	3.17E-04	3.38E+03	0.00E+00	3.66E-01
BATCH-72	8/20/18	198	20.6	0.24	3.34E-11	1.06E+01	9.40E-02	0.00E+00	0.00E+00	1.99E-04	2.47E+01	9.00E-03	2.08E-07	5.43E-07	7.41E-01	3.17E-04	3.38E+03	0.00E+00	3.66E-01
BATCH-73	8/22/18	198	20.6	0.24	3.33E-11	1.06E+01	9.40E-02	0.00E+00	0.00E+00	1.99E-04	2.47E+01	9.00E-03	2.08E-07	5.42E-07	7.41E-01	3.16E-04	3.38E+03	0.00E+00	3.65E-01
BATCH-74	9/10/18	197	20.6	0.24	3.33E-11	1.06E+01	9.40E-02	0.00E+00	0.00E+00	1.98E-04	2.47E+01	9.00E-03	2.07E-07	5.41E-07	7.39E-01	3.16E-04	3.37E+03	0.00E+00	3.65E-01
BATCH-75	9/12/18	200	20.8	0.24	9.76E-09	6.62E+01	7.65E-01	0.00E+00	0.00E+00	2.80E-03	1.84E+01	3.00E-03	3.45E-05	9.01E-06	2.39E-01	4.00E-03	3.41E+03	0.00E+00	7.69E-01
BATCH-76	10/1/18	324	33.8	0.24	2.95E-06	2.43E+02	4.04E-01	0.00E+00	0.00E+00	9.40E-03	4.45E+01	8.86E-04	2.03E-04	3.00E-03	7.85E-01	9.36E-05	3.85E+03	0.00E+00	5.83E-01
BATCH-77	10/3/18	199	20.8	0.24	1.20E-08	7.93E+01	9.23E-01	0.00E+00	0.00E+00	3.40E-03	1.68E+01	9.79E-04	4.26E-05	1.08E-05	1.17E-01	5.00E-03	3.41E+03	0.00E+00	8.63E-01
BATCH-78	10/24/18	199	20.8	0.24	1.20E-08	7.93E+01	9.23E-01	0.00E+00	0.00E+00	3.40E-03	1.68E+01	9.79E-04	4.26E-05	1.08E-05	1.17E-01	5.00E-03	3.40E+03	0.00E+00	8.62E-01
BATCH-79	11/4/18	199	20.8	0.24	1.20E-08	7.92E+01	9.22E-01	0.00E+00	0.00E+00	3.40E-03	1.68E+01	9.78E-04	4.25E-05	1.08E-05	1.17E-01	5.00E-03	3.40E+03	0.00E+00	8.62E-01
BATCH-80	11/14/18	199	20.7	0.24	1.20E-08	7.91E+01	9.21E-01	0.00E+00	0.00E+00	3.40E-03	1.68E+01	9.77E-04	4.25E-05	1.08E-05	1.16E-01	5.00E-03	3.40E+03	0.00E+00	8.61E-01
BATCH-81	11/25/18	184	19.2	0.24	7.30E-07	8.28E+01	8.06E-01	0.00E+00	0.00E+00	2.80E-03	1.78E+01	8.42E-04	6.65E-05	3.00E-03	9.50E-02	4.00E-03	3.14E+03	0.00E+00	6.92E-01
BATCH-82	12/5/18	163	17.0	0.24	3.86E-06	1.17E+02	5.12E-01	0.00E+00	0.00E+00	4.00E-04	2.60E+01	4.73E-04	1.80E-04	1.40E-02	2.80E-02	7.68E-04	2.78E+03	0.00E+00	1.51E-01
BATCH-83	12/14/18	157	16.4	0.24	3.72E-06	1.13E+02	4.94E-01	0.00E+00	0.00E+00	4.00E-04	2.50E+01	4.56E-04	1.74E-04	1.30E-02	2.60E-02	7.42E-04	2.68E+03	0.00E+00	1.46E-01
BATCH-84	12/22/18	104	10.8	0.24	9.44E-07	7.79E+01	1.29E-01	0.00E+00	0.00E+00	3.00E-03	1.42E+01	2.84E-04	6.51E-05	9.61E-04	2.51E-01	3.00E-05	1.23E+03	0.00E+00	1.86E-01
BATCH-85	12/31/18	157	16.4	0.24	3.72E-06	1.13E+02	4.93E-01	0.00E+00	0.00E+00	4.00E-04	2.50E+01	4.55E-04	1.74E-04	1.30E-02	2.60E-02	7.41E-04	2.68E+03	0.00E+00	1.45E-01
BATCH-86	1/2/19	157	16.4	0.24	3.72E-06	1.13E+02	4.93E-01	0.00E+00	0.00E+00	4.00E-04	2.50E+01	4.55E-04	1.74E-04	1.30E-02	2.60E-02	7.41E-04	2.68E+03	0.00E+00	1.45E-01
BATCH-87	1/16/19	157	16.4	0.24	3.72E-06	1.13E+02	4.93E-01	0.00E+00	0.00E+00	4.00E-04	2.50E+01	4.55E-04	1.74E-04	1.30E-02	2.60E-02	7.40E-04	2.68E+03	0.00E+00	1.45E-01
BATCH-88	1/19/19	146	15.2	0.24	3.45E-06	1.04E+02	4.58E-01	0.00E+00	0.00E+00	4.00E-04	2.32E+01	4.22E-04	1.61E-04	1.20E-02	2.50E-02	6.87E-04	2.49E+03	0.00E+00	1.35E-01
BATCH-89	2/2/19	201	21.0	0.24	1.03E-05	6.01E+01	2.43E-01	0.00E+00	0.00E+00	3.20E-03	3.22E+01	1.00E-03	1.00E-03	8.00E-03	7.55E-01	8.35E-04	3.44E+03	0.00E+00	2.20E-01
BATCH-90	2/3/19	273	28.5	0.24	1.71E-05	3.45E+01	1.12E-01	0.00E+00	0.00E+00	5.80E-03	4.39E+01	2.00E-03	2.00E-03	6.00E-03	1.43E+00	1.00E-03	4.67E+03	0.00E+00	3.19E-01
BATCH-91	2/23/19	273	28.5	0.24	1.71E-05	3.45E+01	1.12E-01	0.00E+00	0.00E+00	5.80E-03	4.39E+01	2.00E-03	2.00E-03	6.00E-03	1.43E+00	1.00E-03	4.67E+03	0.00E+00	3.19E-01
BATCH-92	3/4/19	322	33.5	0.24	1.66E-06	2.47E+02	3.82E-01	0.00E+00	0.00E+00	9.40E-03	4.25E+01	6.35E-04	4.01E-04	2.00E-03	7.89E-01	2.81E-04	3.82E+03	0.00E+00	5.86E-01
BATCH-93	3/24/19	273	28.5	0.24	1.71E-05	3.45E+01	1.12E-01	0.00E+00	0.00E+00	5.60E-03	4.38E+01	2.00E-03	2.00E-03	6.00E-03	1.43E+00	1.00E-03	4.67E+03	0.00E+00	3.18E-01
BATCH-94	4/7/19	273	28.5	0.24	1.71E-05	3.45E+01	1.12E-01	0.00E+00	0.00E+00	5.60E-03	4.38E+01	2.00E-03	2.00E-03	6.00E-03	1.43E+00	1.00E-03	4.67E+03	0.00E+00	3.18E-01
BATCH-95	4/21/19	254	26.5	0.24	1.59E-05	3.21E+01	1.04E-01	0.00E+00	0.00E+00	5.20E-03	4.07E+01	2.00E-03	2.00E-03	5.00E-03	1.33E+00	9.99E-04	4.34E+03	0.00E+00	2.96E-01
BATCH-96	5/5/19	245	25.5	0.24	1.53E-05	3.08E+01	1.00E-01	0.00E+00	0.00E+00	5.00E-03	3.92E+01	2.00E-03	2.00E-03	5.00E-03	1.28E+00	9.58E-04	4.18E+03	0.00E+00	2.85E-01
BATCH-97	5/18/19	272	28.3	0.24	1.70E-05	3.43E+01	1.11E-01	0.00E+00	0.00E+00	5.60E-03	4.36E+01	2.00E-03	2.00E-03	6.00E-03	1.42E+00	1.00E-03	4.65E+03	0.00E+00	3.17E-01

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUN kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Sl+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Tl+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-50	8/6/16	1629	163.5	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.95E-01	1.80E+02	2.98E-05	6.35E+00	1.83E+02	2.00E-03	3.99E-05	0.00E+00	4.80E-02	3.40E-02	5.36E-01
BATCH-51	10/17/16	242	25.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	1.53E+01	8.19E-06	1.36E+01	2.61E+01	2.60E-02	8.10E-04	0.00E+00	1.02E-01	4.50E-02	1.23E-01
BATCH-52	1/4/17	242	25.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	1.53E+01	8.19E-06	1.36E+01	2.61E+01	2.60E-02	8.10E-04	0.00E+00	1.02E-01	4.50E-02	1.23E-01
BATCH-53	1/20/17	1676	168.4	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-01	1.79E+02	4.77E-05	4.29E+00	2.80E+02	1.00E-03	8.22E-04	0.00E+00	2.08E-01	1.32E-01	4.98E-01
BATCH-54	3/23/17	237	24.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-02	1.50E+01	7.93E-06	1.33E+01	2.55E+01	2.50E-02	7.80E-04	0.00E+00	9.90E-02	4.40E-02	1.21E-01
BATCH-55	6/13/17	358	37.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.50E-02	3.70E+01	1.14E-05	6.19E+01	3.27E+01	5.00E-03	6.62E-04	0.00E+00	1.40E-02	4.20E-02	2.42E+00
BATCH-56	7/12/17	1681	168.9	0.23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-01	1.82E+02	1.99E-05	4.13E+00	2.86E+02	9.49E-04	8.32E-04	0.00E+00	2.02E-01	1.19E-01	5.09E-01
End of Phase 1 - Beginning of Phase 2																			
BATCH-57	9/19/17	358	37.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.50E-02	3.70E+01	1.13E-05	6.18E+01	3.28E+01	5.00E-03	6.40E-04	0.00E+00	1.40E-02	4.10E-02	2.42E+00
BATCH-58	12/25/17	358	37.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.50E-02	3.70E+01	1.13E-05	6.18E+01	3.28E+01	5.00E-03	6.40E-04	0.00E+00	1.40E-02	4.10E-02	2.42E+00
BATCH-59	1/2/18	353	36.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	2.89E+01	5.60E-11	2.65E-01	1.75E+01	1.74E-07	2.58E-09	0.00E+00	7.47E-04	7.00E-03	9.72E-04
BATCH-60	2/1/18	353	36.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	2.89E+01	0.00E+00	2.64E-01	1.75E+01	7.57E-09	0.00E+00	0.00E+00	7.47E-04	7.00E-03	9.71E-04
BATCH-61	2/8/18	352	36.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	2.89E+01	0.00E+00	2.64E-01	1.75E+01	7.56E-09	0.00E+00	0.00E+00	7.46E-04	7.00E-03	9.70E-04
BATCH-62	3/10/18	351	36.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	2.88E+01	0.00E+00	2.64E-01	1.74E+01	7.55E-09	0.00E+00	0.00E+00	7.44E-04	7.00E-03	9.68E-04
BATCH-63	3/17/18	343	35.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	4.02E+01	6.85E-10	7.54E+00	4.62E+01	1.00E-03	3.02E-08	0.00E+00	1.04E+00	2.00E-03	2.36E-01
BATCH-64	4/15/18	343	35.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.05E+01	6.99E-10	7.68E+00	4.68E+01	1.00E-03	3.08E-08	0.00E+00	1.07E+00	1.00E-03	2.40E-01
BATCH-65	4/22/18	343	35.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.04E+01	6.98E-10	7.68E+00	4.67E+01	1.00E-03	3.08E-08	0.00E+00	1.06E+00	1.00E-03	2.40E-01
BATCH-66	5/21/18	343	35.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.04E+01	6.97E-10	7.67E+00	4.67E+01	1.00E-03	3.08E-08	0.00E+00	1.06E+00	1.00E-03	2.40E-01
BATCH-67	5/28/18	342	35.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	4.03E+01	6.96E-10	7.66E+00	4.66E+01	1.00E-03	3.07E-08	0.00E+00	1.06E+00	1.00E-03	2.40E-01
BATCH-68	6/26/18	324	33.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.60E-02	3.52E+01	6.26E-06	5.85E+01	3.06E+01	4.00E-03	6.12E-07	0.00E+00	1.10E-02	7.00E-03	2.41E+00
BATCH-69	7/3/18	286	29.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	6.12E+01	1.16E-06	5.14E+00	4.13E+01	4.00E-03	1.89E-08	0.00E+00	6.52E-01	1.00E-03	2.37E-01
BATCH-70	7/30/18	198	20.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	9.47E+01	3.03E-06	1.15E+00	3.31E+01	8.00E-03	1.50E-11	0.00E+00	6.08E-04	1.00E-03	2.34E-01
BATCH-71	8/2/18	198	20.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	9.47E+01	3.03E-06	1.15E+00	3.31E+01	8.00E-03	1.53E-11	0.00E+00	6.18E-04	1.00E-03	2.33E-01
BATCH-72	8/20/18	198	20.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	9.46E+01	3.02E-06	1.15E+00	3.31E+01	8.00E-03	1.53E-11	0.00E+00	6.18E-04	1.00E-03	2.33E-01
BATCH-73	8/22/18	198	20.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	9.45E+01	3.02E-06	1.14E+00	3.30E+01	8.00E-03	1.53E-11	0.00E+00	6.17E-04	1.00E-03	2.33E-01
BATCH-74	9/10/18	197	20.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	9.43E+01	3.02E-06	1.14E+00	3.30E+01	8.00E-03	1.53E-11	0.00E+00	6.16E-04	1.00E-03	2.33E-01
BATCH-75	9/12/18	200	20.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.10E-02	1.08E+02	5.89E-07	1.64E+01	4.56E+01	1.17E-01	8.47E-12	0.00E+00	2.00E-03	2.40E-02	2.24E-01
BATCH-76	10/1/18	324	33.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.60E-02	3.52E+01	6.26E-06	5.85E+01	3.06E+01	4.00E-03	6.10E-07	0.00E+00	1.10E-02	7.00E-03	2.41E+00
BATCH-77	10/3/18	199	20.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-01	1.11E+02	1.34E-09	2.00E+01	4.85E+01	1.42E-01	6.63E-15	0.00E+00	2.00E-03	2.90E-02	2.21E-01
BATCH-78	10/24/18	199	20.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-01	1.11E+02	1.33E-09	2.00E+01	4.84E+01	1.42E-01	6.76E-15	0.00E+00	2.00E-03	2.90E-02	2.21E-01
BATCH-79	11/4/18	199	20.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-01	1.11E+02	1.33E-09	1.99E+01	4.84E+01	1.42E-01	6.75E-15	0.00E+00	2.00E-03	2.90E-02	2.21E-01
BATCH-80	11/14/18	199	20.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	9.35E+01	5.91E-06	1.64E+01	4.54E+01	1.18E-01	4.77E-12	0.00E+00	7.00E-03	2.80E-02	3.75E-01
BATCH-81	11/25/18	184	19.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.33E+01	3.17E-05	5.34E+00	4.32E+01	4.60E-02	2.55E-11	0.00E+00	3.10E-02	3.00E-02	1.09E+00
BATCH-82	12/5/18	163	17.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.18E+01	3.05E-05	5.15E+00	4.17E+01	4.40E-02	2.46E-11	0.00E+00	3.00E-02	2.90E-02	1.06E+00
BATCH-83	12/14/18	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.17E+01	2.83E-05	4.78E+00	3.87E+01	4.10E-02	2.28E-11	0.00E+00	2.80E-02	2.70E-02	9.78E-01
BATCH-84	12/22/18	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.87E+01	1.78E-05	2.82E+00	4.14E+01	1.70E-02	7.20E-06	0.00E+00	3.20E-02	1.80E-02	4.67E-01
BATCH-85	12/31/18	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	3.30E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-86	1/2/19	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	3.34E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-87	1/16/19	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-88	1/19/19	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-89	2/2/19	201	21.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	3.33E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-90	2/23/19	273	28.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	3.34E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-91	2/23/19	273	28.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-92	3/4/19	322	33.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-93	3/24/19	273	28.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-02	3.33E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.41E-01
BATCH-94	4/7/19	273	28.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-02	3.33E+01	1.23E-05	1.73E+00	4.96E+01	1.00E-03	1.38E-05	0.00E+00	3.90E-02	1.40E-02	1.31E-01
BATCH-95	4/21/19	254	26.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-02	3.10E+01	1.14E-05	1.61E+00	4.61E+01	1.00E-03	1.28E-05	0.00E+00	3.60E-02	1.30E-02	1.31E-01
BATCH-96	5/5/19	245	25.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-02	2.98E+01	1.10E-05	1.55E+00	4.44E+01	1.00E-03	1.24E-05	0.00E+00	3.50E-02	1.30E-02	1.26E-01
BATCH-97	5/18/19	272	28.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-02	3.32E+01	1.22E-05	1.72E+00	4.94E+01	1.00E-03	1.37E-05	0.00E+00	3.90E-02	1.40E-02	1.40E-01

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-98	5/31/19	225	23.5	0.24	0.00E+00	0.00E+00	6.55E-01	4.34E-01	5.31E+01	1.22E+00	4.50E+03	5.08E+00	1.05E+00	2.24E+01	2.00E-08	8.26E+00	1.00E-01	1.68E+00	3.98E-02
BATCH-99	6/16/19	122	12.7	0.24	0.00E+00	0.00E+00	4.20E-02	1.20E-02	3.42E+00	2.71E-01	2.13E+03	3.18E-01	5.10E-02	1.17E+01	2.14E-11	1.10E+00	6.00E-03	4.20E-02	1.13E-02
BATCH-100	6/24/19	322	33.5	0.24	0.00E+00	0.00E+00	5.40E-01	7.01E-01	4.40E+01	8.65E-01	6.43E+03	3.91E+00	8.13E-01	3.20E+01	4.48E-08	6.40E+00	1.33E-01	1.20E+00	7.60E-02
BATCH-101	6/29/19	122	12.7	0.24	0.00E+00	0.00E+00	4.20E-02	1.20E-02	3.42E+00	2.71E-01	2.13E+03	3.18E-01	5.10E-02	1.17E+01	2.14E-11	1.10E+00	6.00E-03	4.20E-02	1.13E-02
BATCH-102	7/12/19	114	11.8	0.24	0.00E+00	0.00E+00	3.90E-02	1.10E-02	3.19E+00	2.52E-01	1.98E+03	2.96E-01	4.80E-02	1.09E+01	2.12E-11	1.02E+00	6.00E-03	3.90E-02	1.05E-02
BATCH-103	7/24/19	109	11.4	0.24	0.00E+00	0.00E+00	3.80E-02	1.10E-02	3.07E+00	2.43E-01	1.91E+03	2.85E-01	4.60E-02	1.05E+01	2.10E-11	9.82E+01	5.00E-03	3.80E-02	1.03E-02
BATCH-104	7/27/19	122	12.7	0.24	0.00E+00	0.00E+00	4.20E-02	1.20E-02	3.41E+00	2.70E-01	2.12E+03	3.17E-01	5.10E-02	1.17E+01	2.13E-11	1.09E+00	6.00E-03	4.20E-02	1.13E-02
BATCH-105	8/4/19	116	12.1	0.24	0.00E+00	0.00E+00	4.00E-02	1.10E-02	3.23E+00	2.57E-01	2.01E+03	3.00E-01	4.80E-02	1.11E+01	1.61E-11	1.04E+00	6.00E-03	3.90E-02	1.08E-02
BATCH-106	8/9/19	104	10.9	0.24	0.00E+00	0.00E+00	2.20E-02	1.50E-02	1.79E+00	1.07E-01	1.11E+03	1.85E-01	3.10E-02	5.65E+00	5.55E-09	5.19E-01	4.00E-03	3.70E-02	4.25E-03
BATCH-107	8/16/19	104	10.9	0.24	0.00E+00	0.00E+00	2.20E-02	1.50E-02	1.78E+00	1.07E-01	1.11E+03	1.85E-01	3.10E-02	5.63E+00	5.54E-09	5.17E-01	4.00E-03	3.70E-02	4.00E-03
BATCH-108	8/20/19	123	12.8	0.24	0.00E+00	0.00E+00	2.80E-02	1.80E-02	2.26E+00	1.31E-01	1.37E+03	2.33E-01	4.10E-02	7.24E+00	5.79E-09	6.40E-01	5.00E-03	4.70E-02	5.25E-03
BATCH-109	8/27/19	123	12.8	0.24	0.00E+00	0.00E+00	3.20E-02	4.00E-02	2.61E+00	1.24E-01	1.33E+03	2.77E-01	4.70E-02	6.65E+00	9.68E-09	7.04E-01	7.00E-03	6.30E-02	5.00E-03
BATCH-110	9/2/19	104	10.9	0.24	0.00E+00	0.00E+00	2.20E-02	1.50E-02	1.78E+00	1.07E-01	1.11E+03	1.85E-01	3.10E-02	5.64E+00	5.56E-09	5.18E-01	4.00E-03	3.70E-02	4.25E-03
BATCH-111	9/9/19	322	33.5	0.24	0.00E+00	0.00E+00	5.40E-01	7.01E-01	4.40E+01	8.65E-01	6.43E+03	3.91E+00	8.13E-01	3.20E+01	4.48E-08	6.40E+00	1.33E-01	1.20E+00	7.60E-02
BATCH-112	9/14/19	113	11.8	0.24	0.00E+00	0.00E+00	3.80E-02	2.60E-02	3.06E+00	1.35E-01	1.55E+03	3.08E-01	5.70E-02	7.46E+00	6.05E-09	7.14E-01	7.00E-03	7.80E-02	5.00E-03
BATCH-113	9/26/19	63	6.5	0.24	0.00E+00	0.00E+00	1.20E-02	9.00E-03	9.94E-01	5.94E-02	6.18E+02	1.03E-01	1.70E-02	3.14E+00	3.09E-09	2.89E-01	2.00E-03	2.00E-02	2.25E-03
BATCH-114	10/2/19	63	6.5	0.24	0.00E+00	0.00E+00	1.20E-02	9.00E-03	9.91E-01	5.94E-02	6.16E+02	1.03E-01	1.70E-02	3.14E+00	3.08E-09	2.88E-01	2.00E-03	2.00E-02	2.25E-03
BATCH-115	10/9/19	61	6.4	0.24	0.00E+00	0.00E+00	1.30E-02	8.00E-03	1.03E+00	5.94E-02	6.25E+02	1.06E-01	1.80E-02	3.30E+00	2.64E-09	2.92E-01	2.00E-03	2.10E-02	2.25E-03
BATCH-116	10/13/19	64	6.7	0.24	0.00E+00	0.00E+00	1.60E-02	2.00E-02	1.27E+00	6.03E-02	6.48E+02	1.35E-01	2.30E-02	3.24E+00	4.72E-09	3.43E-01	3.00E-03	3.10E-02	2.50E-03
BATCH-117	10/16/19	63	6.5	0.24	0.00E+00	0.00E+00	1.20E-02	9.00E-03	9.93E-01	5.94E-02	6.18E+02	1.03E-01	1.70E-02	3.14E+00	3.10E-09	2.88E-01	2.00E-03	2.00E-02	2.25E-03
BATCH-118	10/20/19	66	6.8	0.24	0.00E+00	0.00E+00	2.00E-02	1.40E-02	1.66E+00	7.29E-02	8.36E+02	1.66E-01	3.10E-02	4.03E+00	3.27E-09	3.86E-01	4.00E-03	4.20E-02	2.75E-03
BATCH-119	10/22/19	22	2.3	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	2.86E-01	1.71E-02	1.78E+02	3.00E-02	5.00E-03	9.04E-01	8.89E-10	8.30E-02	6.93E-04	6.00E-03	7.50E-04
BATCH-120	10/25/19	22	2.3	0.24	0.00E+00	0.00E+00	3.00E-03	2.00E-03	2.85E-01	1.71E-02	1.77E+02	3.00E-02	5.00E-03	9.01E-01	8.87E-10	8.30E-02	6.89E-04	6.00E-03	7.50E-04
BATCH-121	10/27/19	21	2.2	0.24	0.00E+00	0.00E+00	3.00E-03	2.00E-03	2.83E-01	1.62E-02	1.72E+02	2.90E-02	5.00E-03	9.08E-01	7.27E-10	8.00E-02	6.65E-04	6.00E-03	7.50E-04
BATCH-122	10/28/19	24	2.5	0.24	0.00E+00	0.00E+00	5.00E-03	6.00E-03	3.88E-01	1.80E-02	1.97E+02	4.10E-02	7.00E-03	9.88E-01	1.44E-09	1.05E-01	9.93E-04	9.00E-03	7.50E-04
BATCH-123	10/30/19	22	2.3	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	2.86E-01	1.71E-02	1.78E+02	3.00E-02	5.00E-03	9.04E-01	8.91E-10	8.30E-02	6.92E-04	6.00E-03	7.50E-04
BATCH-124	10/30/19	174	18.2	0.24	0.00E+00	0.00E+00	5.90E-02	1.60E-02	4.83E+00	3.86E-01	3.02E+03	4.48E-01	7.20E-02	1.67E+01	5.46E-12	1.56E+00	9.00E-03	5.80E-02	1.63E-02
BATCH-125	11/1/19	24	2.5	0.24	0.00E+00	0.00E+00	6.00E-03	4.00E-03	5.05E-01	2.25E-02	2.55E+02	5.10E-02	9.00E-03	1.23E+00	9.97E-10	1.18E-01	1.00E-03	1.30E-02	7.50E-04
BATCH-126	11/4/19	322	33.5	0.24	0.00E+00	0.00E+00	5.40E-01	7.01E-01	4.40E+01	8.65E-01	6.43E+03	3.91E+00	8.13E-01	3.20E+01	4.48E-08	6.40E+00	1.33E-01	1.20E+00	7.60E-02
BATCH-127	11/18/19	169	17.6	0.24	0.00E+00	0.00E+00	1.07E-01	4.90E-02	8.69E+00	5.61E-01	2.77E+03	6.67E-01	1.63E-01	1.68E+01	3.67E-09	1.57E+00	1.80E-02	2.30E-01	1.85E-02
BATCH-128	12/6/19	174	18.2	0.24	0.00E+00	0.00E+00	1.31E-01	6.50E-02	1.07E+01	6.59E-01	2.79E+03	7.88E-01	2.08E-01	1.74E+01	5.36E-09	1.65E+00	2.20E-02	3.12E-01	2.05E-02
BATCH-129	12/8/19	174	18.2	0.24	0.00E+00	0.00E+00	1.31E-01	6.50E-02	1.07E+01	6.59E-01	2.79E+03	7.87E-01	2.08E-01	1.74E+01	5.35E-09	1.65E+00	2.20E-02	3.12E-01	2.05E-02
BATCH-130	12/24/19	174	18.2	0.24	0.00E+00	0.00E+00	1.31E-01	6.50E-02	1.07E+01	6.58E-01	2.79E+03	7.87E-01	2.08E-01	1.73E+01	5.35E-09	1.65E+00	2.20E-02	3.12E-01	2.05E-02
BATCH-131	12/26/19	174	18.2	0.24	0.00E+00	0.00E+00	1.31E-01	6.50E-02	1.07E+01	6.58E-01	2.78E+03	7.87E-01	2.08E-01	1.73E+01	5.35E-09	1.65E+00	2.20E-02	3.11E-01	2.05E-02
BATCH-132	1/12/20	142	14.8	0.24	0.00E+00	0.00E+00	1.07E-01	4.60E-02	8.63E+00	5.36E-01	2.22E+03	6.42E-01	1.61E-01	1.41E+01	2.19E-09	1.28E+00	1.40E-02	2.54E-01	1.68E-02
BATCH-133	1/13/20	126	13.1	0.24	0.00E+00	0.00E+00	1.24E-01	5.90E-02	1.00E+01	4.61E-01	2.51E+03	8.17E-01	1.88E-01	1.25E+01	1.85E-09	1.41E+00	1.50E-02	3.04E-01	1.48E-02
BATCH-134	1/26/20	322	33.5	0.24	0.00E+00	0.00E+00	5.40E-01	6.14E-01	4.37E+01	8.65E-01	6.43E+03	3.91E+00	7.72E-01	3.20E+01	2.25E-08	6.10E+00	1.03E-01	1.20E+00	7.60E-02
BATCH-135	1/27/20	131	13.6	0.24	0.00E+00	0.00E+00	1.35E-01	6.50E-02	1.09E+01	4.77E-01	2.61E+03	8.95E-01	2.04E-01	1.30E+01	1.90E-09	1.52E+00	1.60E-02	3.30E-01	1.53E-02
BATCH-136	2/9/20	131	13.6	0.24	0.00E+00	0.00E+00	1.35E-01	6.50E-02	1.08E+01	4.76E-01	2.61E+03	8.95E-01	2.04E-01	1.30E+01	1.90E-09	1.52E+00	1.60E-02	3.30E-01	1.53E-02
BATCH-137	2/23/20	131	13.6	0.24	0.00E+00	0.00E+00	1.35E-01	6.50E-02	1.08E+01	4.76E-01	2.61E+03	8.95E-01	2.04E-01	1.30E+01	1.90E-09	1.52E+00	1.60E-02	3.30E-01	1.53E-02
BATCH-138	2/29/20	118	12.3	0.24	0.00E+00	0.00E+00	3.00E-02	1.20E-02	2.45E+00	1.63E-01	8.33E+02	1.93E-01	4.30E-02	1.02E+01	4.79E-10	4.56E-01	4.00E-03	6.20E-02	5.50E-03
BATCH-139	3/8/20	146	15.3	0.24	0.00E+00	0.00E+00	5.10E-02	2.20E-02	4.08E+00	2.31E-01	1.33E+03	3.28E-01	7.40E-02	1.46E+01	7.67E-10	6.76E-01	6.00E-03	1.13E-01	7.75E-03
BATCH-140	3/14/20	134	14.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.60E-02	4.62E+00	2.43E-01	1.32E+03	3.64E-01	8.70E-02	1.34E+01	9.83E-10	6.66E-01	7.00E-03	1.38E-01	7.75E-03
BATCH-141	3/21/20	134	14.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.60E-02	4.62E+00	2.42E-01	1.32E+03	3.63E-01	8.70E-02	1.34E+01	9.82E-10	6.65E-01	7.00E-03	1.38E-01	7.75E-03
BATCH-142	3/29/20	134	14.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.60E-02	4.62E+00	2.42E-01	1.32E+03	3.63E-01	8.70E-02	1.34E+01	9.82E-10	6.65E-01	7.00E-03	1.38E-01	7.75E-03
BATCH-143	4/4/20	103	10.8	0.24	0.00E+00	0.00E+00	1.73E-01	1.97E-01	1.40E+01	2.77E-01	2.06E+03	1.25E+00	2.48E-01	1.03E+01	7.23E-09	1.96E+00	3.30E-02	3.86E-01	2.45E-02
BATCH-144	4/13/20	134	14.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.60E-02	4.61E+00	2.42E-01	1.32E+03	3.63E-01	8.60E-02	1.33E+01	9.81E-10	6.64E-01	7.00E-03	1.38E-01	7.75E-03
BATCH-145	4/15/20	134	14.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.60E-02	4.61E+00	2.42E-01	1.32E+03	3.62E-01	8.60E-02	1.33E+01	9.79E-10	6.63E-01	7.00E-03	1.38E-01	7.75E-03
BATCH-146	4/27/20	62	6.4	0.24	0.00E+00	0.00E+00	1.50E-02	6.00E-03	1.17E+00	7.83E-02	3.99E+02	9.30E-02	2.10E-02	4.91E+00	2.29E-10	2.18E-01	2.00E-03	3.00E-02	2.75E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-98	5/31/19	225	23.5	0.24	2.70E-05	6.75E+02	2.94E+03	3.24E-01	2.37E+01	2.15E+00	8.56E-01	1.21E-04	4.00E-03	1.00E-03	1.00E-03	4.00E-03	1.46E-01	7.13E-01	2.24E-01
BATCH-99	6/16/19	122	12.7	0.24	2.80E-06	3.66E+02	5.48E+01	8.00E-03	2.39E-01	1.37E-01	7.64E-04	2.43E-06	7.48E-04	7.33E-05	6.02E-05	2.32E-04	1.00E-03	5.00E-03	3.00E-03
BATCH-100	6/24/19	322	33.5	0.24	1.08E-04	9.65E+02	2.30E+03	2.63E-01	2.05E+01	1.90E+00	2.76E-01	9.42E-05	3.00E-03	8.94E-04	1.00E-03	3.00E-03	1.30E-01	6.33E-01	2.14E-01
BATCH-101	6/29/19	122	12.7	0.24	2.80E-06	3.66E+02	5.48E+01	8.00E-03	2.39E-01	1.37E-01	7.64E-04	2.43E-06	7.48E-04	7.33E-05	6.02E-05	2.32E-04	1.00E-03	5.00E-03	3.00E-03
BATCH-102	7/12/19	114	11.8	0.24	2.60E-06	3.40E+02	5.12E+01	8.00E-03	2.23E-01	1.28E-01	7.63E-04	2.27E-06	6.96E-04	6.83E-05	5.61E-05	2.16E-04	9.70E-04	5.00E-03	3.00E-03
BATCH-103	7/24/19	109	11.4	0.24	2.51E-06	3.28E+02	4.94E+01	8.00E-03	2.16E-01	1.23E-01	7.62E-04	2.19E-06	6.71E-04	6.58E-05	5.41E-05	2.08E-04	9.39E-04	5.00E-03	2.00E-03
BATCH-104	7/27/19	122	12.7	0.24	2.79E-06	3.65E+02	5.47E+01	8.00E-03	2.38E-01	1.37E-01	7.61E-04	2.43E-06	7.46E-04	7.31E-05	6.01E-05	2.31E-04	1.00E-03	5.00E-03	3.00E-03
BATCH-105	8/4/19	116	12.1	0.24	2.65E-06	3.47E+02	5.14E+01	8.00E-03	2.21E-01	1.30E-01	5.45E-04	2.28E-06	7.09E-04	6.93E-05	5.69E-05	2.19E-04	9.49E-04	5.00E-03	3.00E-03
BATCH-106	8/9/19	104	10.9	0.24	2.69E-06	3.12E+02	3.97E+01	5.00E-03	2.50E-01	5.60E-02	1.81E-01	1.62E-06	2.66E-04	3.27E-05	5.13E-05	1.20E-04	8.92E-04	4.00E-03	3.00E-03
BATCH-107	8/16/19	104	10.9	0.24	2.69E-06	3.12E+02	3.94E+01	5.00E-03	2.47E-01	5.60E-02	1.80E-01	1.61E-06	2.65E-04	3.24E-05	5.12E-05	1.19E-04	8.70E-04	4.00E-03	3.00E-03
BATCH-108	8/20/19	123	12.8	0.24	3.04E-06	3.69E+02	4.80E+01	6.00E-03	2.72E-01	6.20E-02	1.89E-01	1.96E-06	3.28E-04	3.98E-05	6.83E-05	1.49E-04	1.00E-03	5.00E-03	4.00E-03
BATCH-109	8/27/19	123	12.8	0.24	4.16E-06	3.68E+02	8.79E+01	1.10E-02	7.08E-01	1.08E-01	3.15E-01	3.53E-06	3.62E-04	5.99E-05	6.94E-05	2.31E-04	1.00E-03	7.00E-03	5.00E-03
BATCH-110	9/2/19	104	10.9	0.24	2.69E-06	3.12E+02	3.95E+01	5.00E-03	2.48E-01	5.60E-02	1.81E-01	1.62E-06	2.66E-04	3.25E-05	5.13E-05	1.19E-04	8.73E-04	4.00E-03	3.00E-03
BATCH-111	9/9/19	322	33.5	0.24	1.08E-04	9.65E+02	2.30E+03	2.63E-01	2.05E+01	1.90E+00	2.76E-01	9.42E-05	3.00E-03	8.94E-04	1.00E-03	3.00E-03	1.30E-01	6.33E-01	2.14E-01
BATCH-112	9/14/19	113	11.8	0.24	3.35E-06	3.38E+02	1.11E+02	1.30E-02	8.25E-01	1.08E-01	2.02E-01	4.57E-06	3.49E-04	5.75E-05	8.16E-05	2.08E-04	4.00E-03	2.20E-02	9.00E-03
BATCH-113	9/26/19	63	6.5	0.24	1.50E-06	1.88E+02	2.21E+01	3.00E-03	1.39E-01	3.10E-02	1.01E-01	9.04E-07	1.48E-04	1.82E-05	2.86E-05	6.69E-05	4.97E-04	2.00E-03	2.00E-03
BATCH-114	10/2/19	63	6.5	0.24	1.49E-06	1.88E+02	2.19E+01	3.00E-03	1.38E-01	3.10E-02	1.00E-01	8.98E-07	1.48E-04	1.81E-05	2.85E-05	6.63E-05	4.84E-04	2.00E-03	2.00E-03
BATCH-115	10/9/19	61	6.4	0.24	1.38E-06	1.83E+02	2.19E+01	3.00E-03	1.24E-01	2.80E-02	8.60E-02	8.91E-07	1.50E-04	1.81E-05	3.11E-05	6.77E-05	4.57E-04	2.00E-03	2.00E-03
BATCH-116	10/13/19	64	6.7	0.24	2.03E-06	1.93E+02	4.29E+01	5.00E-03	3.45E-01	5.30E-02	1.54E-01	1.72E-06	1.76E-04	2.92E-05	3.38E-05	1.13E-04	7.24E-04	4.00E-03	2.00E-03
BATCH-117	10/16/19	63	6.5	0.24	1.50E-06	1.88E+02	2.20E+01	3.00E-03	1.38E-01	3.10E-02	1.01E-01	9.00E-07	1.48E-04	1.81E-05	2.86E-05	6.64E-05	4.86E-04	2.00E-03	2.00E-03
BATCH-118	10/20/19	66	6.8	0.24	1.81E-06	1.96E+02	6.01E+01	7.00E-03	4.46E-01	5.80E-02	1.09E-01	2.47E-06	1.89E-04	3.11E-05	4.41E-05	1.12E-04	2.00E-03	1.20E-02	5.00E-03
BATCH-119	10/22/19	22	2.3	0.24	4.31E-07	6.73E+01	6.37E+00	7.98E-04	4.00E-02	9.00E-03	2.90E-02	2.60E-07	4.26E-05	5.23E-06	8.22E-06	1.93E-05	1.43E-04	7.09E-04	5.23E-04
BATCH-120	10/25/19	22	2.3	0.24	4.30E-07	6.72E+01	6.31E+00	7.91E-04	4.00E-02	9.00E-03	2.90E-02	2.58E-07	4.24E-05	5.19E-06	8.19E-06	1.91E-05	1.39E-04	6.91E-04	5.19E-04
BATCH-121	10/27/19	21	2.2	0.24	3.81E-07	6.40E+01	6.02E+00	7.51E-04	3.40E-02	8.00E-03	2.40E-02	2.46E-07	4.12E-05	5.00E-06	8.56E-06	1.87E-05	1.26E-04	6.25E-04	4.72E-04
BATCH-122	10/28/19	24	2.5	0.24	6.18E-07	7.11E+01	1.31E+01	2.00E-03	1.05E-01	1.60E-02	4.70E-02	5.24E-07	5.37E-05	8.89E-06	1.03E-05	3.43E-05	2.20E-04	1.00E-03	7.36E-04
BATCH-123	10/30/19	22	2.3	0.24	4.32E-07	6.73E+01	6.34E+00	7.94E-04	4.00E-02	9.00E-03	2.90E-02	2.59E-07	4.26E-05	5.20E-06	8.22E-06	1.91E-05	1.40E-04	6.94E-04	5.21E-04
BATCH-124	10/30/19	174	18.2	0.24	3.97E-06	5.23E+02	7.48E+01	1.20E-02	3.12E-01	1.94E-01	1.10E-05	3.33E-06	1.00E-03	1.04E-04	8.47E-05	3.27E-04	1.00E-03	6.00E-03	4.00E-03
BATCH-125	11/1/19	24	2.5	0.24	5.52E-07	7.23E+01	1.83E+01	2.00E-03	1.36E-01	1.80E-02	3.30E-02	7.53E-07	5.75E-05	9.48E-06	1.34E-05	3.42E-05	7.32E-04	4.00E-03	1.00E-03
BATCH-126	11/4/19	322	33.5	0.24	1.08E-04	9.65E+02	2.30E+03	2.63E-01	2.05E+01	1.90E+00	2.76E-01	9.42E-05	3.00E-03	8.94E-04	1.00E-03	3.00E-03	1.30E-01	6.33E-01	2.14E-01
BATCH-127	11/18/19	169	17.6	0.24	4.49E-06	5.07E+02	2.26E+02	2.40E-02	1.74E+00	2.11E-01	1.58E-01	9.81E-06	1.00E-03	1.07E-04	2.06E-04	2.91E-04	7.00E-03	3.30E-02	1.80E-02
BATCH-128	12/6/19	174	18.2	0.24	4.91E-06	5.23E+02	2.99E+02	3.10E-02	2.41E+00	2.27E-01	2.30E-01	1.30E-05	1.00E-03	1.14E-04	2.66E-04	2.89E-04	9.00E-03	4.60E-02	2.50E-02
BATCH-129	12/9/19	174	18.2	0.24	4.90E-06	5.23E+02	2.99E+02	3.10E-02	2.41E+00	2.27E-01	2.30E-01	1.29E-05	1.00E-03	1.14E-04	2.66E-04	2.88E-04	9.00E-03	4.60E-02	2.50E-02
BATCH-130	12/24/19	174	18.2	0.24	4.90E-06	5.22E+02	2.99E+02	3.10E-02	2.41E+00	2.27E-01	2.30E-01	1.29E-05	1.00E-03	1.14E-04	2.66E-04	2.88E-04	9.00E-03	4.60E-02	2.50E-02
BATCH-131	12/26/19	174	18.2	0.24	4.90E-06	5.22E+02	2.99E+02	3.00E-02	2.41E+00	2.27E-01	2.30E-01	1.29E-05	1.00E-03	1.14E-04	2.66E-04	2.88E-04	9.00E-03	4.60E-02	2.50E-02
BATCH-132	1/12/20	142	14.8	0.24	2.86E-06	4.26E+02	2.42E+02	2.40E-02	1.81E+00	1.61E-01	1.87E-01	1.02E-05	9.96E-04	9.27E-05	2.17E-04	2.35E-04	8.00E-03	3.70E-02	2.00E-02
BATCH-133	1/13/20	126	13.1	0.24	2.25E-06	3.76E+02	3.74E+02	3.60E-02	2.73E+00	2.13E-01	1.57E-01	1.56E-05	7.32E-04	1.09E-04	2.71E-04	2.99E-04	1.80E-02	9.00E-02	3.70E-02
BATCH-134	1/26/20	322	33.5	0.24	8.09E-05	9.65E+02	2.28E+03	2.50E-01	1.89E+01	1.66E+00	2.76E-01	9.12E-05	3.00E-03	8.94E-04	1.00E-03	3.00E-03	1.29E-01	6.33E-01	2.14E-01
BATCH-135	1/27/20	131	13.6	0.24	2.30E-06	3.91E+02	4.18E+02	4.00E-02	3.04E+00	2.35E-01	1.62E-01	1.74E-05	7.35E-04	1.18E-04	2.96E-04	3.27E-04	2.10E-02	1.03E-01	4.20E-02
BATCH-136	2/9/20	131	13.6	0.24	2.30E-06	3.91E+02	4.18E+02	4.00E-02	3.04E+00	2.34E-01	1.62E-01	1.74E-05	7.35E-04	1.18E-04	2.96E-04	3.27E-04	2.10E-02	1.03E-01	4.20E-02
BATCH-137	2/23/20	131	13.6	0.24	2.30E-06	3.91E+02	4.17E+02	4.00E-02	3.04E+00	2.34E-01	1.62E-01	1.74E-05	7.35E-04	1.18E-04	2.96E-04	3.27E-04	2.10E-02	1.03E-01	4.20E-02
BATCH-138	2/29/20	131	13.6	0.24	2.30E-06	3.91E+02	4.17E+02	4.00E-02	3.04E+00	2.34E-01	1.62E-01	1.74E-05	7.35E-04	1.18E-04	2.96E-04	3.27E-04	2.10E-02	1.03E-01	4.20E-02
BATCH-139	3/8/20	118	12.3	0.24	9.59E-07	3.53E+02	6.15E+01	6.00E-03	4.29E-01	5.50E-02	4.10E-02	2.61E-06	3.31E-04	3.25E-05	5.73E-05	9.00E-05	2.00E-03	9.00E-03	5.00E-03
BATCH-140	3/14/20	146	15.3	0.24	1.28E-06	4.39E+02	1.26E+02	1.30E-02	9.00E-01	9.00E-02	6.50E-02	5.29E-06	4.33E-04	4.98E-05	1.02E-04	1.38E-04	5.00E-03	2.50E-02	1.10E-02
BATCH-141	3/21/20	134	14.0	0.24	1.24E-06	4.02E+02	1.55E+02	1.50E-02	1.14E+00	9.30E-02	8.40E-02	6.50E-06	4.17E-04	5.00E-05	1.21E-04	1.33E-04	7.00E-03	3.30E-02	1.50E-02
BATCH-142	3/29/20	134	14.0	0.24	1.24E-06	4.02E+02	1.55E+02	1.50E-02	1.14E+00	9.30E-02	8.40E-02	6.49E-06	4.17E-04	4.99E-05	1.21E-04	1.33E-04	7.00E-03	3.30E-02	1.50E-02
BATCH-143	4/4/20	103	10.8	0.24	2.21E-05	3.09E+02	7.31E+02	8.00E-02	6.07E+00	5.31E-01	8.90E-02	2.92E-05	9.61E-04	2.87E-04	4.47E-04	9.38E-04	4.10E-02	2.03E-01	6.90E-02
BATCH-144	4/13/20	134	14.0	0.24	1.24E-06	4.02E+02	1.55E+02	1.50E-02	1.14E+00	9.30E-02	8.40E-02	6.49E-06	4.16E-04	4.99E-05	1.21E-04	1.33E-04	7.00E-03	3.30E-02	1.50E-02
BATCH-145	4/15/20	134	14.0	0.24	1.23E-06	4.01E+02	1.55E+02	1.50E-02	1.14E+00	9.30E-02	8.40E-02	6.48E-06	4.15E-04	4.98E-05	1.21E-04	1.33E-04	7.00E-03	3.30E-02	1.50E-02
BATCH-146	4/27/20	62	6.4	0.24	4.60E-07	1.85E+02	2.95E+01	3.00E-03	2.06E-01	2.60E-02	2.00E-02	1.25E-06	1.59E-04	1.56E-05	2.75E-05	4.31E-05	8.63E-04	4.00E-03	2.00E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-98	5/31/19	225	23.5	0.24	9.00E-03	7.00E-03	2.88E-01	3.33E-01	2.58E-01	1.39E+01	2.39E+00	2.17E+01	7.75E+00	6.01E-19	1.56E-04	9.66E-04	4.00E-03	3.70E-02	2.17E-04
BATCH-99	6/16/19	122	12.7	0.24	1.16E-04	5.77E-05	5.00E-02	4.00E-03	3.00E-03	1.96E+00	4.71E-01	7.04E-01	1.00E-01	4.13E-20	1.73E-06	5.44E-06	1.28E-04	8.10E-04	5.65E-07
BATCH-100	6/24/19	322	33.5	0.24	8.00E-03	8.00E-03	2.12E-01	4.53E-01	2.35E-01	1.35E+01	2.65E+00	2.24E+01	1.61E+01	1.25E-18	2.53E-04	2.00E-03	4.90E-02	8.09E-01	9.05E-05
BATCH-101	6/29/19	122	12.7	0.24	1.16E-04	5.77E-05	5.00E-02	4.00E-03	3.00E-03	1.96E+00	4.71E-01	7.04E-01	1.00E-01	4.13E-20	1.73E-06	5.43E-06	1.28E-04	8.11E-04	5.65E-07
BATCH-102	7/12/19	114	11.8	0.24	1.08E-04	5.41E-05	4.60E-02	4.00E-03	2.00E-03	1.82E+00	4.38E-01	6.56E-01	9.30E-02	3.84E-20	1.61E-06	5.11E-06	1.19E-04	7.56E-04	5.39E-07
BATCH-103	7/24/19	109	11.4	0.24	1.04E-04	5.23E-05	4.40E-02	4.00E-03	2.00E-03	1.76E+00	4.22E-01	6.33E-01	9.00E-02	3.70E-20	1.56E-06	4.96E-06	1.15E-04	7.29E-04	5.26E-07
BATCH-104	7/27/19	122	12.7	0.24	1.15E-04	5.75E-05	4.90E-02	4.00E-03	3.00E-03	1.95E+00	4.70E-01	7.02E-01	9.90E-02	4.12E-20	1.72E-06	5.42E-06	1.27E-04	8.08E-04	5.63E-07
BATCH-105	8/4/19	116	12.1	0.24	1.08E-04	5.33E-05	4.70E-02	4.00E-03	2.00E-03	1.85E+00	4.46E-01	6.63E-01	9.30E-02	3.90E-20	1.60E-06	4.95E-06	1.20E-04	7.61E-04	4.90E-07
BATCH-106	8/9/19	104	10.9	0.24	1.33E-04	1.43E-04	1.10E-02	1.60E-02	3.00E-03	5.27E-01	1.27E-01	6.85E-01	1.65E-01	2.46E-20	1.56E-05	5.14E-06	6.70E-04	6.00E-03	1.10E-04
BATCH-107	8/16/19	104	10.9	0.24	1.32E-04	1.42E-04	1.10E-02	1.60E-02	3.00E-03	5.25E-01	1.27E-01	6.83E-01	1.65E-01	2.45E-20	1.56E-05	5.08E-06	6.69E-04	6.00E-03	1.10E-04
BATCH-108	8/20/19	123	12.8	0.24	1.54E-04	1.54E-04	1.20E-02	2.10E-02	3.00E-03	6.18E-01	1.51E-01	8.65E-01	1.84E-01	3.21E-20	2.10E-05	6.28E-06	7.39E-04	6.00E-03	1.53E-04
BATCH-109	8/27/19	123	12.8	0.24	1.99E-04	2.40E-04	1.70E-02	1.80E-02	5.00E-03	6.12E-01	1.44E-01	8.47E-01	2.67E-01	2.70E-20	1.79E-05	7.34E-06	1.00E-03	9.00E-03	1.15E-04
BATCH-110	9/2/19	104	10.9	0.24	1.32E-04	1.42E-04	1.10E-02	1.60E-02	3.00E-03	5.25E-01	1.27E-01	6.85E-01	1.65E-01	2.46E-20	1.56E-05	5.10E-06	6.71E-04	6.00E-03	1.10E-04
BATCH-111	9/9/19	322	33.5	0.24	8.00E-03	8.00E-03	2.12E-01	4.53E-01	2.35E-01	1.35E+01	2.65E+00	2.24E+01	1.61E+01	1.25E-18	2.53E-04	2.00E-03	4.90E-02	8.09E-01	9.05E-05
BATCH-112	9/14/19	113	11.8	0.24	3.55E-04	3.11E-04	1.80E-02	2.40E-02	9.00E-03	8.55E-01	1.83E-01	1.21E+00	3.54E-01	3.90E-20	1.94E-05	2.87E-05	7.77E-04	7.00E-03	1.15E-04
BATCH-113	9/26/19	63	6.5	0.24	7.39E-05	7.93E-05	6.00E-03	9.00E-03	2.00E-03	2.93E-01	7.10E-02	3.81E-01	9.20E-02	1.37E-20	8.69E-06	2.86E-06	3.73E-04	3.00E-03	6.11E-05
BATCH-114	10/2/19	63	6.5	0.24	7.34E-05	7.89E-05	6.00E-03	9.00E-03	2.00E-03	2.92E-01	7.10E-02	3.80E-01	9.20E-02	1.36E-20	8.67E-06	2.83E-06	3.72E-04	3.00E-03	6.09E-05
BATCH-115	10/9/19	61	6.4	0.24	7.01E-05	7.01E-05	6.00E-03	1.00E-02	2.00E-03	2.81E-01	6.90E-02	3.94E-01	8.40E-02	1.46E-20	9.55E-06	2.86E-06	3.37E-04	3.00E-03	6.95E-05
BATCH-116	10/13/19	64	6.7	0.24	9.70E-05	1.17E-04	8.00E-03	9.00E-03	2.00E-03	2.98E-01	7.00E-02	4.13E-01	1.30E-01	1.31E-20	8.70E-06	2.84E-06	3.58E-06	5.95E-04	5.60E-05
BATCH-117	10/16/19	63	6.5	0.24	7.37E-05	7.92E-05	6.00E-03	9.00E-03	2.00E-03	2.92E-01	7.10E-02	3.81E-01	9.20E-02	1.37E-20	8.70E-06	2.84E-06	3.74E-04	3.00E-03	6.12E-05
BATCH-118	10/20/19	66	6.8	0.24	1.92E-04	1.68E-04	1.00E-02	1.30E-02	5.00E-03	4.62E-01	9.90E-02	6.55E-01	1.92E-01	2.11E-20	1.05E-05	1.55E-05	4.20E-04	4.00E-03	6.23E-05
BATCH-119	10/22/19	22	2.3	0.24	2.13E-05	2.28E-05	2.00E-03	3.00E-03	4.80E-04	8.40E-02	2.00E-02	1.10E-01	2.70E-02	3.94E-21	2.50E-06	8.24E-07	1.07E-04	9.25E-04	1.76E-05
BATCH-120	10/25/19	22	2.3	0.24	2.11E-05	2.27E-05	2.00E-03	3.00E-03	4.75E-04	8.40E-02	2.00E-02	1.09E-01	2.60E-02	3.92E-21	2.49E-06	8.13E-07	1.07E-04	9.22E-04	1.75E-05
BATCH-121	10/27/19	21	2.2	0.24	1.93E-05	1.93E-05	2.00E-03	3.00E-03	4.36E-04	7.70E-02	1.90E-02	1.09E-01	2.30E-02	4.02E-21	2.63E-06	7.88E-07	9.27E-05	8.07E-04	1.92E-05
BATCH-122	10/28/19	24	2.5	0.24	2.96E-05	3.56E-05	3.00E-03	3.00E-03	6.76E-04	9.10E-02	2.10E-02	1.26E-01	4.00E-02	4.00E-21	2.65E-06	1.09E-06	1.81E-04	1.00E-03	1.71E-05
BATCH-123	10/30/19	22	2.3	0.24	2.12E-05	2.28E-05	2.00E-03	3.00E-03	4.77E-04	8.40E-02	2.00E-02	1.10E-01	2.70E-02	3.93E-21	2.51E-06	8.17E-07	1.08E-04	9.27E-04	1.76E-05
BATCH-124	11/1/19	174	18.2	0.24	1.54E-04	7.38E-05	7.10E-02	5.00E-03	3.00E-03	2.79E+00	6.71E-01	9.81E-01	1.33E-01	5.84E-20	2.27E-06	6.56E-06	1.77E-04	1.00E-03	5.36E-07
BATCH-125	11/1/19	24	2.5	0.24	5.85E-05	5.13E-05	3.00E-03	4.00E-03	2.00E-03	1.41E-01	3.00E-02	2.00E-01	5.80E-02	6.43E-21	3.20E-06	4.73E-06	1.28E-04	1.00E-03	1.90E-05
BATCH-126	11/4/19	322	33.5	0.24	8.00E-03	8.00E-03	2.12E-01	4.53E-01	2.35E-01	1.35E+01	2.65E+00	2.24E+01	1.61E+01	1.25E-18	2.53E-04	2.00E-03	4.90E-02	8.09E-01	9.05E-05
BATCH-127	11/18/19	169	17.6	0.24	7.40E-04	4.50E-02	2.50E-02	1.90E-02	1.90E-02	1.78E+00	3.56E-01	1.75E+00	5.53E-01	1.03E-19	1.11E-05	4.41E-05	6.34E-04	5.00E-03	1.23E-05
BATCH-128	12/6/19	174	18.2	0.24	1.00E-03	7.10E-04	3.60E-02	3.40E-02	2.60E-02	1.45E+00	2.41E-01	2.15E+00	7.53E-01	1.26E-19	1.52E-05	6.18E-05	8.53E-04	6.00E-03	1.77E-05
BATCH-129	12/8/19	174	18.2	0.24	1.00E-03	7.09E-04	3.60E-02	3.40E-02	2.60E-02	1.44E+00	2.41E-01	2.15E+00	7.52E-01	1.26E-19	1.52E-05	6.17E-05	8.52E-04	6.00E-03	1.77E-05
BATCH-130	12/24/19	174	18.2	0.24	1.00E-03	7.09E-04	3.60E-02	3.40E-02	2.60E-02	1.44E+00	2.40E-01	2.15E+00	7.51E-01	1.25E-19	1.52E-05	6.16E-05	8.51E-04	6.00E-03	1.77E-05
BATCH-131	12/26/19	174	18.2	0.24	1.00E-03	7.08E-04	3.60E-02	3.40E-02	2.60E-02	1.44E+00	2.40E-01	2.15E+00	7.51E-01	1.25E-19	1.52E-05	6.16E-05	8.51E-04	6.00E-03	1.44E-05
BATCH-132	1/12/20	142	14.8	0.24	8.28E-04	5.77E-04	2.90E-02	2.70E-02	2.10E-02	1.18E+00	1.96E-01	1.75E+00	5.84E-01	2.17E-20	1.24E-05	5.02E-05	6.77E-04	5.00E-03	1.44E-05
BATCH-133	1/13/20	126	13.1	0.24	2.00E-03	1.00E-03	3.70E-02	5.30E-02	3.80E-02	1.88E+00	3.30E-01	2.48E+00	1.32E+00	2.80E-20	2.47E-05	7.76E-05	7.48E-04	5.00E-03	2.25E-05
BATCH-134	1/26/20	322	33.5	0.24	8.00E-03	8.00E-03	2.12E-01	4.50E-01	2.35E-01	1.35E+01	2.65E+00	2.24E+01	1.54E+01	2.67E-19	2.53E-04	2.00E-03	4.80E-02	7.78E-01	9.05E-05
BATCH-135	1/27/20	131	13.6	0.24	2.00E-03	2.00E-03	4.10E-02	6.00E-02	4.30E-02	2.11E+00	3.71E-01	2.75E+00	1.51E+00	3.07E-20	2.82E-05	8.67E-05	8.05E-04	6.00E-03	2.52E-05
BATCH-136	2/9/20	131	13.6	0.24	2.00E-03	2.00E-03	4.10E-02	6.00E-02	4.30E-02	2.11E+00	3.71E-01	2.74E+00	1.51E+00	3.07E-20	2.82E-05	8.67E-05	8.05E-04	6.00E-03	2.52E-05
BATCH-137	2/23/20	131	13.6	0.24	2.00E-03	2.00E-03	4.10E-02	6.00E-02	4.30E-02	2.11E+00	3.71E-01	2.74E+00	1.51E+00	3.06E-20	2.82E-05	8.67E-05	8.05E-04	6.00E-03	2.52E-05
BATCH-138	2/29/20	131	13.6	0.24	2.00E-03	2.00E-03	4.10E-02	6.00E-02	4.30E-02	2.11E+00	3.71E-01	2.74E+00	1.51E+00	3.06E-20	2.82E-05	8.67E-05	8.05E-04	6.00E-03	2.52E-05
BATCH-139	3/8/20	118	12.3	0.24	1.99E-04	1.35E-04	1.50E-02	7.00E-03	5.00E-03	5.87E-01	1.22E-01	4.98E-01	1.42E-01	6.21E-21	2.97E-06	1.17E-05	1.68E-04	1.00E-03	3.21E-06
BATCH-140	3/14/20	146	15.3	0.24	4.66E-04	3.82E-04	2.00E-02	1.60E-02	1.20E-02	8.91E-01	1.74E-01	9.16E-01	3.80E-01	1.08E-20	7.38E-06	2.52E-05	2.91E-04	2.00E-03	7.13E-06
BATCH-141	3/21/20	134	14.0	0.24	5.95E-04	5.00E-04	1.70E-02	2.00E-02	1.50E-02	7.72E-01	1.33E-01	1.06E+00	4.88E-01	1.24E-20	9.48E-06	3.22E-05	3.52E-04	3.00E-03	9.31E-06
BATCH-142	3/29/20	134	14.0	0.24	5.95E-04	5.00E-04	1.70E-02	2.00E-02	1.50E-02	7.71E-01	1.33E-01	1.06E+00	4.88E-01	1.24E-20	9.47E-06	3.22E-05	3.52E-04	3.00E-03	9.30E-06
BATCH-143	4/4/20	103	10.8	0.24	3.00E-03	3.00E-03	6.80E-02	1.44E-01	7.50E-02	4.34E+00	8.50E-01	7.17E+00	4.93E+00	8.54E-20	8.11E-05	5.15E-04	1.50E-02	2.50E-01	2.90E-05
BATCH-144	4/13/20	134	14.0	0.24	5.94E-04	4.99E-04	1.70E-02	2.00E-02	1.50E-02	7.70E-01	1.33E-01	1.06E+00	4.87E-01	1.24E-20	9.46E-06	3.21E-05	3.52E-04	3.00E-03	9.29E-06
BATCH-145	4/15/20	134	14.0	0.24	5.93E-04	4.99E-04	1.70E-02	2.00E-02	1.50E-02	7.69E-01	1.33E-01	1.06E+00	4.87E-01	1.23E-20	9.44E-06	3.21E-05	3.51E-04	3.00E-03	9.28E-06
BATCH-146	4/27/20	62	6.4	0.24	9.53E-05	6.46E-05	7.00E-03	3.00E-03	2.00E-03	2.81E-01	5.90E-02	2.39E-01	6.80E-02	2.97E-21	1.43E-06	5.63E-06	8.06E-05	5.64E-04	1.54E-06

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-98	5/31/19	225	23.5	0.24	0.00E+00	3.48E+02	1.55E-04	2.80E-02	1.21E-04	1.25E-15	4.00E-03	3.37E-01	8.04E-04	3.80E-02	5.89E+01	0.00E+00	0.00E+00	1.73E+01	4.50E-02
BATCH-99	6/16/19	122	12.7	0.24	6.16E-23	1.23E+02	1.38E-07	3.20E-02	1.07E-07	1.09E-15	8.00E-03	4.59E-01	1.20E-04	7.10E-02	2.56E+01	0.00E+00	3.32E-24	2.08E+00	8.09E-05
BATCH-100	6/24/19	322	33.5	0.24	2.90E+02	2.14E+02	9.16E-05	1.20E-02	5.43E-05	0.00E+00	3.70E-02	1.55E+00	1.53E-04	1.10E-02	4.70E+01	0.00E+00	6.33E+00	9.61E+00	4.90E-02
BATCH-101	6/29/19	122	12.7	0.24	0.00E+00	1.23E+02	1.38E-07	3.20E-02	1.07E-07	1.08E-15	8.00E-03	4.59E-01	1.20E-04	7.10E-02	2.56E+01	0.00E+00	0.00E+00	2.08E+00	8.09E-05
BATCH-102	7/12/19	114	11.8	0.24	0.00E+00	1.15E+02	1.38E-07	3.00E-02	1.07E-07	1.21E-15	7.00E-03	4.27E-01	1.11E-04	6.60E-02	2.38E+01	0.00E+00	0.00E+00	1.93E+00	8.09E-05
BATCH-103	7/24/19	109	11.4	0.24	0.00E+00	1.11E+02	1.38E-07	2.90E-02	1.07E-07	2.99E-16	7.00E-03	4.11E-01	1.07E-04	6.30E-02	2.29E+01	0.00E+00	0.00E+00	1.86E+00	8.09E-05
BATCH-104	7/27/19	122	12.7	0.24	0.00E+00	1.23E+02	1.37E-07	3.20E-02	1.07E-07	7.83E-19	8.00E-03	4.58E-01	1.19E-04	7.10E-02	2.55E+01	0.00E+00	0.00E+00	2.07E+00	8.09E-05
BATCH-105	8/4/19	116	12.1	0.24	0.00E+00	1.17E+02	9.82E-08	3.10E-02	7.64E-08	7.88E-19	7.00E-03	4.36E-01	1.13E-04	6.70E-02	2.43E+01	0.00E+00	0.00E+00	1.97E+00	5.39E-05
BATCH-106	8/9/19	104	10.9	0.24	2.93E+02	0.00E+00	6.33E-05	1.30E-02	4.01E-05	3.67E-05	1.50E-01	4.14E-01	1.03E-04	3.80E-02	1.18E+01	0.00E+00	8.61E+00	0.00E+00	1.58E-02
BATCH-107	8/16/19	104	10.9	0.24	2.92E+02	0.00E+00	6.32E-05	1.30E-02	4.00E-05	3.66E-05	1.49E-01	4.13E-01	1.03E-04	3.80E-02	1.17E+01	0.00E+00	8.60E+00	0.00E+00	1.58E-02
BATCH-108	8/20/19	123	12.8	0.24	3.20E+02	0.00E+00	6.63E-05	1.50E-02	4.24E-05	4.03E-05	2.26E-01	4.83E-01	1.13E-04	4.70E-02	1.45E+01	0.00E+00	9.28E+00	0.00E+00	1.68E-02
BATCH-109	8/27/19	123	12.8	0.24	3.29E+02	0.00E+00	1.17E-04	1.60E-02	8.18E-05	1.60E-04	1.06E-01	4.51E-01	2.38E-04	4.40E-02	1.43E+01	0.00E+00	9.52E+00	0.00E+00	2.68E-02
BATCH-110	9/2/19	104	10.9	0.24	2.93E+02	0.00E+00	6.34E-05	1.30E-02	4.02E-05	3.68E-05	1.50E-01	4.14E-01	1.03E-04	3.80E-02	1.18E+01	0.00E+00	8.61E+00	0.00E+00	1.58E-02
BATCH-111	9/9/19	322	33.5	0.24	2.90E+02	2.14E+02	9.16E-05	1.20E-02	5.43E-05	0.00E+00	3.70E-02	1.55E+00	1.53E-04	1.10E-02	4.70E+01	0.00E+00	6.33E+00	9.61E+00	4.90E-02
BATCH-112	9/14/19	113	11.8	0.24	3.21E+02	0.00E+00	6.72E-05	1.30E-02	4.32E-05	3.68E-05	1.52E-01	4.35E-01	1.22E-04	3.90E-02	1.31E+01	0.00E+00	9.52E+00	0.00E+00	1.69E-02
BATCH-113	9/26/19	63	6.5	0.24	1.63E+02	0.00E+00	3.52E-05	7.00E-03	2.23E-05	2.04E-05	8.30E-02	2.30E-01	5.74E-05	2.10E-02	6.55E+00	0.00E+00	4.79E+00	0.00E+00	8.79E-03
BATCH-114	10/2/19	63	6.5	0.24	1.63E+02	0.00E+00	3.52E-05	7.00E-03	2.23E-05	2.04E-05	8.30E-02	2.30E-01	5.73E-05	2.10E-02	6.54E+00	0.00E+00	4.79E+00	0.00E+00	8.77E-03
BATCH-115	10/9/19	61	6.4	0.24	1.46E+02	0.00E+00	3.02E-05	7.00E-03	1.93E-05	1.83E-05	1.03E-01	2.20E-01	5.16E-05	2.20E-02	6.59E+00	0.00E+00	4.23E+00	0.00E+00	7.66E-03
BATCH-116	10/13/19	64	6.7	0.24	1.60E+02	0.00E+00	5.71E-05	8.00E-03	3.99E-05	7.81E-05	5.20E-02	2.20E-01	1.16E-04	2.20E-02	6.97E+00	0.00E+00	4.64E+00	0.00E+00	1.31E-02
BATCH-117	10/16/19	63	6.5	0.24	1.63E+02	0.00E+00	3.53E-05	7.00E-03	2.24E-05	2.05E-05	8.40E-02	2.31E-01	5.75E-05	2.10E-02	6.55E+00	0.00E+00	4.79E+00	0.00E+00	8.82E-03
BATCH-118	10/20/19	66	6.8	0.24	1.74E+02	0.00E+00	3.63E-05	7.00E-03	2.33E-05	1.99E-05	8.20E-02	2.35E-01	6.61E-05	2.10E-02	7.07E+00	0.00E+00	5.15E+00	0.00E+00	9.14E-03
BATCH-119	10/22/19	22	2.3	0.24	4.69E+01	0.00E+00	1.01E-05	2.00E-03	6.43E-06	5.88E-06	2.40E-02	6.60E-02	1.65E-05	6.00E-03	1.89E+00	0.00E+00	1.38E+00	0.00E+00	2.54E-03
BATCH-120	10/25/19	22	2.3	0.24	4.68E+01	0.00E+00	1.01E-05	2.00E-03	6.41E-06	5.86E-06	2.40E-02	6.60E-02	1.65E-05	6.00E-03	1.88E+00	0.00E+00	1.38E+00	0.00E+00	2.51E-03
BATCH-121	10/27/19	21	2.2	0.24	4.02E+01	0.00E+00	8.31E-06	2.00E-03	5.31E-06	5.05E-06	2.80E-02	6.10E-02	1.42E-05	6.00E-03	1.81E+00	0.00E+00	1.16E+00	0.00E+00	2.10E-03
BATCH-122	10/28/19	24	2.5	0.24	4.89E+01	0.00E+00	1.74E-05	2.00E-03	1.22E-05	2.38E-05	1.60E-02	6.70E-02	3.53E-05	7.00E-03	2.12E+00	0.00E+00	1.41E+00	0.00E+00	3.99E-03
BATCH-123	10/30/19	22	2.3	0.24	4.69E+01	0.00E+00	1.02E-05	2.00E-03	6.44E-06	5.89E-06	2.40E-02	6.60E-02	1.65E-05	6.00E-03	1.89E+00	0.00E+00	1.38E+00	0.00E+00	2.54E-03
BATCH-124	10/30/19	174	18.2	0.24	9.00E-03	1.76E+02	1.88E-09	4.60E-02	1.19E-09	1.09E-09	1.10E-02	6.57E-01	1.70E-04	1.01E-01	3.66E+01	0.00E+00	2.55E-04	2.95E+00	5.39E-05
BATCH-125	11/1/19	24	2.5	0.24	5.29E+01	0.00E+00	1.11E-05	2.00E-03	7.12E-06	6.06E-06	2.50E-02	7.20E-02	2.01E-05	6.00E-03	2.16E+00	0.00E+00	1.57E+00	0.00E+00	2.78E-03
BATCH-126	11/4/19	322	33.5	0.24	2.90E+02	2.14E+02	9.16E-05	1.20E-02	5.43E-05	0.00E+00	3.70E-02	1.55E+00	1.53E-04	1.10E-02	4.70E+01	0.00E+00	6.33E+00	9.61E+00	4.90E-02
BATCH-127	11/18/19	169	17.6	0.24	6.00E-03	1.87E+02	3.87E-05	1.90E-02	3.17E-05	7.99E-10	5.00E-03	6.36E-01	3.12E-04	3.70E-02	3.90E+01	0.00E+00	1.88E-04	7.93E+00	3.83E-03
BATCH-128	12/6/19	174	18.2	0.24	6.00E-03	2.01E+02	5.65E-05	9.00E-03	4.63E-05	7.67E-10	3.00E-03	6.55E-01	3.85E-04	1.20E-02	4.17E+01	0.00E+00	1.77E-04	1.04E+01	5.58E-03
BATCH-129	12/8/19	174	18.2	0.24	9.00E-03	2.01E+02	5.65E-05	9.00E-03	4.63E-05	4.23E-09	3.00E-03	6.55E-01	3.85E-04	1.20E-02	4.17E+01	0.00E+00	2.51E-04	1.04E+01	5.58E-03
BATCH-130	12/24/19	174	18.2	0.24	8.00E-03	2.00E+02	5.64E-05	9.00E-03	4.63E-05	9.57E-10	3.00E-03	6.55E-01	3.85E-04	1.20E-02	4.17E+01	0.00E+00	2.24E-04	1.04E+01	5.58E-03
BATCH-131	12/26/19	174	18.2	0.24	9.00E-03	2.00E+02	5.64E-05	9.00E-03	4.63E-05	1.08E-09	3.00E-03	6.54E-01	3.84E-04	1.20E-02	4.17E+01	0.00E+00	2.80E-04	1.03E+01	5.58E-03
BATCH-132	1/12/20	142	14.8	0.24	3.91E-06	1.63E+02	4.60E-05	7.00E-03	3.77E-05	4.90E-13	2.00E-03	5.34E-01	3.13E-04	9.00E-03	3.40E+01	0.00E+00	1.15E-07	8.43E+00	4.56E-03
BATCH-133	1/13/20	126	13.1	0.24	2.05E-06	1.45E+02	1.29E-05	2.00E-03	4.64E-05	2.56E-13	2.00E-03	6.58E-01	3.58E-04	8.00E-03	3.48E+01	0.00E+00	6.02E-08	1.17E+01	6.53E-03
BATCH-134	1/26/20	322	33.5	0.24	2.90E+02	2.14E+02	9.16E-05	1.20E-02	5.43E-05	0.00E+00	3.70E-02	1.55E+00	1.53E-04	1.10E-02	4.70E+01	0.00E+00	6.33E+00	9.61E+00	4.90E-02
BATCH-135	1/27/20	131	13.6	0.24	3.10E-06	1.51E+02	8.48E-06	2.00E-03	5.07E-05	3.89E-13	2.00E-03	7.18E-01	3.87E-04	8.00E-03	3.71E+01	0.00E+00	8.98E-08	1.30E+01	7.23E-03
BATCH-136	2/9/20	131	13.6	0.24	4.41E-06	1.51E+02	8.48E-06	2.00E-03	5.06E-05	2.15E-12	2.00E-03	7.18E-01	3.87E-04	8.00E-03	3.71E+01	0.00E+00	1.27E-07	1.30E+01	7.23E-03
BATCH-137	2/23/20	131	13.6	0.24	3.87E-06	1.51E+02	8.48E-06	2.00E-03	5.06E-05	4.86E-13	2.00E-03	7.18E-01	3.87E-04	8.00E-03	3.71E+01	0.00E+00	1.14E-07	1.30E+01	7.23E-03
BATCH-138	2/29/20	131	13.6	0.24	4.79E-06	1.51E+02	8.48E-06	2.00E-03	5.06E-05	5.49E-13	2.00E-03	7.18E-01	3.87E-04	8.00E-03	3.71E+01	0.00E+00	1.42E-07	1.30E+01	7.23E-03
BATCH-139	3/8/20	118	12.3	0.24	3.36E+02	0.00E+00	1.00E-05	7.00E-03	8.23E-06	1.29E-10	1.40E-02	3.59E-01	8.86E-05	1.40E-02	1.17E+01	0.00E+00	2.21E+01	0.00E+00	2.13E-03
BATCH-140	3/14/20	146	15.3	0.24	3.60E+02	0.00E+00	1.10E-05	7.00E-03	1.61E-05	3.08E-10	7.00E-03	5.00E-01	1.47E-04	1.40E-02	1.71E+01	0.00E+00	2.47E+01	0.00E+00	2.78E-03
BATCH-141	3/21/20	134	14.0	0.24	3.44E+02	0.00E+00	1.35E-05	2.00E-03	2.09E-05	1.58E-10	2.00E-03	4.86E-01	1.66E-04	4.00E-03	1.69E+01	0.00E+00	2.46E+01	0.00E+00	2.78E-03
BATCH-142	3/29/20	134	14.0	0.24	3.44E+02	0.00E+00	1.35E-05	2.00E-03	2.09E-05	8.69E-10	2.00E-03	4.86E-01	1.66E-04	4.00E-03	1.69E+01	0.00E+00	2.46E+01	0.00E+00	2.78E-03
BATCH-143	4/4/20	103	10.8	0.24	9.29E+01	6.87E+01	2.94E-05	4.00E-03	1.74E-05	0.00E+00	1.20E-02	4.96E-01	4.90E-05	4.00E-03	1.51E+01	0.00E+00	2.03E+00	3.08E+00	1.57E-02
BATCH-144	4/13/20	134	14.0	0.24	3.44E+02	0.00E+00	1.35E-05	2.00E-03	2.09E-05	1.97E-10	2.00E-03	4.85E-01	1.66E-04	4.00E-03	1.69E+01	0.00E+00	2.46E+01	0.00E+00	2.78E-03
BATCH-145	4/15/20	134	14.0	0.24	3.44E+02	0.00E+00	1.35E-05	2.00E-03	2.09E-05	2.22E-10	2.00E-03	4.85E-01	1.66E-04	4.00E-03	1.69E+01	0.00E+00	2.46E+01	0.00E+00	2.78E-03
BATCH-146	4/27/20	62	6.4	0.24	1.61E+02	0.00E+00	4.80E-06	3.00E-03	3.94E-06	6.17E-11	7.00E-03	1.72E-01	4.24E-05	7.00E-03	5.63E+00	0.00E+00	5.90E+00	0.00E+00	4.85E-04

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are *Ci for radionuclides and kg-mol for chemicals*)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-98	5/31/19	225	23.5	0.24	1.16E-05	4.78E+01	2.52E-01	0.00E+00	0.00E+00	4.20E-03	3.30E+01	2.00E-03	2.00E-03	4.00E-03	9.73E+01	7.26E-04	3.85E+03	0.00E+00	2.44E-01
BATCH-99	6/16/19	122	12.7	0.24	1.03E-08	7.43E+01	5.35E-01	0.00E+00	0.00E+00	1.00E-03	9.98E+00	2.00E-03	1.37E-06	3.54E-06	1.40E-02	2.92E-06	2.08E+03	0.00E+00	8.70E-02
BATCH-100	6/24/19	322	33.5	0.24	1.66E-06	2.47E+02	5.35E-01	0.00E+00	0.00E+00	9.40E-03	4.25E+01	6.35E-04	4.01E-04	2.00E-03	7.89E-01	2.81E-04	3.82E+03	0.00E+00	5.86E-01
BATCH-101	6/29/19	122	12.7	0.24	1.02E-08	7.43E+01	5.35E-01	0.00E+00	0.00E+00	1.00E-03	9.98E+00	2.00E-03	1.37E-06	3.54E-06	1.40E-02	2.92E-06	2.08E+03	0.00E+00	8.70E-02
BATCH-102	7/12/19	114	11.8	0.24	1.02E-08	6.92E+01	4.98E-01	0.00E+00	0.00E+00	1.00E-03	9.28E+00	2.00E-03	1.37E-06	3.53E-06	1.30E-02	2.76E-06	1.94E+03	0.00E+00	8.10E-02
BATCH-103	7/24/19	109	11.4	0.24	1.02E-08	6.66E+01	4.79E-01	0.00E+00	0.00E+00	1.00E-03	8.94E+00	2.00E-03	1.37E-06	3.53E-06	1.20E-02	2.68E-06	1.87E+03	0.00E+00	7.80E-02
BATCH-104	7/27/19	122	12.7	0.24	1.02E-08	7.41E+01	5.34E-01	0.00E+00	0.00E+00	1.00E-03	9.95E+00	2.00E-03	1.37E-06	3.52E-06	1.40E-02	2.91E-06	2.08E+03	0.00E+00	8.70E-02
BATCH-105	8/4/19	116	12.1	0.24	7.30E-09	7.05E+01	5.08E-01	0.00E+00	0.00E+00	1.00E-03	9.46E+00	2.00E-03	9.78E-07	2.52E-06	1.30E-02	2.62E-06	1.98E+03	0.00E+00	8.30E-02
BATCH-106	8/9/19	104	10.9	0.24	4.16E-07	2.70E+01	4.87E-01	0.00E+00	0.00E+00	4.00E-04	5.29E+00	3.69E-04	2.31E-05	1.00E-03	1.60E-02	5.12E-04	1.78E+03	0.00E+00	9.40E-02
BATCH-107	8/16/19	104	10.9	0.24	4.15E-07	2.69E+01	4.87E-01	0.00E+00	0.00E+00	4.00E-04	5.27E+00	3.69E-04	2.28E-05	1.00E-03	1.60E-02	5.11E-04	1.78E+03	0.00E+00	9.40E-02
BATCH-108	8/20/19	123	12.8	0.24	4.35E-07	3.13E+01	5.36E-01	0.00E+00	0.00E+00	6.00E-04	6.21E+00	4.23E-04	2.57E-05	1.00E-03	2.20E-02	7.68E-04	2.10E+03	0.00E+00	1.35E-01
BATCH-109	8/27/19	123	12.8	0.24	7.24E-07	3.37E+01	4.92E-01	0.00E+00	0.00E+00	4.00E-04	7.13E+00	4.65E-04	3.61E-05	3.00E-03	2.30E-02	4.26E-04	2.09E+03	0.00E+00	8.60E-02
BATCH-110	9/2/19	104	10.9	0.24	4.17E-07	2.70E+01	4.87E-01	0.00E+00	0.00E+00	4.00E-04	5.29E+00	3.68E-04	2.29E-05	1.00E-03	1.60E-02	5.13E-04	1.78E+03	0.00E+00	9.50E-02
BATCH-111	9/9/19	322	33.5	0.24	1.66E-06	2.47E+02	3.82E-01	0.00E+00	0.00E+00	9.40E-03	4.25E+01	6.35E-04	4.01E-04	2.00E-03	7.89E-01	2.81E-04	3.82E+03	0.00E+00	5.86E-01
BATCH-112	9/14/19	113	11.8	0.24	6.99E-07	2.78E+01	5.15E-01	0.00E+00	0.00E+00	6.00E-04	6.04E+00	4.05E-04	6.06E-05	2.00E-03	4.00E-02	5.31E-04	1.93E+03	0.00E+00	1.00E-01
BATCH-113	9/26/19	63	6.5	0.24	2.32E-07	1.50E+01	2.71E-01	0.00E+00	0.00E+00	2.00E-04	2.94E+00	2.05E-04	1.28E-05	8.29E-04	9.00E-03	2.85E-04	1.07E+03	0.00E+00	5.30E-02
BATCH-114	10/2/19	63	6.5	0.24	2.31E-07	1.50E+01	2.71E-01	0.00E+00	0.00E+00	2.00E-04	2.94E+00	2.05E-04	1.27E-05	8.26E-04	9.00E-03	2.84E-04	1.07E+03	0.00E+00	5.30E-02
BATCH-115	10/9/19	61	6.4	0.24	1.98E-07	1.43E+01	2.44E-01	0.00E+00	0.00E+00	2.00E-04	2.83E+00	1.93E-04	1.17E-05	7.07E-04	1.00E-02	3.49E-04	1.04E+03	0.00E+00	6.20E-02
BATCH-116	10/13/19	64	6.7	0.24	3.53E-07	1.64E+01	2.40E-01	0.00E+00	0.00E+00	1.76E-04	3.48E+00	2.27E-04	1.76E-05	1.00E-03	1.10E-02	2.08E-04	1.10E+03	0.00E+00	4.20E-02
BATCH-117	10/16/19	63	6.5	0.24	2.32E-07	1.50E+01	2.71E-01	0.00E+00	0.00E+00	2.00E-04	2.94E+00	2.05E-04	1.27E-05	8.29E-04	9.00E-03	2.86E-04	1.07E+03	0.00E+00	5.30E-02
BATCH-118	10/20/19	66	6.8	0.24	3.78E-07	1.50E+01	2.78E-01	0.00E+00	0.00E+00	2.00E-04	3.26E+00	2.19E-04	3.28E-05	8.58E-04	2.10E-02	2.87E-04	1.12E+03	0.00E+00	5.40E-02
BATCH-119	10/22/19	22	2.3	0.24	6.67E-08	4.32E+00	7.80E-02	0.00E+00	0.00E+00	6.79E-05	8.46E-01	5.91E-05	3.69E-06	2.38E-04	3.00E-03	8.20E-05	3.84E+02	0.00E+00	1.50E-02
BATCH-120	10/25/19	22	2.3	0.24	6.65E-08	4.31E+00	7.80E-02	0.00E+00	0.00E+00	6.78E-05	8.44E-01	5.90E-05	3.65E-06	2.37E-04	3.00E-03	8.17E-05	3.83E+02	0.00E+00	1.50E-02
BATCH-121	10/27/19	21	2.2	0.24	5.45E-08	3.93E+00	6.70E-02	0.00E+00	0.00E+00	7.35E-05	7.78E-01	5.30E-05	3.22E-06	1.95E-04	3.00E-03	9.62E-05	3.65E+02	0.00E+00	1.70E-02
BATCH-122	10/28/19	24	2.5	0.24	1.08E-07	5.01E+00	7.30E-02	0.00E+00	0.00E+00	5.37E-05	1.06E+00	6.90E-05	5.36E-06	3.85E-04	3.00E-03	6.32E-05	4.05E+02	0.00E+00	1.30E-02
BATCH-123	10/30/19	22	2.3	0.24	6.68E-08	4.32E+00	7.80E-02	0.00E+00	0.00E+00	6.80E-05	8.47E-01	5.90E-05	3.67E-06	2.39E-04	3.00E-03	8.22E-05	3.84E+02	0.00E+00	1.50E-02
BATCH-124	10/30/19	174	18.2	0.24	1.23E-11	1.06E+02	7.66E-01	0.00E+00	0.00E+00	1.40E-03	1.43E+01	3.00E-03	2.80E-09	4.41E-08	1.80E-02	3.27E-06	2.98E+03	0.00E+00	1.25E-01
BATCH-125	11/1/19	24	2.5	0.24	1.15E-07	4.57E+00	8.50E-02	0.00E+00	0.00E+00	8.59E-05	9.95E-01	6.68E-05	9.99E-06	2.62E-04	7.00E-03	8.75E-05	4.12E-02	0.00E+00	1.70E-02
BATCH-126	11/4/19	322	33.5	0.24	1.66E-06	2.47E+02	3.82E-01	0.00E+00	0.00E+00	9.40E-03	4.25E+01	6.35E-04	4.01E-04	2.00E-03	7.89E-01	2.81E-04	3.82E+03	0.00E+00	5.86E-01
BATCH-127	11/18/19	169	17.6	0.24	3.56E-06	1.10E+02	6.95E-01	0.00E+00	0.00E+00	6.00E-04	1.91E+01	7.91E-04	2.78E-04	1.00E-03	1.16E-01	1.34E-06	2.89E+03	0.00E+00	1.38E+00
BATCH-128	12/6/19	174	18.2	0.24	5.20E-06	1.17E+02	6.96E-01	0.00E+00	0.00E+00	1.90E-04	2.20E+01	7.35E-06	4.07E-04	2.00E-03	1.62E-01	6.06E-07	2.98E+03	0.00E+00	1.96E+00
BATCH-129	12/8/19	174	18.2	0.24	5.20E-06	1.17E+02	6.96E-01	0.00E+00	0.00E+00	1.90E-04	2.20E+01	7.35E-06	4.06E-04	2.00E-03	1.62E-01	6.02E-07	2.98E+03	0.00E+00	1.96E+00
BATCH-130	12/24/19	174	18.2	0.24	5.20E-06	1.17E+02	6.96E-01	0.00E+00	0.00E+00	1.90E-04	2.20E+01	7.35E-06	4.06E-04	2.00E-03	1.62E-01	6.04E-07	2.98E+03	0.00E+00	1.96E+00
BATCH-131	12/26/19	174	18.2	0.24	5.19E-06	1.17E+02	6.95E-01	0.00E+00	0.00E+00	1.90E-04	2.20E+01	7.34E-06	4.06E-04	2.00E-03	1.62E-01	6.06E-07	2.98E+03	0.00E+00	1.96E+00
BATCH-132	1/12/20	142	14.8	0.24	4.23E-06	9.53E+01	5.67E-01	0.00E+00	0.00E+00	1.55E-04	1.79E+01	7.22E-06	3.31E-04	1.00E-03	1.32E-01	4.83E-07	2.43E+03	0.00E+00	1.60E+00
BATCH-133	1/13/20	126	13.1	0.24	2.31E-05	5.82E+01	5.93E-01	0.00E+00	0.00E+00	2.00E-04	1.73E+01	1.45E-05	4.16E-04	3.33E-04	2.26E-01	2.02E-04	2.14E+03	0.00E+00	1.89E+00
BATCH-134	1/26/20	322	33.5	0.24	1.66E-06	2.47E+02	3.82E-01	0.00E+00	0.00E+00	9.40E-03	4.25E+01	6.35E-04	4.01E-04	2.00E-03	7.89E-01	2.81E-04	3.82E+03	0.00E+00	5.86E-01
BATCH-135	1/27/20	131	13.6	0.24	2.75E-05	5.59E+01	6.33E-01	0.00E+00	0.00E+00	4.00E-04	1.82E+01	1.64E-05	4.54E-04	1.93E-04	2.55E-01	2.46E-04	2.23E+03	0.00E+00	2.05E+00
BATCH-136	2/9/20	131	13.6	0.24	2.75E-05	5.59E+01	6.33E-01	0.00E+00	0.00E+00	4.00E-04	1.82E+01	1.64E-05	4.54E-04	1.93E-04	2.55E-01	2.46E-04	2.23E+03	0.00E+00	2.05E+00
BATCH-137	2/23/20	131	13.6	0.24	2.75E-05	5.59E+01	6.33E-01	0.00E+00	0.00E+00	4.00E-04	1.82E+01	1.64E-05	4.54E-04	1.93E-04	2.55E-01	2.46E-04	2.23E+03	0.00E+00	2.05E+00
BATCH-138	2/29/20	131	13.6	0.24	2.75E-05	5.59E+01	6.33E-01	0.00E+00	0.00E+00	4.00E-04	1.82E+01	1.64E-05	4.54E-04	1.93E-04	2.55E-01	2.46E-04	2.23E+03	0.00E+00	2.05E+00
BATCH-139	3/8/20	118	12.3	0.24	9.23E-07	3.34E+01	3.86E-01	0.00E+00	0.00E+00	2.00E-04	5.60E+00	3.29E-04	7.22E-05	2.94E-04	3.10E-02	4.93E-07	2.01E+03	0.00E+00	3.63E-01
BATCH-140	3/14/20	146	15.3	0.24	5.30E-06	4.07E+01	4.07E-01	0.00E+00	0.00E+00	2.00E-04	8.25E+00	3.07E-04	1.43E-04	3.14E-04	7.10E-02	3.99E-05	2.50E+03	0.00E+00	6.78E-01
BATCH-141	3/21/20	134	14.0	0.24	7.26E-06	3.67E+01	3.34E-01	0.00E+00	0.00E+00	1.12E-04	8.62E+00	5.21E-06	1.86E-04	3.84E-04	9.10E-02	5.54E-05	2.29E+03	0.00E+00	8.65E-01
BATCH-142	3/29/20	134	14.0	0.24	7.25E-06	3.66E+01	3.34E-01	0.00E+00	0.00E+00	1.11E-04	8.62E+00	5.21E-06	1.86E-04	3.83E-04	9.10E-02	5.54E-05	2.29E+03	0.00E+00	8.64E-01
BATCH-143	4/4/20	103	10.8	0.24	5.30E-07	7.93E+01	1.23E-01	0.00E+00	0.00E+00	3.00E-03	1.36E-01	2.04E-04	1.29E-04	7.80E-04	2.53E-01	8.99E-05	1.23E+03	0.00E+00	1.88E-01
BATCH-144	4/13/20	134	14.0	0.24	7.24E-06	3.66E+01	3.33E-01	0.00E+00	0.00E+00	1.11E-04	8.61E+00	5.20E-06	1.86E-04	3.83E-04	9.10E-02	5.53E-05	2.29E+03	0.00E+00	8.63E-01
BATCH-145	4/15/20	134	14.0	0.24	7.23E-06	3.65E+01	3.33E-01	0.00E+00	0.00E+00	1.11E-04	8.59E+00	5.19E-06	1.85E-04	3.82E-04	9.00E-02	5.53E-05	2.29E+03	0.00E+00	8.61E-01
BATCH-146	4/27/20	62	6.4	0.24	4.43E-07	1.60E+01	1.85E-01	0.00E+00	0.00E+00	9.79E-05	2.68E+00	1.58E-04	3.46E-05	1.41E-04	1.50E-02	2.36E-07	1.05E+03	0.00E+00	1.74E-01

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-98	5/31/19	225	23.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	4.49E-01	8.32E-06	4.99E+00	5.00E+01	1.20E-02	9.35E-06	0.00E+00	2.70E-02	1.00E-02	1.31E-01
BATCH-99	6/16/19	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.80E+01	7.39E-09	1.16E+01	4.97E+01	3.40E-02	8.30E-09	0.00E+00	3.28E-05	8.65E-04	1.08E-01
BATCH-100	6/24/19	322	33.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-101	6/29/19	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.80E+01	7.39E-09	1.16E+01	4.98E+01	3.40E-02	8.29E-09	0.00E+00	3.28E-05	8.65E-04	1.08E-01
BATCH-102	7/12/19	114	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.32E+01	7.38E-09	1.08E+01	4.63E+01	3.20E-02	8.28E-09	0.00E+00	3.21E-05	8.05E-04	1.01E-01
BATCH-103	7/24/19	109	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.09E+01	7.37E-09	1.04E+01	4.46E+01	3.00E-02	8.28E-09	0.00E+00	3.18E-05	7.75E-04	9.70E-02
BATCH-104	7/27/19	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.78E+01	7.35E-09	1.16E+01	4.96E+01	3.40E-02	8.27E-09	0.00E+00	3.27E-05	8.62E-04	1.08E-01
BATCH-105	8/4/19	116	12.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.44E+01	5.26E-09	1.10E+01	4.72E+01	3.20E-02	5.91E-09	0.00E+00	2.56E-05	8.18E-04	1.03E-01
BATCH-106	8/9/19	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.56E+01	3.40E-06	7.17E+00	1.44E+01	2.00E-02	9.17E-10	0.00E+00	4.00E-03	6.00E-03	1.47E-01
BATCH-107	8/16/19	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.56E+01	3.40E-06	7.17E+00	1.44E+01	2.00E-02	9.16E-10	0.00E+00	4.00E-03	6.00E-03	1.47E-01
BATCH-108	8/20/19	123	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	3.15E+01	3.56E-06	8.35E+00	1.70E+01	2.70E-02	1.00E-09	0.00E+00	4.00E-03	7.00E-03	1.63E-01
BATCH-109	8/27/19	123	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.73E+01	5.97E-06	7.29E+00	1.67E+01	1.90E-02	9.81E-10	0.00E+00	7.00E-03	7.00E-03	2.30E-01
BATCH-110	9/2/19	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.56E+01	3.41E-06	7.17E+00	1.44E+01	2.00E-02	9.11E-10	0.00E+00	4.00E-03	6.00E-03	1.48E-01
BATCH-111	9/9/19	322	33.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-112	9/14/19	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	2.69E+01	3.62E-06	7.68E+00	1.54E+01	2.00E-02	2.29E-07	0.00E+00	4.00E-03	6.00E-03	1.50E-01
BATCH-113	9/26/19	63	6.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.43E+01	1.90E-06	3.99E+00	8.04E+00	1.10E-02	5.11E-10	0.00E+00	2.00E-03	3.00E-03	8.20E-02
BATCH-114	10/2/19	63	6.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.43E+01	1.89E-06	3.99E+00	8.03E+00	1.10E-02	5.10E-10	0.00E+00	2.00E-03	3.00E-03	8.20E-02
BATCH-115	10/9/19	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.43E+01	1.62E-06	3.80E+00	7.75E+00	1.20E-02	4.56E-10	0.00E+00	2.00E-03	3.00E-03	7.40E-02
BATCH-116	10/13/19	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.33E+01	2.91E-06	3.55E+00	8.12E+00	9.00E-03	4.78E-10	0.00E+00	3.00E-03	4.00E-03	1.12E-01
BATCH-117	10/16/19	63	6.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.43E+01	1.90E-06	3.99E+00	8.03E+00	1.10E-02	5.07E-10	0.00E+00	2.00E-03	3.00E-03	8.20E-02
BATCH-118	10/20/19	66	6.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.46E+01	1.96E-06	4.15E+00	8.35E+00	1.10E-02	1.24E-07	0.00E+00	2.00E-03	3.00E-03	8.10E-02
BATCH-119	10/22/19	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.11E+00	5.45E-07	1.15E+00	2.31E+00	3.00E-03	1.47E-10	0.00E+00	5.63E-04	9.03E-04	2.40E-02
BATCH-120	10/25/19	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.10E+00	5.44E-07	1.15E+00	2.31E+00	3.00E-03	1.47E-10	0.00E+00	5.61E-04	9.01E-04	2.40E-02
BATCH-121	10/27/19	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.95E+00	4.46E-07	1.05E+00	2.13E+00	3.00E-03	1.26E-10	0.00E+00	4.71E-04	8.94E-04	2.00E-02
BATCH-122	10/28/19	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.06E+00	8.85E-07	1.08E+00	2.48E+00	3.00E-03	1.46E-10	0.00E+00	9.95E-04	1.00E-03	3.40E-02
BATCH-123	10/30/19	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.11E+00	5.47E-07	1.15E+00	2.31E+00	3.00E-03	1.46E-10	0.00E+00	5.64E-04	9.05E-04	2.40E-02
BATCH-124	10/30/19	174	18.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	9.73E+01	1.01E-10	1.66E+01	7.12E+01	4.90E-02	2.72E-14	0.00E+00	1.33E-05	1.00E-03	1.55E-01
BATCH-125	11/1/19	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.44E+00	5.96E-07	1.27E+00	2.55E+00	3.00E-03	3.78E-08	0.00E+00	6.88E-04	9.71E-04	2.50E-02
BATCH-126	11/4/19	322	33.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-127	11/18/19	169	17.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	7.03E+01	4.29E-06	9.43E+00	7.87E+01	2.70E-02	3.58E-12	0.00E+00	1.80E-02	5.10E-02	5.50E-02
BATCH-128	12/6/19	174	18.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	6.23E+01	6.27E-06	6.87E+00	8.54E+01	1.90E-02	5.22E-12	0.00E+00	2.60E-02	7.40E-02	1.70E-02
BATCH-129	12/8/19	174	18.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	6.23E+01	6.27E-06	6.87E+00	8.53E+01	1.90E-02	5.23E-12	0.00E+00	2.60E-02	7.40E-02	1.70E-02
BATCH-130	12/24/19	174	18.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	6.23E+01	6.27E-06	6.86E+00	8.53E+01	1.90E-02	5.22E-12	0.00E+00	2.60E-02	7.40E-02	1.70E-02
BATCH-131	12/26/19	174	18.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	6.22E+01	6.26E-06	6.86E+00	8.52E+01	1.90E-02	1.19E-11	0.00E+00	2.60E-02	7.40E-02	1.70E-02
BATCH-132	1/12/20	142	14.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	5.08E+01	5.11E-06	5.60E+00	6.95E+01	1.50E-02	4.23E-12	0.00E+00	2.10E-02	6.00E-02	1.40E-02
BATCH-133	1/13/20	126	13.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	3.44E+01	1.14E-06	4.51E+00	3.55E+01	5.00E-03	2.12E-05	0.00E+00	2.20E-02	5.90E-02	3.00E-02
BATCH-134	1/26/20	322	33.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.52E+01	5.14E-06	5.85E+01	3.03E+01	4.00E-03	6.10E-07	0.00E+00	9.00E-03	6.00E-03	2.48E+00
BATCH-135	1/27/20	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.40E+01	5.89E-07	4.62E+00	3.23E+01	3.00E-03	2.58E-05	0.00E+00	2.40E-02	6.20E-02	3.40E-02
BATCH-136	2/9/20	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.40E+01	5.89E-07	4.62E+00	3.23E+01	3.00E-03	2.58E-05	0.00E+00	2.40E-02	6.20E-02	3.40E-02
BATCH-137	2/23/20	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.40E+01	5.89E-07	4.62E+00	3.23E+01	3.00E-03	2.58E-05	0.00E+00	2.40E-02	6.20E-02	3.40E-02
BATCH-138	2/29/20	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.40E+01	5.89E-07	4.62E+00	3.23E+01	3.00E-03	2.58E-05	0.00E+00	2.40E-02	6.20E-02	3.40E-02
BATCH-139	3/8/20	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	2.98E+01	1.11E-06	1.47E+01	2.44E+01	9.00E-03	9.27E-13	0.00E+00	5.00E-03	1.30E-02	2.10E-02
BATCH-140	3/14/20	146	15.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.50E+01	1.17E-06	1.86E+01	2.86E+01	9.00E-03	4.15E-06	0.00E+00	9.00E-03	2.30E-02	2.50E-02
BATCH-141	3/21/20	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	2.84E+01	1.42E-06	1.85E+01	2.58E+01	5.00E-03	5.82E-06	0.00E+00	1.10E-02	2.90E-02	1.10E-02
BATCH-142	3/29/20	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	2.84E+01	1.42E-06	1.85E+01	2.58E+01	5.00E-03	5.81E-06	0.00E+00	1.10E-02	2.90E-02	1.10E-02
BATCH-143	4/4/20	103	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	1.13E+01	1.65E-06	1.87E+01	9.72E+00	1.00E-03	1.96E-07	0.00E+00	3.00E-03	2.00E-03	7.94E-01
BATCH-144	4/13/20	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	2.84E+01	1.42E-06	1.85E+01	2.58E+01	5.00E-03	5.81E-06	0.00E+00	1.10E-02	2.90E-02	1.10E-02
BATCH-145	4/15/20	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	2.83E+01	1.42E-06	1.85E+01	2.57E+01	5.00E-03	5.80E-06	0.00E+00	1.10E-02	2.90E-02	1.10E-02
BATCH-146	4/27/20	62	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.43E+01	5.34E-07	7.07E+00	1.17E+01	4.00E-03	4.44E-13	0.00E+00	2.00E-03	6.00E-03	1.00E-02

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-147	4/29/20	66	6.9	0.24	0.00E+00	0.00E+00	2.10E-02	9.00E-03	1.72E+00	9.81E-02	5.63E+02	1.38E-01	3.10E-02	6.61E+00	3.24E-10	2.85E-01	3.00E-03	4.80E-02	3.25E-03
BATCH-147	5/4/20	71	7.5	0.24	0.00E+00	0.00E+00	2.90E-02	1.30E-02	2.32E+00	1.22E-01	6.63E+02	1.82E-01	4.30E-02	7.12E+00	4.92E-10	3.34E-01	4.00E-03	6.90E-02	3.75E-03
BATCH-148	5/6/20	71	7.4	0.24	0.00E+00	0.00E+00	2.90E-02	1.30E-02	2.32E+00	1.22E-01	6.63E+02	1.82E-01	4.30E-02	7.11E+00	4.92E-10	3.33E-01	4.00E-03	6.90E-02	3.75E-03
BATCH-149	5/11/20	71	7.4	0.24	0.00E+00	0.00E+00	2.90E-02	1.30E-02	2.31E+00	1.22E-01	6.62E+02	1.82E-01	4.30E-02	7.11E+00	4.92E-10	3.33E-01	4.00E-03	6.90E-02	3.75E-03
BATCH-150	5/14/20	71	7.4	0.24	0.00E+00	0.00E+00	2.90E-02	1.30E-02	2.31E+00	1.22E-01	6.62E+02	1.82E-01	4.30E-02	7.10E+00	4.91E-10	3.33E-01	4.00E-03	6.90E-02	3.75E-03
BATCH-151	5/19/20	21	2.2	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.02E-01	1.98E-02	1.03E+02	2.40E-02	5.00E-03	1.26E+00	5.91E-11	5.60E-02	4.77E-04	8.00E-03	7.50E-04
BATCH-152	5/21/20	24	2.5	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	5.13E-01	2.88E-02	1.68E+02	4.10E-02	9.00E-03	2.00E+00	9.63E-11	8.50E-02	7.81E-04	1.40E-02	1.00E-03
BATCH-153	5/22/20	27	2.8	0.24	0.00E+00	0.00E+00	9.00E-03	4.00E-03	7.62E-01	3.96E-02	2.18E+02	6.00E-02	1.40E-02	2.72E+00	1.62E-10	1.10E-01	1.00E-03	2.30E-02	1.25E-03
BATCH-154	5/24/20	27	2.8	0.24	0.00E+00	0.00E+00	9.00E-03	4.00E-03	7.61E-01	3.96E-02	2.18E+02	6.00E-02	1.40E-02	2.72E+00	1.62E-10	1.10E-01	1.00E-03	2.30E-02	1.25E-03
BATCH-155	5/25/20	27	2.8	0.24	0.00E+00	0.00E+00	9.00E-03	4.00E-03	7.60E-01	3.96E-02	2.18E+02	6.00E-02	1.40E-02	2.72E+00	1.61E-10	1.09E-01	1.00E-03	2.30E-02	1.25E-03
BATCH-156	5/27/20	27	2.8	0.24	0.00E+00	0.00E+00	9.00E-03	4.00E-03	7.59E-01	3.96E-02	2.17E+02	6.00E-02	1.40E-02	2.71E+00	1.61E-10	1.09E-01	1.00E-03	2.30E-02	1.25E-03
BATCH-157	5/28/20	185	19.2	0.24	0.00E+00	0.00E+00	1.90E-01	9.20E-02	1.53E+01	6.73E-01	3.69E+03	1.27E+00	2.89E-01	1.84E+01	2.69E-09	2.15E+00	2.20E-02	4.67E-01	2.18E-02
BATCH-158	5/30/20	184	19.2	0.24	0.00E+00	0.00E+00	1.90E-01	9.20E-02	1.53E+01	6.72E-01	3.68E+03	1.26E+00	2.88E-01	1.83E+01	2.69E-09	2.15E+00	2.20E-02	4.66E-01	2.18E-02
BATCH-159	6/17/20	169	17.6	0.24	0.00E+00	0.00E+00	8.60E-02	3.70E-02	6.92E+00	3.83E-01	3.38E+03	6.55E-01	1.12E-01	1.68E+01	4.37E-10	1.71E+00	9.00E-03	1.42E-01	1.35E-02
BATCH-160	6/19/20	177	18.4	0.24	0.00E+00	0.00E+00	7.00E-02	2.90E-02	5.68E+00	3.49E-01	3.54E+03	5.75E-01	8.30E-02	1.63E+01	1.10E-11	1.71E+00	7.00E-03	8.60E-02	1.28E-02
BATCH-161	7/5/20	177	18.4	0.24	0.00E+00	0.00E+00	7.00E-02	2.90E-02	5.67E+00	3.49E-01	3.53E+03	5.74E-01	8.30E-02	1.63E+01	1.10E-11	1.71E+00	7.00E-03	8.60E-02	1.28E-02
BATCH-162	7/8/20	177	18.4	0.24	0.00E+00	0.00E+00	7.00E-02	2.90E-02	5.67E+00	3.49E-01	3.53E+03	5.74E-01	8.30E-02	1.63E+01	1.10E-11	1.71E+00	7.00E-03	8.50E-02	1.25E-02
BATCH-163	7/23/20	121	12.7	0.24	0.00E+00	0.00E+00	4.80E-02	2.00E-02	3.90E+00	2.40E-01	2.43E+03	3.95E-01	5.70E-02	1.12E+01	1.10E-11	1.71E+00	7.00E-03	5.90E-02	8.75E-03
BATCH-164	7/26/20	121	12.7	0.24	0.00E+00	0.00E+00	4.80E-02	2.00E-02	3.90E+00	2.40E-01	2.43E+03	3.94E-01	5.70E-02	1.12E+01	9.12E-12	1.18E+00	5.00E-03	5.90E-02	8.75E-03
BATCH-165	8/5/20	122	12.7	0.24	0.00E+00	0.00E+00	7.70E-02	3.30E-02	6.24E+00	2.62E-01	2.44E+03	5.40E-01	9.80E-02	1.21E+01	2.18E-10	1.24E+00	8.00E-03	1.32E-01	9.25E-03
BATCH-166	8/8/20	138	14.4	0.24	0.00E+00	0.00E+00	1.29E-01	5.70E-02	1.04E+01	3.26E-01	2.76E+03	8.20E-01	1.70E-01	1.38E+01	5.50E-10	1.49E+00	1.30E-02	2.56E-01	1.13E-02
BATCH-167	8/18/20	138	14.4	0.24	0.00E+00	0.00E+00	1.29E-01	5.70E-02	1.04E+01	3.26E-01	2.76E+03	8.19E-01	1.70E-01	1.38E+01	5.50E-10	1.49E+00	1.30E-02	2.56E-01	1.13E-02
BATCH-168	8/23/20	138	14.4	0.24	0.00E+00	0.00E+00	1.29E-01	5.70E-02	1.04E+01	3.26E-01	2.76E+03	3.21E-01	7.00E-02	1.10E+01	5.90E-10	6.02E-01	5.00E-03	1.08E-01	5.75E-03
BATCH-169	9/2/20	110	11.5	0.24	0.00E+00	0.00E+00	4.70E-02	2.20E-02	3.79E+00	1.75E-01	1.36E+03	3.20E-01	6.90E-02	1.09E+01	5.88E-10	6.00E-01	5.00E-03	1.08E-01	5.75E-03
BATCH-170	9/7/20	110	11.4	0.24	0.00E+00	0.00E+00	4.70E-02	2.20E-02	3.78E+00	1.74E-01	1.36E+03	5.93E-01	1.23E-01	9.95E+00	3.98E-10	1.08E+00	9.00E-03	1.85E-01	8.25E-03
BATCH-171	9/13/20	100	10.4	0.24	0.00E+00	0.00E+00	9.40E-02	4.10E-02	7.54E+00	2.36E-01	2.00E+03	7.07E-01	1.47E-01	1.19E+01	4.74E-10	1.29E+00	1.10E-02	2.21E-01	9.75E-03
BATCH-172	9/18/20	119	12.4	0.24	0.00E+00	0.00E+00	1.11E-01	4.90E-02	8.99E+00	2.81E-01	2.38E+03	7.06E-01	1.47E-01	1.18E+01	4.74E-10	1.29E+00	1.10E-02	2.21E-01	9.75E-03
BATCH-173	9/24/20	119	12.4	0.24	0.00E+00	0.00E+00	1.11E-01	4.90E-02	8.98E+00	2.80E-01	2.37E+03	7.04E-01	1.46E-01	1.18E+01	4.73E-10	1.28E+00	1.10E-02	2.20E-01	9.75E-03
BATCH-174	10/1/20	119	12.4	0.24	0.00E+00	0.00E+00	1.11E-01	4.90E-02	8.96E+00	2.80E-01	2.37E+03	7.04E-01	1.46E-01	1.18E+01	4.73E-10	1.28E+00	1.10E-02	2.20E-01	9.75E-03
BATCH-175	10/7/20	66	6.9	0.24	0.00E+00	0.00E+00	2.60E-02	1.20E-02	2.12E+00	9.72E-02	7.61E+02	1.80E-01	3.90E-02	6.60E+00	3.30E-10	3.37E-01	3.00E-03	6.10E-02	3.25E-03
BATCH-176	10/13/20	66	6.9	0.24	0.00E+00	0.00E+00	2.60E-02	1.20E-02	2.12E+00	9.72E-02	7.59E+02	1.79E-01	3.90E-02	6.59E+00	3.29E-10	3.36E-01	3.00E-03	6.10E-02	3.25E-03
BATCH-177	10/14/20	136	14.1	0.24	0.00E+00	0.00E+00	4.30E-02	1.90E-02	3.50E+00	1.62E-01	1.61E+03	3.05E-01	5.90E-02	1.04E+01	3.29E-10	6.64E-01	5.00E-03	8.50E-02	5.50E-03
BATCH-178	10/20/20	97	10.2	0.24	0.00E+00	0.00E+00	2.80E-02	1.20E-02	2.22E+00	9.00E-02	1.12E+03	1.90E-01	3.50E-02	5.08E+00	8.35E-11	4.24E-01	3.00E-03	4.80E-02	3.25E-03
BATCH-179	10/28/20	97	10.1	0.24	0.00E+00	0.00E+00	2.80E-02	1.20E-02	2.22E+00	8.91E-02	1.12E+03	1.89E-01	3.50E-02	5.08E+00	8.33E-11	4.23E-01	3.00E-03	4.80E-02	3.25E-03
BATCH-180	10/31/20	97	10.1	0.24	0.00E+00	0.00E+00	2.70E-02	1.20E-02	2.21E+00	8.91E-02	1.12E+03	1.89E-01	3.50E-02	5.07E+00	8.31E-11	4.22E-01	3.00E-03	4.80E-02	3.25E-03
BATCH-181	11/7/20	24	2.5	0.24	0.00E+00	0.00E+00	8.00E-03	4.00E-03	6.18E-01	2.88E-02	2.22E+02	5.20E-02	1.10E-02	2.12E+00	9.61E-11	9.80E-02	8.79E-04	1.80E-02	1.00E-03
BATCH-182	11/10/20	24	2.5	0.24	0.00E+00	0.00E+00	8.00E-03	4.00E-03	6.15E-01	2.79E-02	2.21E+02	5.20E-02	1.10E-02	2.11E+00	9.57E-11	9.80E-02	8.75E-04	1.80E-02	1.00E-03
BATCH-183	11/10/20	60	6.3	0.24	0.00E+00	0.00E+00	1.80E-02	8.00E-03	1.42E+00	6.57E-02	6.50E+02	1.24E-01	2.40E-02	4.20E+00	1.33E-10	2.69E-01	2.00E-03	3.50E-02	2.25E-03
BATCH-184	11/10/20	60	6.3	0.24	0.00E+00	0.00E+00	1.80E-02	8.00E-03	1.42E+00	6.57E-02	6.50E+02	1.24E-01	2.40E-02	4.20E+00	4.47E-11	2.27E-01	1.00E-03	2.60E-02	1.75E-03
BATCH-185	11/13/20	57	6.0	0.24	0.00E+00	0.00E+00	1.50E-02	6.00E-03	1.19E+00	4.77E-02	6.01E+02	1.01E-01	1.90E-02	2.72E+00	4.46E-11	2.26E-01	1.00E-03	2.60E-02	1.75E-03
BATCH-186	11/17/20	57	6.0	0.24	0.00E+00	0.00E+00	1.50E-02	6.00E-03	1.19E+00	4.77E-02	5.99E+02	1.01E-01	1.90E-02	2.71E+00	4.45E-11	2.26E-01	1.00E-03	2.60E-02	1.75E-03
BATCH-187	11/19/20	57	6.0	0.24	0.00E+00	0.00E+00	1.50E-02	6.00E-03	1.19E+00	4.77E-02	5.99E+02	1.01E-01	1.90E-02	2.71E+00	4.45E-11	2.26E-01	1.00E-03	2.60E-02	1.75E-03
BATCH-188	11/23/20	163	16.9	0.24	0.00E+00	0.00E+00	2.24E-01	1.04E-01	1.80E+01	4.22E-01	3.25E+03	1.53E+00	3.03E-01	1.62E+01	1.85E-10	2.59E+00	2.10E-02	4.61E-01	1.53E-02
BATCH-189	11/25/20	164	17.1	0.24	0.00E+00	0.00E+00	2.40E-01	1.13E-01	1.93E+01	4.34E-01	3.28E+03	1.66E+00	3.26E-01	1.63E+01	9.62E-11	2.78E+00	2.30E-02	4.96E-01	1.58E-02
BATCH-190	12/10/20	21	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	2.00E-03	3.71E-01	1.71E-02	1.71E+02	3.20E-02	6.00E-03	1.10E+00	3.49E-11	7.10E-02	4.91E-04	9.00E-03	5.00E-04
BATCH-191	12/12/20	19	2.0	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	2.93E-01	1.17E-02	1.48E+02	2.50E-02	5.00E-03	6.71E-01	1.10E-11	5.60E-02	3.57E-04	6.00E-03	5.00E-04
BATCH-192	12/12/20	19	2.0	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	2.92E-01	1.17E-02	1.48E+02	2.50E-02	5.00E-03	6.69E-01	1.10E-11	5.60E-02	3.56E-04	6.00E-03	5.00E-04
BATCH-193	12/14/20	19	2.0	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	2.92E-01	1.17E-02	1.48E+02	2.50E-02	5.00E-03	6.67E-01	1.10E-11	5.60E-02	3.55E-04	6.00E-03	5.00E-04
BATCH-194	12/15/20	147	15.3	0.24	0.00E+00	0.00E+00	2.15E-01	1.01E-01	1.73E+01	3.89E-01	2.94E+03	1.49E+00	2.92E-01	1.46E+01	8.61E-11	2.49E+00	2.00E-02	4.44E-01	1.40E-02
BATCH-195	12/17/20	150	15.6	0.24	0.00E+00	0.00E+00	2.20E-01	1.03E-01	1.76E+01	3.97E-01	3.00E+03	1.52E+00	2.98E-01	1.49E+01	8.80E-11	2.54E+00	2.10E-02	4.54E-01	1.45E-02

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-147	4/29/20	66	6.9	0.24	5.40E-07	1.99E+02	5.31E+01	5.00E-03	3.80E-01	3.80E-02	2.80E-02	2.23E-06	1.83E-04	2.10E-05	4.31E-05	5.81E-05	2.00E-03	1.10E-02	5.00E-03
BATCH-148	5/4/20	71	7.5	0.24	6.21E-07	2.14E+02	7.77E+01	8.00E-03	5.72E-01	4.70E-02	4.20E-02	3.26E-06	2.09E-04	2.50E-05	6.08E-05	6.67E-05	3.00E-03	1.60E-02	7.00E-03
BATCH-149	5/6/20	71	7.4	0.24	6.20E-07	2.14E+02	7.77E+01	8.00E-03	5.72E-01	4.70E-02	4.20E-02	3.25E-06	2.09E-04	2.50E-05	6.07E-05	6.66E-05	3.00E-03	1.60E-02	7.00E-03
BATCH-150	5/11/20	71	7.4	0.24	6.20E-07	2.14E+02	7.76E+01	8.00E-03	5.71E-01	4.70E-02	4.20E-02	3.25E-06	2.08E-04	2.50E-05	6.06E-05	6.65E-05	3.00E-03	1.60E-02	7.00E-03
BATCH-151	5/14/20	71	7.4	0.24	6.19E-07	2.14E+02	7.75E+01	8.00E-03	5.71E-01	4.70E-02	4.20E-02	3.22E-07	4.09E-05	4.01E-06	7.07E-06	1.11E-05	2.22E-04	1.00E-03	5.93E-04
BATCH-152	5/19/20	21	2.2	0.24	1.18E-07	6.20E+01	7.59E+00	7.96E-04	5.30E-02	7.00E-03	5.00E-03	6.65E-07	5.44E-05	6.25E-06	1.29E-05	1.73E-05	6.41E-04	3.00E-03	1.00E-03
BATCH-153	5/21/20	24	2.5	0.24	1.61E-07	7.20E+01	1.58E+01	2.00E-03	1.13E-01	1.10E-02	8.00E-03	6.65E-07	5.44E-05	6.88E-05	8.24E-06	2.00E-05	2.19E-05	1.00E-03	5.00E-03
BATCH-154	5/22/20	27	2.8	0.24	2.04E-07	8.19E+01	2.56E+01	2.00E-03	1.88E-01	1.50E-02	1.40E-02	1.07E-06	6.87E-05	8.23E-06	2.00E-05	2.19E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-155	5/24/20	27	2.8	0.24	2.04E-07	8.19E+01	2.55E+01	2.00E-03	1.88E-01	1.50E-02	1.40E-02	1.07E-06	6.86E-05	8.22E-06	2.00E-05	2.19E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-156	5/25/20	27	2.8	0.24	2.04E-07	8.18E+01	2.55E+01	2.00E-03	1.88E-01	1.50E-02	1.40E-02	1.07E-06	6.85E-05	8.21E-06	1.99E-05	2.18E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-157	5/27/20	27	2.8	0.24	2.03E-07	8.17E+01	2.55E+01	2.00E-03	1.88E-01	1.50E-02	1.40E-02	1.07E-06	6.85E-05	8.21E-06	1.99E-05	2.18E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-158	5/28/20	185	19.2	0.24	3.25E-06	5.53E+02	5.90E+02	5.70E-02	4.30E+00	3.31E-01	2.29E-01	2.46E-05	1.00E-03	1.67E-04	4.18E-04	4.63E-04	3.00E-02	1.46E-01	6.00E-02
BATCH-159	5/30/20	184	19.2	0.24	3.24E-06	5.53E+02	5.89E+02	5.70E-02	4.29E+00	3.31E-01	2.29E-01	2.46E-05	1.00E-03	1.67E-04	4.17E-04	4.62E-04	3.00E-02	1.46E-01	6.00E-02
BATCH-160	6/17/20	169	17.6	0.24	2.10E-06	5.07E+02	2.02E+02	2.20E-02	1.55E+00	1.28E-01	3.70E-02	8.28E-06	7.31E-04	9.55E-05	1.67E-04	2.82E-04	1.30E-02	6.40E-02	2.00E-02
BATCH-161	6/19/20	177	18.4	0.24	2.01E-06	5.30E+02	1.37E+02	1.60E-02	1.10E+00	9.50E-02	7.23E-04	5.53E-06	7.16E-04	8.73E-05	1.27E-04	2.63E-04	1.00E-02	5.10E-02	1.40E-02
BATCH-162	7/5/20	177	18.4	0.24	2.01E-06	5.30E+02	1.37E+02	1.60E-02	1.10E+00	9.50E-02	7.22E-04	5.53E-06	7.15E-04	8.72E-05	1.27E-04	2.63E-04	1.00E-02	5.10E-02	1.40E-02
BATCH-163	7/8/20	177	18.4	0.24	2.01E-06	5.30E+02	1.37E+02	1.60E-02	1.10E+00	9.50E-02	6.33E-04	3.81E-06	4.92E-04	6.00E-05	8.76E-05	1.81E-04	7.00E-03	3.50E-02	9.00E-03
BATCH-164	7/23/20	121	12.7	0.24	1.38E-06	3.64E+02	9.44E+01	1.10E-02	7.57E-01	6.60E-02	6.32E-04	3.80E-06	4.91E-04	5.99E-05	8.75E-05	1.81E-04	7.00E-03	3.50E-02	9.00E-03
BATCH-165	7/26/20	121	12.7	0.24	1.38E-06	3.64E+02	9.43E+01	1.10E-02	7.57E-01	6.60E-02	6.32E-04	3.80E-06	9.21E-04	1.06E-04	1.28E-04	2.65E-04	1.50E-02	7.50E-02	2.20E-02
BATCH-166	8/5/20	122	12.7	0.24	1.15E-06	3.66E+02	2.19E+02	2.20E-02	1.65E+00	1.31E-01	1.80E-02	9.06E-06	9.21E-04	1.06E-04	2.02E-04	4.21E-04	2.90E-02	1.43E-01	4.30E-02
BATCH-167	8/8/20	138	14.4	0.24	9.52E-07	4.14E+02	4.27E+02	4.20E-02	3.17E+00	2.42E-01	4.70E-02	1.78E-05	2.00E-03	1.87E-04	2.02E-04	4.21E-04	2.90E-02	1.43E-01	4.30E-02
BATCH-168	8/18/20	138	14.4	0.24	9.51E-07	4.14E+02	4.27E+02	4.20E-02	3.17E+00	2.42E-01	4.70E-02	1.78E-05	2.00E-03	1.87E-04	2.02E-04	4.21E-04	2.90E-02	1.43E-01	4.30E-02
BATCH-169	8/23/20	138	14.4	0.24	9.51E-07	4.14E+02	4.27E+02	4.20E-02	3.17E+00	2.42E-01	4.70E-02	1.78E-05	2.00E-03	1.87E-04	2.02E-04	4.21E-04	7.00E-03	3.60E-02	1.40E-02
BATCH-170	9/2/20	110	11.5	0.24	8.65E-07	3.30E+02	1.40E+02	1.40E-02	1.03E+00	8.00E-02	5.00E-02	5.81E-06	2.82E-04	4.32E-05	1.01E-04	1.21E-04	7.00E-03	3.60E-02	1.40E-02
BATCH-171	9/7/20	110	11.4	0.24	8.62E-07	3.29E+02	1.39E+02	1.40E-02	1.02E+00	8.00E-02	5.00E-02	5.80E-06	2.81E-04	4.31E-05	1.01E-04	1.21E-04	7.00E-03	3.60E-02	1.40E-02
BATCH-172	9/13/20	100	10.4	0.24	6.88E-07	3.00E+02	3.09E+02	3.00E-02	2.29E+00	1.75E-01	3.40E-02	1.29E-05	1.00E-03	1.35E-04	1.46E-04	3.05E-04	2.10E-02	1.03E-01	3.10E-02
BATCH-173	9/18/20	119	12.4	0.24	8.19E-07	3.57E+02	3.68E+02	3.60E-02	2.73E+00	2.09E-01	4.00E-02	1.54E-05	1.00E-03	1.61E-04	1.74E-04	3.63E-04	2.50E-02	1.23E-01	3.70E-02
BATCH-174	9/24/20	119	12.4	0.24	8.19E-07	3.57E+02	3.68E+02	3.60E-02	2.73E+00	2.08E-01	4.00E-02	1.53E-05	1.00E-03	1.61E-04	1.73E-04	3.62E-04	2.50E-02	1.23E-01	3.70E-02
BATCH-175	10/1/20	119	12.4	0.24	8.17E-07	3.56E+02	3.67E+02	3.60E-02	2.72E+00	2.08E-01	4.00E-02	1.53E-05	1.00E-03	1.61E-04	2.42E-05	5.67E-05	6.80E-05	4.00E-03	2.00E-02	8.00E-03
BATCH-176	10/7/20	66	6.9	0.24	4.84E-07	1.99E+02	7.82E+01	8.00E-03	5.74E-01	4.50E-02	2.80E-02	3.25E-06	1.58E-04	2.41E-05	5.65E-05	6.78E-05	4.00E-03	2.00E-02	8.00E-03
BATCH-177	10/13/20	66	6.9	0.24	4.83E-07	1.98E+02	7.80E+01	8.00E-03	5.73E-01	4.50E-02	2.80E-02	3.25E-06	1.58E-04	2.41E-05	8.37E-05	1.31E-04	7.00E-03	3.60E-02	1.20E-02
BATCH-178	10/14/20	136	14.1	0.24	7.92E-07	4.07E+02	1.21E+02	1.20E-02	9.08E-01	7.20E-02	2.80E-02	5.03E-06	3.74E-04	4.86E-05	8.37E-05	1.31E-04	7.00E-03	2.70E-02	8.00E-03
BATCH-179	10/20/20	97	10.2	0.24	3.77E-07	2.92E+02	7.98E+01	8.00E-03	6.02E-01	4.70E-02	7.00E-03	3.31E-06	3.32E-04	3.81E-05	4.50E-05	9.38E-05	6.00E-03	2.70E-02	8.00E-03
BATCH-180	10/28/20	97	10.1	0.24	3.77E-07	2.92E+02	7.97E+01	8.00E-03	6.01E-01	4.70E-02	7.00E-03	3.31E-06	3.31E-04	3.81E-05	4.50E-05	9.36E-05	6.00E-03	2.70E-02	8.00E-03
BATCH-181	10/31/20	97	10.1	0.24	3.76E-07	2.91E+02	7.95E+01	8.00E-03	5.99E-01	4.70E-02	7.00E-03	3.30E-06	3.31E-04	3.80E-05	4.49E-05	9.34E-05	6.00E-03	2.70E-02	8.00E-03
BATCH-182	11/7/20	24	2.5	0.24	1.41E-07	7.09E+01	2.28E+01	2.00E-03	1.67E-01	1.30E-02	8.00E-03	9.47E-07	4.60E-05	7.04E-06	1.65E-05	1.98E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-183	11/10/20	24	2.5	0.24	1.40E-07	7.07E+01	2.27E+01	2.00E-03	1.66E-01	1.30E-02	8.00E-03	9.43E-07	4.58E-05	7.01E-06	1.64E-05	1.97E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-184	11/10/20	60	6.3	0.24	3.21E-07	1.80E+02	4.92E+01	5.00E-03	3.68E-01	2.90E-02	1.10E-02	2.04E-06	1.52E-04	1.97E-05	3.39E-05	5.31E-05	3.00E-03	1.50E-02	5.00E-03
BATCH-185	11/13/20	57	6.0	0.24	2.02E-07	1.72E+02	4.27E+01	4.00E-03	3.22E-01	2.50E-02	4.00E-03	1.77E-06	1.78E-04	2.04E-05	2.41E-05	5.02E-05	3.00E-03	1.50E-02	4.00E-03
BATCH-186	11/17/20	57	6.0	0.24	2.02E-07	1.72E+02	4.27E+01	4.00E-03	3.22E-01	2.50E-02	4.00E-03	1.77E-06	1.77E-04	2.04E-05	2.41E-05	5.01E-05	3.00E-03	1.50E-02	4.00E-03
BATCH-187	11/19/20	57	6.0	0.24	2.01E-07	1.72E+02	4.26E+01	4.00E-03	3.21E-01	2.50E-02	4.00E-03	1.77E-06	1.77E-04	2.03E-05	2.40E-05	5.00E-05	3.00E-03	1.50E-02	4.00E-03
BATCH-188	11/23/20	163	16.9	0.24	1.76E-06	4.87E+02	8.45E+02	7.70E-02	5.98E+00	4.46E-01	1.50E-02	3.54E-05	2.00E-03	2.79E-04	3.92E-04	6.89E-04	3.90E-02	1.94E-01	7.70E-02
BATCH-189	11/25/20	164	17.1	0.24	1.90E-06	4.92E+02	9.19E+02	8.30E-02	6.48E+00	4.81E-01	7.00E-03	3.85E-05	2.00E-03	2.93E-04	4.25E-04	7.33E-04	4.10E-02	2.00E-01	8.20E-02
BATCH-190	12/10/20	21	2.1	0.24	8.41E-08	6.15E+01	1.29E+01	1.00E-03	9.60E-02	8.00E-03	3.00E-03	5.34E-07	3.97E-05	5.16E-06	8.89E-06	1.39E-05	7.84E-04	4.00E-03	1.00E-03
BATCH-191	12/12/20	19	2.0	0.24	4.97E-08	5.75E+01	1.05E+01	1.00E-03	7.90E-02	6.00E-03	9.30E-04	4.37E-07	4.38E-05	5.03E-06	5.94E-06	1.24E-05	7.35E-04	4.00E-03	1.00E-03
BATCH-192	12/12/20	19	2.0	0.24	4.97E-08	5.74E+01	1.05E+01	1.00E-03	7.90E-02	6.00E-03	9.28E-04	4.36E-07	4.37E-05	5.02E-06	5.93E-06	1.23E-05	7.33E-04	4.00E-03	1.00E-03
BATCH-193	12/14/20	19	2.0	0.24	4.95E-08	5.73E+01	1.05E+01	1.00E-03	7.90E-02	6.00E-03	9.25E-04	4.35E-07	4.36E-05	5.00E-06	5.91E-06	1.23E-05	7.31E-04	4.00E-03	1.00E-03
BATCH-194	12/15/20	147	15.3	0.24	1.70E-06	4.40E+02	8.23E+02	7.50E-02	5.80E+00	4.31E-01	7.00E-03	3.45E-05	2.00E-03	2.63E-04	3.81E-04	6.57E-04	3.70E-02	1.79E-01	7.40E-02
BATCH-195	12/17/20	150	15.6	0.24	1.74E-06	4.50E+02	8.41E+02	7.60E-02	5.92E+00	4.40E-01	7.00E-03	3.52E-05	2.00E-03	2.68E-04	3.89E-04	6.71E-04	3.70E-02	1.83E-01	7.50E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-147	4/29/20	66	6.9	0.24	1.97E-04	1.61E-04	9.00E-03	7.00E-03	5.00E-03	3.76E-01	7.40E-02	3.86E-01	1.60E-01	4.58E-21	3.11E-06	1.06E-05	1.23E-04	8.69E-04	3.01E-06
BATCH-148	5/4/20	71	7.5	0.24	2.98E-04	2.51E-04	8.00E-03	1.00E-02	8.00E-03	3.87E-01	6.70E-02	5.31E-01	2.45E-01	6.21E-21	4.75E-06	1.61E-05	1.77E-04	1.00E-03	4.67E-06
BATCH-149	5/6/20	71	7.4	0.24	2.98E-04	2.51E-04	8.00E-03	1.00E-02	8.00E-03	3.86E-01	6.70E-02	5.31E-01	2.45E-01	6.20E-21	4.75E-06	1.61E-05	1.76E-04	1.00E-03	4.66E-06
BATCH-150	5/11/20	71	7.4	0.24	2.98E-04	2.50E-04	8.00E-03	1.00E-02	8.00E-03	3.86E-01	6.70E-02	5.30E-01	2.44E-01	6.20E-21	4.74E-06	1.61E-05	1.76E-04	1.00E-03	4.66E-06
BATCH-151	5/14/20	71	7.4	0.24	2.98E-04	2.50E-04	8.00E-03	1.00E-02	8.00E-03	3.86E-01	6.70E-02	5.30E-01	2.44E-01	6.19E-21	4.74E-06	1.61E-05	1.76E-04	1.00E-03	4.65E-06
BATCH-152	5/19/20	21	2.2	0.24	2.45E-05	1.66E-05	2.00E-03	8.14E-04	6.17E-04	7.20E-02	1.50E-02	6.10E-02	1.80E-02	7.66E-22	3.67E-07	1.45E-06	2.08E-05	1.45E-04	3.96E-07
BATCH-153	5/21/20	24	2.5	0.24	5.86E-05	4.80E-05	3.00E-03	2.00E-03	1.00E-03	1.12E-01	2.20E-02	1.15E-01	4.80E-02	1.36E-21	9.27E-07	3.17E-06	3.65E-05	2.59E-04	8.96E-07
BATCH-154	5/22/20	27	2.8	0.24	9.82E-05	8.25E-05	3.00E-03	3.00E-03	2.00E-03	1.27E-01	2.20E-02	1.75E-01	8.10E-02	2.04E-21	1.56E-06	5.31E-06	5.81E-05	4.16E-04	1.54E-06
BATCH-155	5/24/20	27	2.8	0.24	9.81E-05	8.24E-05	3.00E-03	3.00E-03	2.00E-03	1.27E-01	2.20E-02	1.75E-01	8.00E-02	2.04E-21	1.56E-06	5.31E-06	5.81E-05	4.15E-04	1.53E-06
BATCH-156	5/25/20	27	2.8	0.24	9.80E-05	8.23E-05	3.00E-03	3.00E-03	2.00E-03	1.27E-01	2.20E-02	1.74E-01	8.00E-02	2.04E-21	1.56E-06	5.30E-06	5.80E-05	4.15E-04	1.53E-06
BATCH-157	5/27/20	185	19.2	0.24	9.78E-05	8.22E-05	3.00E-03	3.00E-03	2.00E-03	1.27E-01	2.20E-02	1.74E-01	8.00E-02	2.03E-21	1.56E-06	5.29E-06	5.79E-05	4.14E-04	1.53E-06
BATCH-158	5/28/20	184	19.2	0.24	2.00E-03	2.00E-03	5.80E-02	8.50E-02	6.10E-02	2.98E+00	5.25E-01	3.88E+00	2.14E+00	4.33E-20	3.98E-05	1.23E-04	1.00E-03	8.00E-03	3.56E-05
BATCH-159	5/30/20	184	19.2	0.24	2.00E-03	2.00E-03	5.80E-02	8.40E-02	6.10E-02	2.98E+00	5.24E-01	3.88E+00	2.14E+00	4.33E-20	3.98E-05	1.22E-04	1.00E-03	8.00E-03	3.55E-05
BATCH-160	6/17/20	169	17.6	0.24	8.26E-04	6.65E-04	2.80E-02	2.90E-02	2.20E-02	4.86E+00	1.12E+00	2.48E+00	6.88E-01	2.27E-20	1.30E-05	4.29E-05	4.28E-04	3.00E-03	5.82E-06
BATCH-161	6/19/20	177	18.4	0.24	5.57E-04	3.94E-04	2.30E-02	1.90E-02	1.50E-02	5.55E+00	1.32E+00	2.36E+00	4.40E-01	2.01E-20	8.44E-06	2.97E-05	3.13E-04	2.00E-03	1.99E-07
BATCH-162	7/5/20	177	18.4	0.24	5.57E-04	3.94E-04	2.30E-02	1.90E-02	1.50E-02	5.55E+00	1.32E+00	2.36E+00	4.40E-01	2.01E-20	8.44E-06	2.97E-05	3.13E-04	2.00E-03	1.99E-07
BATCH-163	7/8/20	177	18.4	0.24	5.56E-04	3.94E-04	2.30E-02	1.90E-02	1.50E-02	5.54E+00	1.32E+00	2.36E+00	4.39E-01	2.00E-20	8.43E-06	2.96E-05	3.13E-04	2.00E-03	1.99E-07
BATCH-164	7/23/20	121	12.7	0.24	2.72E-04	1.60E-02	1.30E-02	1.10E-02	9.03E-01	1.62E+00	3.03E-01	1.38E-20	5.82E-06	2.04E-05	2.15E-04	2.00E-03	1.58E-07		
BATCH-165	7/26/20	121	12.7	0.24	3.83E-04	2.71E-04	1.60E-02	1.30E-02	1.10E-02	3.80E+00	9.02E-01	1.62E+00	3.03E-01	1.38E-20	5.81E-06	2.04E-05	2.15E-04	2.00E-03	1.58E-07
BATCH-166	8/5/20	122	12.7	0.24	9.00E-04	6.29E-04	2.60E-02	2.60E-02	2.40E-02	2.95E+00	6.44E-01	1.85E+00	5.93E-01	1.45E-20	1.15E-05	4.16E-05	2.59E-04	2.00E-03	2.25E-06
BATCH-167	8/8/20	138	14.4	0.24	2.00E-03	1.00E-03	4.50E-02	4.70E-02	4.50E-02	2.08E+00	3.48E-01	2.41E+00	1.45E-20	1.74E-05	7.76E-05	3.56E-04	3.00E-03	5.58E-06	
BATCH-168	8/18/20	138	14.4	0.24	2.00E-03	1.00E-03	4.50E-02	4.70E-02	4.50E-02	2.07E+00	3.48E-01	2.41E+00	1.09E+00	1.74E-20	2.12E-05	7.76E-05	3.55E-04	3.00E-03	5.58E-06
BATCH-169	8/23/20	138	14.4	0.24	2.00E-03	1.00E-03	4.50E-02	4.70E-02	4.50E-02	2.07E+00	3.48E-01	2.41E+00	1.09E+00	1.74E-20	2.12E-05	7.76E-05	3.55E-04	3.00E-03	5.58E-06
BATCH-170	9/2/20	110	11.5	0.24	5.74E-04	5.18E-04	1.40E-02	2.00E-02	1.50E-02	1.08E+00	2.16E-01	1.03E+00	5.02E-01	1.10E-20	9.37E-06	2.91E-05	2.73E-04	2.00E-03	7.81E-06
BATCH-171	9/7/20	110	11.4	0.24	5.72E-04	5.16E-04	1.40E-02	2.00E-02	1.50E-02	1.07E+00	2.15E-01	1.03E+00	5.01E-01	1.10E-20	9.34E-06	2.90E-05	2.72E-04	2.00E-03	7.78E-06
BATCH-172	9/13/20	100	10.4	0.24	1.00E-03	8.88E-04	3.20E-02	3.40E-02	3.30E-02	1.50E+00	2.52E-01	1.74E+00	7.90E-01	1.26E-20	1.53E-05	5.62E-05	2.57E-04	2.00E-03	4.04E-06
BATCH-173	9/18/20	119	12.4	0.24	2.00E-03	1.00E-03	3.80E-02	4.00E-02	3.90E-02	1.79E+00	3.00E-01	2.08E+00	9.41E-01	1.50E-20	1.83E-05	6.69E-05	3.06E-04	2.00E-03	4.81E-06
BATCH-174	9/24/20	119	12.4	0.24	2.00E-03	1.00E-03	3.80E-02	4.00E-02	3.90E-02	1.79E+00	2.99E-01	2.07E+00	9.40E-01	1.50E-20	1.83E-05	6.68E-05	3.06E-04	2.00E-03	4.80E-06
BATCH-175	10/1/20	119	12.4	0.24	2.00E-03	1.00E-03	3.80E-02	4.00E-02	3.90E-02	1.78E+00	2.99E-01	2.07E+00	9.38E-01	1.50E-20	1.82E-05	6.67E-05	3.06E-04	2.00E-03	4.80E-06
BATCH-176	10/7/20	66	6.9	0.24	3.21E-04	2.90E-04	8.00E-03	1.10E-02	8.00E-03	6.03E-01	1.21E-01	5.77E-01	2.81E-01	6.17E-21	5.24E-06	1.63E-05	1.53E-04	1.00E-03	4.37E-06
BATCH-177	10/13/20	66	6.9	0.24	3.20E-04	2.89E-04	8.00E-03	1.10E-02	8.00E-03	6.01E-01	1.20E-01	5.75E-01	2.80E-01	6.15E-21	5.23E-06	1.62E-05	1.53E-04	1.00E-03	4.36E-06
BATCH-178	10/14/20	136	14.1	0.24	4.99E-04	4.05E-04	1.40E-02	1.60E-02	1.30E-02	1.51E+00	3.29E-01	1.04E+00	3.94E-01	9.68E-21	7.45E-06	2.46E-05	2.06E-04	2.00E-03	4.23E-06
BATCH-179	10/20/20	97	10.2	0.24	3.29E-04	2.30E-04	9.00E-03	9.00E-03	9.00E-03	9.58E-01	2.06E-01	6.36E-01	2.15E-01	4.94E-21	4.15E-06	1.51E-05	8.97E-05	6.57E-04	8.57E-07
BATCH-180	10/28/20	97	10.1	0.24	3.28E-04	2.29E-04	9.00E-03	9.00E-03	9.00E-03	9.57E-01	2.06E-01	6.35E-01	2.14E-01	4.93E-21	4.14E-06	1.50E-05	8.96E-05	6.56E-04	8.56E-07
BATCH-181	10/31/20	97	10.1	0.24	3.28E-04	2.29E-04	9.00E-03	9.00E-03	9.00E-03	9.55E-01	2.05E-01	6.34E-01	2.14E-01	4.93E-21	4.14E-06	1.50E-05	8.94E-05	6.55E-04	8.54E-07
BATCH-182	11/7/20	24	2.5	0.24	9.35E-05	8.43E-05	2.00E-03	3.00E-03	2.00E-03	1.75E-01	3.50E-02	1.68E-01	8.20E-02	1.80E-21	1.53E-06	4.74E-06	4.45E-05	3.21E-04	1.27E-06
BATCH-183	11/10/20	24	2.5	0.24	9.31E-05	8.40E-05	2.00E-03	3.00E-03	2.00E-03	1.75E-01	3.50E-02	1.67E-01	8.20E-02	1.79E-21	1.52E-06	4.72E-06	4.43E-05	3.20E-04	1.27E-06
BATCH-184	11/10/20	60	6.3	0.24	2.02E-04	1.64E-04	6.00E-03	7.00E-03	5.00E-03	6.13E-01	1.33E-01	4.21E-01	1.59E-01	3.92E-21	3.01E-06	9.95E-06	8.36E-05	6.08E-04	1.71E-06
BATCH-185	11/13/20	57	6.0	0.24	1.76E-04	1.23E-04	5.00E-03	5.00E-03	5.00E-03	5.13E-01	1.10E-01	3.40E-01	1.15E-01	2.64E-21	2.22E-06	8.05E-06	4.80E-05	3.51E-04	4.59E-07
BATCH-186	11/17/20	57	6.0	0.24	1.76E-04	1.23E-04	5.00E-03	5.00E-03	5.00E-03	5.12E-01	1.10E-01	3.39E-01	1.14E-01	2.64E-21	2.22E-06	8.04E-06	4.79E-05	3.51E-04	4.58E-07
BATCH-187	11/19/20	57	6.0	0.24	1.75E-04	1.22E-04	5.00E-03	5.00E-03	5.00E-03	5.12E-01	1.10E-01	3.39E-01	1.14E-01	2.64E-21	2.22E-06	8.04E-06	4.79E-05	3.51E-04	4.57E-07
BATCH-188	11/23/20	163	16.9	0.24	3.00E-03	2.00E-03	8.30E-02	8.80E-02	8.20E-02	4.05E+00	6.67E-01	4.65E+00	2.06E+00	3.35E-20	3.91E-05	1.47E-04	5.56E-04	4.00E-03	1.64E-06
BATCH-189	11/25/20	164	17.1	0.24	3.00E-03	2.00E-03	9.00E-02	9.50E-02	8.80E-02	4.40E+00	7.24E-01	5.05E+00	2.23E+00	3.63E-20	4.23E-05	1.59E-04	5.88E-04	4.00E-03	6.89E-07
BATCH-190	12/10/20	21	2.1	0.24	5.30E-05	4.30E-05	1.00E-03	2.00E-03	1.00E-03	1.61E-01	3.50E-02	1.10E-01	4.20E-02	1.03E-21	7.90E-07	2.61E-06	2.19E-05	1.60E-04	4.49E-07
BATCH-191	12/12/20	19	2.0	0.24	4.34E-05	3.03E-05	1.00E-03	1.00E-03	1.00E-03	1.26E-01	2.70E-02	8.40E-02	2.80E-02	6.52E-22	5.48E-07	1.99E-06	1.18E-05	8.67E-05	1.13E-07
BATCH-192	12/12/20	19	2.0	0.24	4.33E-05	3.02E-05	1.00E-03	1.00E-03	1.00E-03	1.26E-01	2.70E-02	8.40E-02	2.80E-02	6.51E-22	5.47E-07	1.98E-06	1.18E-05	8.65E-05	1.13E-07
BATCH-193	12/14/20	147	15.3	0.24	4.32E-05	3.01E-05	1.00E-03	1.00E-03	1.00E-03	1.26E-01	2.70E-02	8.30E-02	2.80E-02	6.49E-22	5.45E-07	1.98E-06	1.18E-05	8.63E-05	1.13E-07
BATCH-194	12/15/20	147	15.3	0.24	3.00E-03	2.00E-03	8.10E-02	8.50E-02	7.90E-02	3.94E+00	6.48E-01	4.52E+00	2.00E+00	3.25E-20	3.78E-05	1.42E-04	5.26E-04	4.00E-03	6.18E-07
BATCH-195	12/17/20	150	15.6	0.24	3.00E-03	2.00E-03	8.20E-02	8.70E-02	8.00E-02	4.03E+00	6.62E-01	4.62E+00	2.04E+00	3.32E-20	3.87E-05	1.45E-04	5.38E-04	4.00E-03	6.30E-07

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-147	4/29/20	66	6.9	0.24	1.52E+02	0.00E+00	4.65E-06	3.00E-03	6.77E-06	1.30E-10	3.00E-03	2.11E-01	6.19E-05	6.00E-03	7.22E+00	0.00E+00	9.32E+00	0.00E+00	8.90E-04
BATCH-148	5/4/20	71	7.5	0.24	1.73E+02	0.00E+00	6.78E-06	1.00E-03	1.05E-05	7.90E-11	8.10E-04	2.44E-01	8.33E-05	2.00E-03	8.48E+00	0.00E+00	1.24E+01	0.00E+00	1.40E-03
BATCH-149	5/6/20	71	7.4	0.24	1.73E+02	0.00E+00	6.77E-06	1.00E-03	1.05E-05	4.35E-10	8.09E-04	2.44E-01	8.33E-05	2.00E-03	8.48E+00	0.00E+00	1.24E+01	0.00E+00	1.40E-03
BATCH-150	5/11/20	71	7.4	0.24	1.72E+02	0.00E+00	6.76E-06	1.00E-03	1.05E-05	9.86E-11	8.09E-04	2.43E-01	8.32E-05	2.00E-03	8.47E+00	0.00E+00	1.24E+01	0.00E+00	1.40E-03
BATCH-151	5/14/20	71	7.4	0.24	1.72E+02	0.00E+00	6.75E-06	1.00E-03	1.05E-05	1.11E-10	8.08E-04	2.43E-01	8.31E-05	2.00E-03	8.46E+00	0.00E+00	1.23E+01	0.00E+00	1.38E-03
BATCH-152	5/19/20	21	2.2	0.24	4.15E+01	0.00E+00	1.24E-06	8.74E-04	1.02E-06	1.59E-11	2.00E-03	4.40E-02	1.09E-05	2.00E-03	1.45E+00	0.00E+00	1.52E+00	0.00E+00	1.35E-04
BATCH-153	5/21/20	24	2.5	0.24	4.52E+01	0.00E+00	1.38E-06	8.66E-04	2.02E-06	3.87E-11	8.90E-04	6.30E-02	1.84E-05	2.00E-03	2.15E+00	0.00E+00	2.78E+00	0.00E+00	2.70E-04
BATCH-154	5/22/20	27	2.8	0.24	5.68E+01	0.00E+00	2.23E-06	3.71E-04	3.45E-06	2.60E-11	2.66E-04	8.00E-02	2.74E-05	7.03E-04	2.79E+00	0.00E+00	4.07E+00	0.00E+00	4.58E-04
BATCH-155	5/24/20	27	2.8	0.24	5.68E+01	0.00E+00	2.23E-06	3.70E-04	3.45E-06	1.43E-10	2.66E-04	8.00E-02	2.74E-05	7.03E-04	2.79E+00	0.00E+00	4.06E+00	0.00E+00	4.58E-04
BATCH-156	5/25/20	27	2.8	0.24	5.67E+01	0.00E+00	2.22E-06	3.70E-04	3.44E-06	3.24E-11	2.66E-04	8.00E-02	2.73E-05	7.00E-04	2.78E+00	0.00E+00	4.06E+00	0.00E+00	4.58E-04
BATCH-157	5/27/20	27	2.8	0.24	5.66E+01	0.00E+00	2.22E-06	3.69E-04	3.44E-06	3.65E-11	2.66E-04	8.00E-02	2.73E-05	7.00E-04	2.78E+00	0.00E+00	4.06E+00	0.00E+00	4.58E-04
BATCH-158	5/28/20	185	19.2	0.24	6.00E-03	2.13E+02	1.20E-05	2.00E-03	7.16E-05	2.13E-15	3.00E-03	1.02E+00	5.47E-04	1.20E-02	5.24E+01	0.00E+00	2.04E-04	1.83E+01	1.02E-02
BATCH-159	5/30/20	184	19.2	0.24	8.00E-03	2.13E+02	1.19E-05	2.00E-03	7.15E-05	6.47E-15	3.00E-03	1.01E+00	5.46E-04	1.20E-02	5.23E+01	0.00E+00	4.64E-04	1.83E+01	1.02E-02
BATCH-160	6/17/20	169	17.6	0.24	8.00E-03	1.76E+02	1.95E-06	4.08E-04	1.16E-05	3.51E-15	1.10E-02	9.15E-01	9.18E-05	1.14E-01	4.17E+01	0.00E+00	5.49E-04	7.46E+00	1.73E-03
BATCH-161	6/19/20	177	18.4	0.24	1.30E-02	1.80E+02	6.57E-08	2.39E-05	2.66E-07	3.27E-14	1.30E-02	9.54E-01	6.12E-06	1.42E-01	4.22E+01	0.00E+00	9.27E-04	5.76E+00	1.35E-04
BATCH-162	7/5/20	177	18.4	0.24	1.30E-02	1.80E+02	6.56E-08	2.39E-05	2.66E-07	7.38E-15	1.30E-02	9.54E-01	6.11E-06	1.42E-01	4.22E+01	0.00E+00	9.25E-04	5.75E+00	1.35E-04
BATCH-163	7/8/20	177	18.4	0.24	1.30E-02	1.80E+02	6.56E-08	2.39E-05	2.66E-07	8.32E-15	1.30E-02	9.53E-01	6.11E-06	1.42E-01	4.22E+01	0.00E+00	9.23E-04	5.75E+00	1.35E-04
BATCH-164	7/23/20	121	12.7	0.24	3.37E-06	1.24E+02	5.19E-08	1.79E-05	2.25E-07	1.29E-18	9.00E-03	6.55E-01	4.52E-06	9.70E-02	2.90E+01	0.00E+00	1.24E-07	3.96E+00	8.09E-05
BATCH-165	7/26/20	121	12.7	0.24	4.57E-06	1.23E+02	5.19E-08	1.78E-05	2.25E-07	3.92E-18	9.00E-03	6.54E-01	4.52E-06	9.70E-02	2.90E+01	0.00E+00	2.81E-07	3.96E+00	8.09E-05
BATCH-166	8/5/20	122	12.7	0.24	3.61E-06	1.07E+02	7.50E-07	1.76E-04	4.42E-06	1.66E-18	6.00E-03	6.59E-01	3.34E-05	5.90E-02	2.18E+01	0.00E+00	2.59E-07	7.69E+00	7.82E-04
BATCH-167	8/8/20	138	14.4	0.24	7.00E-06	9.57E+01	1.87E-06	4.31E-04	1.11E-05	1.77E-17	3.00E-03	7.48E-01	7.98E-05	1.20E-02	1.41E+01	0.00E+00	5.02E-07	1.41E+01	1.89E-03
BATCH-168	8/18/20	138	14.4	0.24	6.99E-06	9.57E+01	1.87E-06	4.30E-04	1.11E-05	4.00E-18	3.00E-03	7.48E-01	7.98E-05	1.20E-02	1.41E+01	0.00E+00	5.01E-07	1.41E+01	1.89E-03
BATCH-169	8/23/20	138	14.4	0.24	6.97E-06	9.57E+01	1.87E-06	4.30E-04	1.11E-05	4.50E-18	3.00E-03	7.48E-01	7.98E-05	1.20E-02	1.41E+01	0.00E+00	5.00E-07	1.41E+01	1.89E-03
BATCH-170	9/2/20	110	11.5	0.24	2.76E+02	0.00E+00	2.62E-06	5.38E-04	1.57E-05	4.66E-16	1.10E-02	5.43E-01	1.20E-04	1.30E-02	1.47E+01	0.00E+00	2.41E+01	0.00E+00	2.24E-03
BATCH-171	9/7/20	110	11.4	0.24	2.76E+02	0.00E+00	2.61E-06	5.36E-04	1.58E-05	1.41E-15	1.10E-02	5.42E-01	1.20E-04	1.30E-02	1.47E+01	0.00E+00	2.41E+01	0.00E+00	2.24E-03
BATCH-172	9/13/20	100	10.4	0.24	2.70E-09	6.92E+01	1.35E-06	3.12E-04	8.04E-06	1.24E-21	2.00E-03	5.41E-01	5.78E-05	9.00E-03	1.02E+01	0.00E+00	1.93E-10	1.02E+01	1.35E-03
BATCH-173	9/18/20	119	12.4	0.24	4.39E-09	8.24E+01	1.61E-06	3.71E-04	9.58E-06	1.11E-20	2.00E-03	6.45E-01	6.88E-05	1.00E-02	1.21E+01	0.00E+00	3.14E-10	1.21E+01	1.62E-03
BATCH-174	9/24/20	119	12.4	0.24	4.38E-09	8.24E+01	1.61E-06	3.71E-04	9.57E-06	2.50E-21	2.00E-03	6.44E-01	6.87E-05	1.00E-02	1.21E+01	0.00E+00	3.14E-10	1.21E+01	1.62E-03
BATCH-175	10/1/20	119	12.4	0.24	4.37E-09	8.22E+01	1.61E-06	3.70E-04	9.55E-06	2.82E-21	2.00E-03	6.43E-01	6.86E-05	1.00E-02	1.21E+01	0.00E+00	3.13E-10	1.21E+01	1.62E-03
BATCH-176	10/7/20	66	6.9	0.24	1.55E+02	0.00E+00	1.47E-06	3.01E-04	8.78E-06	2.61E-16	6.00E-03	3.04E-01	6.73E-05	8.00E-03	8.23E+00	0.00E+00	1.35E+01	0.00E+00	1.27E-03
BATCH-177	10/13/20	66	6.9	0.24	1.54E+02	0.00E+00	1.46E-06	3.00E-04	8.76E-06	7.91E-16	6.00E-03	3.04E-01	6.71E-05	7.00E-03	8.21E+00	0.00E+00	1.35E+01	0.00E+00	1.27E-03
BATCH-178	10/14/20	136	14.1	0.24	3.06E+02	0.00E+00	1.42E-06	2.96E-04	8.46E-06	2.33E-15	2.10E-02	7.01E-01	6.50E-05	2.90E-02	1.45E+01	0.00E+00	3.29E+01	0.00E+00	1.24E-03
BATCH-179	10/20/20	97	10.2	0.24	2.24E+02	0.00E+00	2.87E-07	6.71E-05	1.69E-06	3.82E-15	1.60E-02	5.63E-01	1.26E-05	1.80E-02	7.04E+00	0.00E+00	3.49E+01	0.00E+00	2.97E-04
BATCH-180	10/28/20	97	10.1	0.24	2.24E+02	0.00E+00	2.86E-07	6.70E-05	1.68E-06	8.63E-16	1.60E-02	5.62E-01	1.26E-05	1.80E-02	7.04E+00	0.00E+00	3.48E+01	0.00E+00	2.97E-04
BATCH-181	10/31/20	97	10.1	0.24	2.23E+02	0.00E+00	2.86E-07	6.69E-05	1.68E-06	9.71E-16	1.60E-02	5.62E-01	1.26E-05	1.80E-02	7.02E+00	0.00E+00	3.48E+01	0.00E+00	2.97E-04
BATCH-182	11/7/20	24	2.5	0.24	4.50E+01	0.00E+00	4.27E-07	8.77E-05	2.56E-06	7.60E-17	2.00E-03	8.90E-02	1.96E-05	2.00E-03	2.40E+00	0.00E+00	3.93E+00	0.00E+00	3.78E-04
BATCH-183	11/10/20	24	2.5	0.24	4.49E+01	0.00E+00	4.25E-07	8.73E-05	2.55E-06	2.30E-16	2.00E-03	8.80E-02	1.95E-05	2.00E-03	2.39E+00	0.00E+00	3.92E+00	0.00E+00	3.78E-04
BATCH-184	11/10/20	60	6.3	0.24	1.24E+02	0.00E+00	5.74E-07	1.20E-04	3.43E-06	9.42E-16	9.00E-03	2.84E-01	2.63E-05	1.20E-02	5.88E+00	0.00E+00	1.33E+01	0.00E+00	5.12E-04
BATCH-185	11/13/20	57	6.0	0.24	1.20E+02	0.00E+00	1.53E-07	3.59E-05	9.05E-07	2.04E-15	8.00E-03	3.01E-01	6.76E-06	1.00E-02	3.77E+00	0.00E+00	1.86E+01	0.00E+00	1.62E-04
BATCH-186	11/17/20	57	6.0	0.24	1.20E+02	0.00E+00	1.53E-07	3.59E-05	9.04E-07	4.62E-16	8.00E-03	3.01E-01	6.76E-06	1.00E-02	3.77E+00	0.00E+00	1.86E+01	0.00E+00	1.62E-04
BATCH-187	11/19/20	57	6.0	0.24	1.20E+02	0.00E+00	1.53E-07	3.58E-05	9.02E-07	5.20E-16	8.00E-03	3.01E-01	6.74E-06	1.00E-02	3.76E+00	0.00E+00	1.86E+01	0.00E+00	1.62E-04
BATCH-188	11/23/20	163	16.9	0.24	8.00E-03	1.59E+02	1.79E-06	3.20E-04	3.44E-06	1.31E-20	3.00E-02	8.99E-01	2.89E-05	2.10E-02	2.32E+01	0.00E+00	6.77E-04	1.46E+01	7.01E-04
BATCH-189	11/25/20	164	17.1	0.24	9.00E-03	1.69E+02	1.72E-06	2.87E-04	1.59E-06	4.78E-20	3.60E-02	9.11E-01	1.65E-05	2.30E-02	2.47E+01	0.00E+00	8.13E-04	1.43E+01	4.05E-04
BATCH-190	12/10/20	21	2.1	0.24	3.25E+01	0.00E+00	1.51E-07	3.15E-05	8.99E-07	2.47E-16	2.00E-03	7.40E-02	6.90E-06	3.00E-03	1.54E+00	0.00E+00	3.50E+00	0.00E+00	1.35E-04
BATCH-191	12/12/20	19	2.0	0.24	2.95E+01	0.00E+00	3.78E-08	8.85E-06	2.23E-07	5.04E-16	2.00E-03	7.40E-02	1.67E-06	2.00E-03	9.29E-01	0.00E+00	4.60E+00	0.00E+00	2.70E-05
BATCH-192	12/12/20	19	2.0	0.24	2.95E+01	0.00E+00	3.77E-08	8.84E-06	2.23E-07	1.14E-16	2.00E-03	7.40E-02	1.66E-06	2.00E-03	9.27E-01	0.00E+00	4.59E+00	0.00E+00	2.70E-05
BATCH-193	12/14/20	19	2.0	0.24	2.94E+01	0.00E+00	3.76E-08	8.81E-06	2.22E-07	1.28E-16	2.00E-03	7.40E-02	1.66E-06	2.00E-03	9.25E-01	0.00E+00	4.58E+00	0.00E+00	2.70E-05
BATCH-194	12/15/20	147	15.3	0.24	4.01E-06	1.52E+02	1.54E-06	2.57E-04	1.43E-06	6.77E-24	3.20E-02	8.15E-01	1.48E-05	2.00E-02	2.21E+01	0.00E+00	3.50E-07	1.28E+01	3.78E-04
BATCH-195	12/17/20	150	15.6	0.24	4.71E-06	1.55E+02	1.58E-06	2.62E-04	1.46E-06	2.42E-23	3.30E-02	8.33E-01	1.51E-05	2.10E-02	2.25E+01	0.00E+00	4.11E-07	1.31E+01	3.78E-04

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are *Ci for radionuclides and kg-mol for chemicals*)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-147	4/29/20	66	6.9	0.24	2.24E-06	1.72E-01	1.72E-01	0.00E+00	0.00E+00	1.02E-04	3.48E+00	1.30E-04	6.01E-05	1.33E-04	3.00E-02	1.68E-05	1.13E+03	0.00E+00	2.86E-01
BATCH-148	5/4/20	71	7.5	0.24	3.64E-06	1.84E+01	1.67E-01	0.00E+00	0.00E+00	5.59E-05	4.32E+00	2.61E-06	9.32E-05	1.92E-04	4.50E-02	2.78E-05	1.22E+03	0.00E+00	4.33E-01
BATCH-149	5/6/20	71	7.4	0.24	3.63E-06	1.84E+01	1.67E-01	0.00E+00	0.00E+00	5.59E-05	4.32E+00	2.61E-06	9.31E-05	1.92E-04	4.50E-02	2.78E-05	1.22E+03	0.00E+00	4.33E-01
BATCH-150	5/11/20	71	7.4	0.24	3.63E-06	1.83E+01	1.67E-01	0.00E+00	0.00E+00	5.58E-05	4.31E+00	2.61E-06	9.30E-05	1.92E-04	4.50E-02	2.77E-05	1.22E+03	0.00E+00	4.32E-01
BATCH-151	5/14/20	71	7.4	0.24	3.63E-06	1.83E+01	1.67E-01	0.00E+00	0.00E+00	5.58E-05	4.31E+00	2.61E-06	9.29E-05	1.92E-04	4.50E-02	2.77E-05	1.22E+03	0.00E+00	4.32E-01
BATCH-152	5/19/20	21	2.2	0.24	1.14E-07	4.12E+00	4.80E-02	0.00E+00	0.00E+00	2.52E-05	6.90E-01	4.05E-05	8.91E-06	3.63E-05	4.00E-03	6.08E-08	3.54E+02	0.00E+00	4.50E-02
BATCH-153	5/21/20	24	2.5	0.24	6.66E-07	5.11E+00	5.10E-02	0.00E+00	0.00E+00	3.04E-05	1.04E+00	3.86E-05	1.79E-05	3.95E-05	9.00E-03	5.01E-06	4.10E+02	0.00E+00	8.50E-02
BATCH-154	5/22/20	27	2.8	0.24	1.20E-06	6.05E+00	5.50E-02	0.00E+00	0.00E+00	1.84E-05	1.42E+00	8.59E-07	3.07E-05	6.33E-05	1.50E-02	9.14E-06	4.67E+02	0.00E+00	1.43E-01
BATCH-155	5/24/20	27	2.8	0.24	1.20E-06	6.04E+00	5.50E-02	0.00E+00	0.00E+00	1.84E-05	1.42E+00	8.59E-07	3.06E-05	6.32E-05	1.50E-02	9.13E-06	4.67E+02	0.00E+00	1.42E-01
BATCH-156	5/25/20	27	2.8	0.24	1.19E-06	6.03E+00	5.50E-02	0.00E+00	0.00E+00	1.84E-05	1.42E+00	8.57E-07	3.06E-05	6.31E-05	1.50E-02	9.12E-06	4.66E+02	0.00E+00	1.42E-01
BATCH-157	5/27/20	27	2.8	0.24	1.19E-06	6.02E+00	5.50E-02	0.00E+00	0.00E+00	1.83E-05	1.42E+00	8.56E-07	3.05E-05	6.30E-05	1.50E-02	9.11E-06	4.66E+02	0.00E+00	1.42E-01
BATCH-158	5/28/20	185	19.2	0.24	3.89E-05	7.90E+01	8.94E-01	0.00E+00	0.00E+00	4.00E-04	2.57E+01	2.32E-05	6.42E-04	2.72E-04	3.61E-01	3.47E-04	3.15E+03	0.00E+00	2.90E+00
BATCH-159	5/30/20	184	19.2	0.24	3.88E-05	7.89E+01	8.93E-01	0.00E+00	0.00E+00	4.00E-04	2.57E+01	2.32E-05	6.41E-04	2.72E-04	3.60E-01	3.47E-04	3.15E+03	0.00E+00	2.89E+00
BATCH-160	6/17/20	169	17.6	0.24	6.32E-06	7.68E+01	1.08E+00	0.00E+00	0.00E+00	1.60E-03	1.44E+01	4.57E-06	1.06E-04	5.38E-05	1.27E-01	5.61E-05	2.89E+03	0.00E+00	8.26E-01
BATCH-161	6/19/20	177	18.4	0.24	1.82E-07	8.13E+01	1.19E+00	0.00E+00	0.00E+00	1.80E-03	1.30E+01	1.10E-06	5.40E-06	1.34E-05	8.80E-02	1.09E-06	3.02E+03	0.00E+00	4.63E-01
BATCH-162	7/5/20	177	18.4	0.24	1.82E-07	8.12E+01	1.19E+00	0.00E+00	0.00E+00	1.80E-03	1.30E+01	1.10E-06	5.40E-06	1.34E-05	8.80E-02	1.09E-06	3.02E+03	0.00E+00	4.62E-01
BATCH-163	7/8/20	177	18.4	0.24	1.82E-07	8.12E+01	1.19E+00	0.00E+00	0.00E+00	1.80E-03	1.30E+01	1.10E-06	5.40E-06	1.34E-05	8.80E-02	1.09E-06	3.02E+03	0.00E+00	4.62E-01
BATCH-164	7/23/20	121	12.7	0.24	1.49E-07	5.58E+01	8.16E-01	0.00E+00	0.00E+00	1.20E-03	8.95E+00	7.71E-07	4.09E-06	9.34E-06	6.10E-02	9.56E-07	2.07E+03	0.00E+00	3.19E-01
BATCH-165	7/26/20	121	12.7	0.24	1.48E-07	5.57E+01	8.15E-01	0.00E+00	0.00E+00	1.20E-03	8.94E+00	7.70E-07	4.09E-06	9.33E-06	6.10E-02	9.55E-07	2.07E+03	0.00E+00	3.19E-01
BATCH-166	8/5/20	122	12.7	0.24	2.38E-06	6.01E+01	6.55E-01	0.00E+00	0.00E+00	8.00E-04	8.14E+00	2.30E-06	4.44E-05	2.39E-05	1.15E-01	2.01E-05	2.08E+03	0.00E+00	8.80E-01
BATCH-167	8/8/20	138	14.4	0.24	5.94E-06	7.41E+01	5.03E-01	0.00E+00	0.00E+00	2.00E-04	8.00E+00	4.83E-06	1.09E-04	4.81E-05	2.07E-01	5.06E-05	2.36E+03	0.00E+00	1.81E+00
BATCH-168	8/18/20	138	14.4	0.24	5.94E-06	7.41E+01	5.03E-01	0.00E+00	0.00E+00	2.00E-04	8.00E+00	4.83E-06	1.09E-04	4.81E-05	2.07E-01	5.06E-05	2.36E+03	0.00E+00	1.81E+00
BATCH-169	8/23/20	138	14.4	0.24	5.94E-06	7.41E+01	5.03E-01	0.00E+00	0.00E+00	2.00E-04	8.00E+00	4.83E-06	1.09E-04	4.81E-05	2.07E-01	5.06E-05	2.36E+03	0.00E+00	1.81E+00
BATCH-170	9/2/20	110	11.5	0.24	8.52E-06	2.35E+01	4.56E-01	0.00E+00	0.00E+00	2.00E-04	6.63E+00	5.17E-06	1.41E-04	6.06E-05	8.60E-02	7.62E-05	1.88E+03	0.00E+00	6.70E-01
BATCH-171	9/7/20	110	11.4	0.24	8.50E-06	2.34E+01	4.55E-01	0.00E+00	0.00E+00	2.00E-04	6.61E+00	5.16E-06	1.41E-04	6.04E-05	8.50E-02	7.59E-05	1.88E+03	0.00E+00	6.68E-01
BATCH-172	9/13/20	100	10.4	0.24	4.30E-06	5.36E+01	3.64E-01	0.00E+00	0.00E+00	2.00E-04	5.79E+00	3.50E-06	7.89E-05	3.48E-05	1.50E-01	3.66E-05	1.71E+03	0.00E+00	1.31E+00
BATCH-173	9/18/20	119	12.4	0.24	5.12E-06	6.38E+01	4.33E-01	0.00E+00	0.00E+00	2.00E-04	6.89E+00	4.17E-06	9.40E-05	4.15E-05	1.79E-01	4.37E-05	2.03E+03	0.00E+00	1.56E+00
BATCH-174	9/24/20	119	12.4	0.24	5.12E-06	6.38E+01	4.33E-01	0.00E+00	0.00E+00	2.00E-04	6.89E+00	4.16E-06	9.39E-05	4.14E-05	1.78E-01	4.36E-05	2.03E+03	0.00E+00	1.56E+00
BATCH-175	10/1/20	119	12.4	0.24	5.11E-06	6.37E+01	4.32E-01	0.00E+00	0.00E+00	2.00E-04	6.87E+00	4.15E-06	9.37E-05	4.14E-05	1.78E-01	4.35E-05	2.03E+03	0.00E+00	1.55E+00
BATCH-176	10/7/20	66	6.9	0.24	4.77E-06	1.32E+01	2.55E-01	0.00E+00	0.00E+00	1.35E-04	3.71E+00	2.90E-06	7.89E-05	3.39E-05	4.80E-02	4.26E-05	1.13E+03	0.00E+00	3.75E-01
BATCH-177	10/13/20	66	6.9	0.24	4.76E-06	1.31E+01	2.55E-01	0.00E+00	0.00E+00	1.35E-04	3.70E+00	2.89E-06	7.87E-05	3.38E-05	4.80E-02	4.25E-05	1.13E+03	0.00E+00	3.74E-01
BATCH-178	10/14/20	136	14.1	0.24	4.60E-06	2.93E+01	6.91E-01	0.00E+00	0.00E+00	4.00E-04	5.78E+00	3.03E-06	7.72E-05	3.50E-05	7.10E-02	4.08E-05	2.32E+03	0.00E+00	5.34E-01
BATCH-179	10/20/20	97	10.2	0.24	9.09E-07	2.06E+01	5.03E-01	0.00E+00	0.00E+00	2.00E-04	2.72E+00	8.51E-07	1.69E-05	8.76E-06	4.10E-02	7.69E-06	1.66E+03	0.00E+00	3.24E-01
BATCH-180	10/28/20	97	10.1	0.24	9.08E-07	2.05E+01	5.03E-01	0.00E+00	0.00E+00	2.00E-04	2.71E+00	8.50E-07	1.69E-05	8.74E-06	4.10E-02	7.68E-06	1.66E+03	0.00E+00	3.23E-01
BATCH-181	10/31/20	97	10.1	0.24	9.05E-07	2.05E+01	5.02E-01	0.00E+00	0.00E+00	2.00E-04	2.71E+00	8.48E-07	1.69E-05	8.72E-06	4.10E-02	7.66E-06	1.65E+03	0.00E+00	3.23E-01
BATCH-182	11/7/20	24	2.5	0.24	1.39E-06	3.83E+00	7.40E-02	0.00E+00	0.00E+00	3.93E-05	1.08E+00	8.43E-07	2.30E-05	9.87E-06	1.40E-02	1.24E-05	4.04E+02	0.00E+00	1.09E-01
BATCH-183	11/10/20	24	2.5	0.24	1.38E-06	3.82E+00	7.40E-02	0.00E+00	0.00E+00	3.91E-05	1.08E+00	8.39E-07	2.29E-05	9.83E-06	1.40E-02	1.24E-05	4.03E+02	0.00E+00	1.09E-01
BATCH-184	11/10/20	60	6.3	0.24	1.86E-06	1.19E+01	2.80E-01	0.00E+00	0.00E+00	1.68E-04	2.34E+00	1.23E-06	3.13E-05	1.42E-05	2.90E-02	1.65E-05	1.03E+03	0.00E+00	2.16E-01
BATCH-185	11/13/20	57	6.0	0.24	4.86E-07	1.10E+01	2.69E-01	0.00E+00	0.00E+00	1.38E-04	1.45E+00	4.55E-07	9.06E-06	4.69E-06	2.20E-02	4.12E-06	9.81E+02	0.00E+00	1.73E-01
BATCH-186	11/17/20	57	6.0	0.24	4.86E-07	1.10E+01	2.69E-01	0.00E+00	0.00E+00	1.38E-04	1.45E+00	4.55E-07	9.04E-06	4.68E-06	2.20E-02	4.11E-06	9.81E+02	0.00E+00	1.73E-01
BATCH-187	11/19/20	57	6.0	0.24	4.85E-07	1.10E+01	2.69E-01	0.00E+00	0.00E+00	1.38E-04	1.45E+00	4.54E-07	9.02E-06	4.67E-06	2.20E-02	4.10E-06	9.80E+02	0.00E+00	1.73E-01
BATCH-188	11/23/20	163	16.9	0.24	1.39E-06	9.46E+01	7.17E-01	0.00E+00	0.00E+00	4.00E-04	9.55E+00	3.61E-06	3.45E-05	6.17E-05	3.61E-01	1.12E-05	2.78E+03	0.00E+00	2.03E+00
BATCH-189	11/25/20	164	17.1	0.24	3.06E-07	9.70E+01	7.48E-01	0.00E+00	0.00E+00	6.00E-04	9.67E+00	3.24E-06	1.65E-05	6.32E-05	3.87E-01	1.80E-06	2.80E+03	0.00E+00	5.70E-02
BATCH-190	12/10/20	21	2.1	0.24	4.88E-07	3.12E+00	7.30E-02	0.00E+00	0.00E+00	4.41E-05	6.13E-01	3.22E-07	8.20E-06	3.71E-06	8.00E-03	4.33E-06	3.50E+02	0.00E+00	5.70E-02
BATCH-191	12/12/20	19	2.0	0.24	1.20E-07	2.71E+00	6.60E-02	0.00E+00	0.00E+00	3.40E-05	3.58E-01	1.12E-07	2.23E-06	1.16E-06	5.00E-03	1.02E-06	3.27E+02	0.00E+00	4.30E-02
BATCH-192	12/12/20	19	2.0	0.24	1.20E-07	2.71E+00	6.60E-02	0.00E+00	0.00E+00	3.40E-05	3.58E-01	1.12E-07	2.23E-06	1.15E-06	5.00E-03	1.01E-06	3.27E+02	0.00E+00	4.30E-02
BATCH-193	12/14/20	19	2.0	0.24	1.19E-07	2.70E+00	6.60E-02	0.00E+00	0.00E+00	3.39E-05	3.57E-01	1.12E-07	2.22E-06	1.15E-06	5.00E-03	1.01E-06	3.27E+02	0.00E+00	4.30E-02
BATCH-194	12/15/20	147	15.3	0.24	2.75E-07	8.68E+01	6.69E-01	0.00E+00	0.00E+00	4.00E-04	8.66E+00	2.90E-06	1.48E-05	5.66E-05	3.46E-01	1.62E-06	2.51E+03	0.00E+00	1.81E+00
BATCH-195	12/17/20	150	15.6	0.24	2.80E-07	8.87E+01	6.84E-01	0.00E+00	0.00E+00	4.00E-04	8.85E+00	2.96E-06	1.51E-05	5.78E-05	3.54E-01	1.64E-06	2.56E+03	0.00E+00	1.85E+00

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date, units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Tl+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses					0.24	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.47E+01	4.92E-07	7.84E+00	1.21E+01	4.00E-03	1.75E-06	0.00E+00	4.00E-03	1.00E-02	1.10E-02
BATCH-147	4/29/20	66	6.9		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.42E+01	7.13E-07	9.29E+00	1.29E+01	2.00E-03	2.92E-06	0.00E+00	6.00E-03	1.50E-02	6.00E-03
BATCH-148	5/4/20	71	7.5		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.42E+01	7.12E-07	9.29E+00	1.29E+01	2.00E-03	2.91E-06	0.00E+00	6.00E-03	1.50E-02	6.00E-03
BATCH-149	5/6/20	71	7.4		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.42E+01	7.12E-07	9.28E+00	1.29E+01	2.00E-03	2.91E-06	0.00E+00	6.00E-03	1.50E-02	6.00E-03
BATCH-150	5/11/20	71	7.4		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.42E+01	7.10E-07	9.28E+00	1.29E+01	2.00E-03	2.91E-06	0.00E+00	6.00E-03	1.50E-02	6.00E-03
BATCH-151	5/14/20	71	7.4		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.42E+01	7.10E-07	9.28E+00	1.29E+01	2.00E-03	2.91E-06	0.00E+00	6.00E-03	1.50E-02	6.00E-03
BATCH-152	5/19/20	21	2.2		0.24	0.00E+00	0.00E+00	0.00E+00	7.15E-04	3.67E+00	1.37E-07	1.82E+00	3.01E+00	1.00E-03	1.14E-13	0.00E+00	6.14E-04	2.00E-03	3.00E-03
BATCH-153	5/21/20	24	2.5		0.24	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.39E+00	1.47E-07	2.33E+00	3.59E+00	1.00E-03	5.21E-07	0.00E+00	1.00E-03	3.00E-03	3.00E-03
BATCH-154	5/22/20	27	2.8		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.69E+00	2.35E-07	3.06E+00	4.26E+00	7.65E-04	9.59E-07	0.00E+00	2.00E-03	5.00E-03	2.00E-03
BATCH-155	5/24/20	27	2.8		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.68E+00	2.34E-07	3.06E+00	4.25E+00	7.65E-04	9.59E-07	0.00E+00	2.00E-03	5.00E-03	2.00E-03
BATCH-156	5/25/20	27	2.8		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.68E+00	2.34E-07	3.05E+00	4.25E+00	7.63E-04	9.57E-07	0.00E+00	2.00E-03	5.00E-03	2.00E-03
BATCH-157	5/27/20	27	2.8		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.67E+00	2.33E-07	3.05E+00	4.24E+00	7.62E-04	9.56E-07	0.00E+00	2.00E-03	5.00E-03	2.00E-03
BATCH-158	5/28/20	185	19.2		0.24	0.00E+00	0.00E+00	0.00E+00	4.30E-02	4.80E+01	8.29E-07	6.53E+00	4.57E+01	5.00E-03	3.65E-05	0.00E+00	3.30E-02	8.80E-02	4.80E-02
BATCH-159	5/30/20	184	19.2		0.24	0.00E+00	0.00E+00	0.00E+00	4.30E-02	4.79E+01	8.28E-07	6.52E+00	4.56E+01	5.00E-03	3.65E-05	0.00E+00	3.30E-02	8.80E-02	4.80E-02
BATCH-160	6/17/20	169	17.6		0.24	0.00E+00	0.00E+00	0.00E+00	1.40E-02	8.95E+01	1.34E-07	1.61E+01	4.52E+01	3.40E-02	5.90E-06	0.00E+00	7.00E-03	1.80E-02	1.61E-01
BATCH-161	6/19/20	177	18.4		0.24	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.04E-02	2.64E-09	1.90E+01	4.80E+01	4.20E-02	1.14E-07	0.00E+00	2.00E-03	4.00E-03	1.94E-01
BATCH-162	7/5/20	177	18.4		0.24	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.04E-02	2.64E-09	1.90E+01	4.80E+01	4.20E-02	1.14E-07	0.00E+00	2.00E-03	4.00E-03	1.94E-01
BATCH-163	7/8/20	177	18.4		0.24	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.04E-02	2.64E-09	1.90E+01	4.80E+01	4.20E-02	1.14E-07	0.00E+00	2.00E-03	4.00E-03	1.94E-01
BATCH-164	7/23/20	121	12.7		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	7.11E+01	2.28E-09	1.30E+01	3.30E+01	2.90E-02	1.00E-07	0.00E+00	1.00E-03	3.00E-03	1.33E-01
BATCH-165	7/26/20	121	12.7		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	7.10E+01	2.27E-09	1.30E+01	3.29E+01	2.90E-02	1.00E-07	0.00E+00	1.00E-03	3.00E-03	1.33E-01
BATCH-166	8/5/20	122	12.7		0.24	0.00E+00	0.00E+00	0.00E+00	1.10E-02	5.93E+01	4.79E-08	1.07E+01	3.73E+01	2.10E-02	2.11E-06	0.00E+00	1.50E-02	2.00E-03	8.10E-02
BATCH-167	8/8/20	138	14.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.90E-02	4.95E+01	1.21E-07	8.65E+00	4.83E+01	1.20E-02	5.33E-06	0.00E+00	3.60E-02	2.00E-03	1.60E-02
BATCH-168	8/18/20	138	14.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.90E-02	4.95E+01	1.21E-07	8.65E+00	4.83E+01	1.20E-02	5.32E-06	0.00E+00	3.60E-02	2.00E-03	1.60E-02
BATCH-169	8/23/20	138	14.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.90E-02	4.95E+01	1.21E-07	8.64E+00	4.83E+01	1.20E-02	5.32E-06	0.00E+00	3.60E-02	2.00E-03	1.60E-02
BATCH-170	9/2/20	110	11.5		0.24	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.62E+01	1.82E-07	1.21E+01	1.46E+01	4.00E-03	8.01E-06	0.00E+00	8.00E-03	2.00E-02	2.50E-02
BATCH-171	9/7/20	110	11.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.61E+01	1.81E-07	1.21E+01	1.45E+01	4.00E-03	7.99E-06	0.00E+00	8.00E-03	2.00E-02	2.50E-02
BATCH-172	9/13/20	100	10.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.58E+01	8.74E-08	6.26E+00	3.49E+01	9.00E-03	3.85E-06	0.00E+00	2.60E-02	1.00E-03	1.20E-02
BATCH-173	9/18/20	119	12.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.27E+01	1.04E-07	7.45E+00	4.16E+01	1.00E-02	4.59E-06	0.00E+00	3.10E-02	2.00E-03	1.40E-02
BATCH-174	9/24/20	119	12.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.26E+01	1.04E-07	7.44E+00	4.16E+01	1.00E-02	4.59E-06	0.00E+00	3.10E-02	2.00E-03	1.40E-02
BATCH-175	10/1/20	119	12.4		0.24	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.25E+01	1.04E-07	7.43E+00	4.15E+01	1.00E-02	4.58E-06	0.00E+00	3.10E-02	2.00E-03	1.40E-02
BATCH-176	10/7/20	66	6.9		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.47E+01	1.02E-07	6.76E+00	8.16E+00	2.00E-03	4.48E-06	0.00E+00	4.00E-03	1.10E-02	1.40E-02
BATCH-177	10/13/20	66	6.9		0.24	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.46E+01	1.01E-07	6.75E+00	8.14E+00	2.00E-03	4.47E-06	0.00E+00	4.00E-03	1.10E-02	1.40E-02
BATCH-178	10/14/20	136	14.1		0.24	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.20E+01	9.73E-08	2.18E+01	1.92E+01	9.00E-03	4.29E-06	0.00E+00	7.00E-03	1.00E-02	4.30E-02
BATCH-179	10/20/20	97	10.2		0.24	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.43E+01	1.84E-08	2.48E+01	1.46E+01	7.00E-03	8.09E-07	0.00E+00	6.00E-03	8.18E-04	2.50E-02
BATCH-180	10/28/20	97	10.1		0.24	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.43E+01	1.83E-08	2.48E+01	1.46E+01	7.00E-03	8.08E-07	0.00E+00	6.00E-03	8.17E-04	2.50E-02
BATCH-181	10/31/20	97	10.1		0.24	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.42E+01	1.83E-08	2.48E+01	1.46E+01	7.00E-03	8.06E-07	0.00E+00	6.00E-03	8.16E-04	2.50E-02
BATCH-182	11/7/20	24	2.5		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.27E+00	2.96E-08	1.97E+00	2.38E+00	6.97E-04	1.31E-06	0.00E+00	1.00E-03	3.00E-03	4.00E-03
BATCH-183	11/10/20	24	2.5		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.25E+00	2.95E-08	1.96E+00	2.37E+00	6.94E-04	1.30E-06	0.00E+00	1.00E-03	3.00E-03	4.00E-03
BATCH-184	11/10/20	60	6.3		0.24	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.70E+01	3.94E-08	8.81E+00	7.77E+00	4.00E-03	1.74E-06	0.00E+00	3.00E-03	4.00E-03	1.70E-02
BATCH-185	11/13/20	57	6.0		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.84E+01	9.82E-09	1.33E+01	7.84E+00	4.00E-03	4.33E-07	0.00E+00	3.00E-03	4.38E-04	1.30E-02
BATCH-186	11/17/20	57	6.0		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.84E+01	9.81E-09	1.33E+01	7.83E+00	4.00E-03	4.32E-07	0.00E+00	3.00E-03	4.37E-04	1.30E-02
BATCH-187	11/19/20	57	6.0		0.24	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.83E+01	9.78E-09	1.33E+01	7.82E+00	4.00E-03	4.32E-07	0.00E+00	3.00E-03	4.37E-04	1.30E-02
BATCH-188	11/23/20	163	16.9		0.24	0.00E+00	0.00E+00	0.00E+00	1.30E-02	9.96E+01	1.79E-07	1.41E+01	7.01E+01	2.40E-02	1.22E-06	0.00E+00	1.30E-01	3.40E-02	3.40E-02
BATCH-189	11/25/20	164	17.1		0.24	0.00E+00	0.00E+00	0.00E+00	1.20E-02	1.09E+02	1.88E-07	1.50E+01	7.33E+01	2.60E-02	2.40E-07	0.00E+00	1.48E-01	4.00E-03	3.70E-02
BATCH-190	12/10/20	21	2.1		0.24	0.00E+00	0.00E+00	0.00E+00	8.19E-04	4.46E+00	1.03E-08	2.31E+00	2.04E+00	9.88E-04	4.55E-07	0.00E+00	7.77E-04	1.00E-03	5.00E-03
BATCH-191	12/12/20	19	2.0		0.24	0.00E+00	0.00E+00	0.00E+00	5.11E-04	4.53E+00	2.42E-09	3.28E+00	1.93E+00	8.83E-04	1.07E-07	0.00E+00	8.43E-04	1.08E-04	3.00E-03
BATCH-192	12/12/20	19	2.0		0.24	0.00E+00	0.00E+00	0.00E+00	5.10E-04	4.52E+00	2.42E-09	3.27E+00	1.93E+00	8.81E-04	1.07E-07	0.00E+00	8.42E-04	1.08E-04	3.00E-03
BATCH-193	12/14/20	19	2.0		0.24	0.00E+00	0.00E+00	0.00E+00	5.08E-04	4.51E+00	2.41E-09	3.27E+00	1.92E+00	8.79E-04	1.06E-07	0.00E+00	8.39E-04	1.08E-04	3.00E-03
BATCH-194	12/15/20	147	15.3		0.24	0.00E+00	0.00E+00	0.00E+00	1.00E-02	9.73E+01	1.68E-07	1.34E+01	6.57E+01	2.30E-02	2.16E-07	0.00E+00	1.33E-01	3.00E-03	3.30E-02
BATCH-195	12/17/20	150	15.6		0.24	0.00E+00	0.00E+00	0.00E+00	1.10E-02	9.94E+01	1.72E-07	1.37E+01	6.71E+01	2.40E-02	2.20E-07	0.00E+00	1.36E-01	3.00E-03	3.40E-02

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
Fraction Remaining After Volatization Losses																			
BATCH-196	12/30/20	164	17.1	0.24	0.00E+00	0.00E+00	2.40E-01	1.12E-01	1.92E+01	4.33E-01	3.27E+03	1.66E+00	3.25E-01	1.63E+01	9.59E-11	2.77E+00	2.30E-02	4.95E-01	1.58E-02
BATCH-197	1/1/21	157	16.4	0.24	0.00E+00	0.00E+00	2.25E-01	9.20E-02	1.79E+01	4.13E-01	3.14E+03	1.55E+00	2.88E-01	1.57E+01	5.39E-11	2.51E+00	1.60E-02	4.60E-01	1.50E-02
BATCH-198	1/15/21	177	18.5	0.24	0.00E+00	0.00E+00	1.03E-01	2.60E-02	8.27E+00	3.93E-01	3.45E+03	5.95E-01	7.70E-02	1.45E+01	2.77E-10	2.04E+00	5.00E-03	8.50E-02	1.48E-02
BATCH-199	1/18/21	177	18.4	0.24	0.00E+00	0.00E+00	1.03E-01	2.60E-02	8.26E+00	3.93E-01	3.45E+03	5.95E-01	7.70E-02	1.45E+01	2.77E-10	2.04E+00	5.00E-03	8.50E-02	1.48E-02
BATCH-200	2/4/21	145	15.1	0.24	0.00E+00	0.00E+00	8.40E-02	2.20E-02	6.78E+00	3.22E-01	2.83E+03	4.88E-01	6.30E-02	1.19E+01	2.27E-10	1.67E+00	4.00E-03	7.00E-02	1.20E-02
BATCH-201	2/6/21	148	15.5	0.24	0.00E+00	0.00E+00	8.60E-02	2.20E-02	6.93E+00	3.29E-01	2.89E+03	4.99E-01	6.40E-02	1.22E+01	2.32E-10	1.71E+00	4.00E-03	7.20E-02	1.23E-02
BATCH-202	2/20/21	162	16.9	0.24	0.00E+00	0.00E+00	9.40E-02	2.40E-02	7.56E+00	3.59E-01	3.16E+03	5.44E-01	7.00E-02	1.33E+01	2.53E-10	1.86E+00	4.00E-03	7.80E-02	1.35E-02
BATCH-203	2/21/21	155	16.1	0.24	0.00E+00	0.00E+00	9.00E-02	2.30E-02	7.22E+00	3.43E-01	3.02E+03	5.20E-01	6.70E-02	1.27E+01	2.42E-10	1.78E+00	4.00E-03	7.50E-02	1.28E-02
BATCH-204	3/9/21	130	13.5	0.24	0.00E+00	0.00E+00	1.64E-01	1.13E-01	1.32E+01	4.08E-01	2.59E+03	1.16E+00	1.94E-01	1.29E+01	1.69E-09	2.30E+00	1.70E-02	2.92E-01	2.20E-02
BATCH-205	3/10/21	129	13.5	0.24	0.00E+00	0.00E+00	1.78E-01	1.27E-01	1.43E+01	4.26E-01	2.59E+03	1.27E+00	2.15E-01	1.29E+01	1.92E-09	2.42E+00	1.90E-02	3.28E-01	2.35E-02
BATCH-206	3/22/21	106	11.1	0.24	0.00E+00	0.00E+00	1.46E-01	1.04E-01	1.17E+01	3.49E-01	2.12E+03	1.04E+00	1.76E-01	1.06E+01	1.58E-09	1.98E+00	1.60E-02	2.69E-01	1.93E-02
BATCH-207	3/24/21	108	11.3	0.24	0.00E+00	0.00E+00	1.49E-01	1.07E-01	1.20E+01	3.56E-01	2.17E+03	1.06E+00	1.80E-01	1.08E+01	1.61E-09	2.03E+00	1.60E-02	2.74E-01	1.98E-02
BATCH-208	4/3/21	118	12.3	0.24	0.00E+00	0.00E+00	1.63E-01	1.17E-01	1.31E+01	3.90E-01	2.37E+03	1.16E+00	1.97E-01	1.18E+01	1.76E-09	2.21E+00	1.80E-02	3.00E-01	2.15E-02
BATCH-209	4/4/21	113	11.8	0.24	0.00E+00	0.00E+00	1.56E-01	1.11E-01	1.25E+01	3.73E-01	2.26E+03	1.11E+00	1.88E-01	1.13E+01	1.68E-09	2.12E+00	1.70E-02	2.87E-01	2.08E-02
BATCH-210	4/15/21	111	11.6	0.24	0.00E+00	0.00E+00	1.53E-01	1.10E-01	1.23E+01	3.66E-01	2.23E+03	1.09E+00	1.85E-01	1.11E+01	1.65E-09	2.08E+00	1.70E-02	2.82E-01	2.03E-02
BATCH-211	4/16/21	100	10.4	0.24	0.00E+00	0.00E+00	1.33E-01	8.20E-02	1.07E+01	3.29E-01	2.00E+03	9.29E-01	1.55E-01	9.94E+00	1.10E-09	1.83E+00	1.30E-02	2.38E-01	1.58E-02
BATCH-212	4/27/21	94	9.8	0.24	0.00E+00	0.00E+00	4.20E-02	1.90E-02	3.33E+00	1.02E-01	1.34E+03	2.77E-01	4.80E-02	5.40E+00	1.46E-10	5.62E-01	3.00E-03	7.30E-02	4.25E-03
BATCH-213	4/27/21	75	7.8	0.24	0.00E+00	0.00E+00	9.40E-02	3.70E-02	7.60E+00	2.47E-01	1.49E+03	6.24E-01	1.00E-01	7.45E+00	2.58E-10	1.32E+00	7.00E-03	1.57E-01	8.25E-03
BATCH-214	5/5/21	82	8.5	0.24	0.00E+00	0.00E+00	1.03E-01	4.10E-02	8.31E+00	2.69E-01	1.63E+03	6.82E-01	1.10E-01	8.13E+00	2.81E-10	1.44E+00	7.00E-03	1.72E-01	9.00E-03
BATCH-215	5/7/21	78	8.2	0.24	0.00E+00	0.00E+00	9.90E-02	3.90E-02	7.95E+00	2.57E-01	1.56E+03	6.53E-01	1.05E-01	7.78E+00	2.69E-10	1.38E+00	7.00E-03	1.64E-01	8.50E-03
BATCH-216	5/14/21	77	8.0	0.24	0.00E+00	0.00E+00	9.70E-02	3.80E-02	7.79E+00	2.53E-01	1.53E+03	6.40E-01	1.03E-01	7.63E+00	2.64E-10	1.35E+00	7.00E-03	1.61E-01	8.25E-03
BATCH-217	5/15/21	77	8.0	0.24	0.00E+00	0.00E+00	9.70E-02	3.80E-02	7.82E+00	2.54E-01	1.54E+03	6.42E-01	1.03E-01	7.66E+00	2.65E-10	1.36E+00	7.00E-03	1.62E-01	8.25E-03
BATCH-218	5/22/21	100	10.4	0.24	0.00E+00	0.00E+00	4.50E-02	2.00E-02	3.60E+00	1.08E-01	1.41E+03	3.01E-01	5.10E-02	5.57E+00	1.49E-10	6.11E-01	3.00E-03	7.80E-02	4.50E-03
BATCH-219	5/23/21	54	5.6	0.24	0.00E+00	0.00E+00	2.10E-02	1.00E-02	1.72E+00	5.22E-02	6.94E+02	1.43E-01	2.50E-02	2.79E+00	7.56E-11	2.90E-01	2.00E-03	3.70E-02	2.25E-03
BATCH-220	5/29/21	74	7.8	0.24	0.00E+00	0.00E+00	9.40E-02	3.70E-02	7.56E+00	2.45E-01	1.49E+03	6.20E-01	1.00E-01	7.40E+00	2.55E-10	1.31E+00	7.00E-03	1.56E-01	8.00E-03
BATCH-221	6/1/21	71	7.4	0.24	0.00E+00	0.00E+00	9.00E-02	3.50E-02	7.23E+00	2.34E-01	1.42E+03	5.93E-01	9.50E-02	7.08E+00	2.44E-10	1.25E+00	6.00E-03	1.49E-01	7.75E-03
BATCH-222	6/6/21	99	10.3	0.24	0.00E+00	0.00E+00	4.10E-02	2.30E-02	3.32E+00	1.15E-01	1.16E+03	2.76E-01	4.40E-02	5.05E+00	3.11E-10	6.30E-01	4.00E-03	6.40E-02	5.25E-03
BATCH-223	6/9/21	98	10.2	0.24	0.00E+00	0.00E+00	3.80E-02	1.90E-02	3.02E+00	1.10E-01	1.08E+03	2.48E-01	3.90E-02	4.68E+00	2.60E-10	5.94E-01	3.00E-03	5.50E-02	5.00E-03
BATCH-224	6/17/21	18	1.9	0.24	0.00E+00	0.00E+00	5.00E-03	2.00E-03	4.13E-01	1.26E-02	1.67E+02	3.40E-02	6.00E-03	6.70E-01	1.82E-11	7.00E-02	3.96E-04	9.00E-03	5.00E-04
BATCH-225	6/19/21	57	6.0	0.24	0.00E+00	0.00E+00	2.30E-02	1.10E-02	1.88E+00	5.67E-02	7.37E+02	1.58E-01	2.70E-02	2.91E+00	7.79E-11	3.19E-01	2.00E-03	4.10E-02	2.25E-03
BATCH-226	6/19/21	98	10.3	0.24	0.00E+00	0.00E+00	4.10E-02	1.90E-02	3.30E+00	1.08E-01	1.22E+03	2.73E-01	4.50E-02	5.06E+00	1.72E-10	5.93E-01	3.00E-03	6.70E-02	4.25E-03
BATCH-227	6/25/21	108	11.3	0.24	0.00E+00	0.00E+00	4.80E-02	2.20E-02	3.88E+00	1.21E-01	1.46E+03	3.23E-01	5.40E-02	5.94E+00	1.75E-10	6.74E-01	4.00E-03	8.20E-02	4.75E-03
BATCH-228	6/30/21	54	5.6	0.24	0.00E+00	0.00E+00	2.00E-02	1.10E-02	1.63E+00	5.67E-02	5.72E+02	1.36E-01	2.20E-02	2.49E+00	1.53E-10	3.11E-01	2.00E-03	3.20E-02	2.50E-03
BATCH-229	7/6/21	56	5.8	0.24	0.00E+00	0.00E+00	1.90E-02	1.00E-02	1.56E+00	5.67E-02	5.57E+02	1.28E-01	2.00E-02	2.42E+00	1.34E-10	3.06E-01	2.00E-03	2.80E-02	2.50E-03
BATCH-230	7/7/21	134	14.0	0.24	0.00E+00	0.00E+00	1.72E-01	7.40E-02	1.38E+01	5.08E-01	2.68E+03	1.21E+00	2.05E-01	1.34E+01	4.46E-08	2.28E+00	1.40E-02	3.43E-01	1.53E-02
BATCH-231	7/12/21	20	2.1	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	5.10E-01	1.53E-02	2.00E+02	4.30E-02	7.00E-03	7.89E-01	2.11E-11	8.70E-02	4.82E-04	1.10E-02	5.00E-04
BATCH-232	7/14/21	57	5.9	0.24	0.00E+00	0.00E+00	2.20E-02	1.00E-02	1.73E+00	5.67E-02	6.39E+02	1.43E-01	2.40E-02	2.66E+00	9.03E-11	3.11E-01	2.00E-03	3.50E-02	2.25E-03
BATCH-233	7/20/21	18	1.9	0.24	0.00E+00	0.00E+00	5.00E-03	3.00E-03	4.07E-01	1.44E-02	1.42E+02	3.40E-02	5.00E-03	6.20E-01	3.82E-11	7.70E-02	4.40E-04	8.00E-03	7.50E-04
BATCH-234	7/21/21	55	5.7	0.24	0.00E+00	0.00E+00	2.20E-02	1.00E-02	1.79E+00	5.58E-02	6.75E+02	1.49E-01	2.50E-02	2.75E+00	8.10E-11	3.11E-01	2.00E-03	3.80E-02	2.25E-03
BATCH-235	7/22/21	19	2.0	0.24	0.00E+00	0.00E+00	5.00E-03	3.00E-03	4.00E-01	1.44E-02	1.43E+02	3.30E-02	5.00E-03	6.20E-01	3.44E-11	7.90E-02	4.07E-04	7.00E-03	7.50E-04
BATCH-236	7/24/21	390	40.7	0.24	0.00E+00	0.00E+00	5.32E-01	3.01E-01	4.25E+01	2.23E+00	7.80E+03	4.58E+00	8.94E-01	3.89E+01	6.40E-07	5.70E+00	6.10E-02	1.70E+00	5.13E-02
BATCH-237	7/27/21	20	2.1	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	4.72E-01	1.53E-02	1.74E+02	3.90E-02	6.00E-03	7.23E-01	2.46E-11	8.50E-02	4.45E-04	1.00E-02	5.00E-04
BATCH-238	7/29/21	341	35.6	0.24	0.00E+00	0.00E+00	4.65E-01	2.63E-01	3.72E+01	1.95E+00	6.82E+03	4.01E+00	7.82E-01	3.40E+01	5.60E-07	4.98E+00	5.30E-02	1.49E+00	4.48E-02
BATCH-239	9/3/21	390	40.6	0.24	0.00E+00	0.00E+00	5.32E-01	3.00E-01	4.25E+01	2.23E+00	7.79E+03	4.58E+00	8.93E-01	3.88E+01	6.40E-07	5.69E+00	6.10E-02	1.70E+00	5.10E-02
BATCH-240	9/3/21	390	40.6	0.24	0.00E+00	0.00E+00	5.31E-01	3.00E-01	4.25E+01	2.23E+00	7.79E+03	4.58E+00	8.93E-01	3.88E+01	6.39E-07	5.69E+00	6.10E-02	1.70E+00	5.10E-02
BATCH-241	10/14/21	19	2.0	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	4.70E-01	1.44E-02	1.77E+02	3.90E-02	7.00E-03	7.20E-01	2.13E-11	8.20E-02	4.42E-04	1.00E-02	5.00E-04
BATCH-242	10/14/21	389	40.6	0.24	0.00E+00	0.00E+00	5.31E-01	3.00E-01	4.24E+01	2.22E+00	7.78E+03	4.57E+00	8.91E-01	3.87E+01	6.38E-07	5.68E+00	6.00E-02	1.70E+00	5.10E-02
BATCH-243	10/16/21	288	30.1	0.24	0.00E+00	0.00E+00	3.94E-01	2.23E-01	3.15E+01	1.65E+00	5.77E+03	3.39E+00	6.62E-01	2.87E+01	4.72E-07	4.22E+00	4.50E-02	1.26E+00	3.78E-02
BATCH-244	11/15/21	101	10.6	0.24	0.00E+00	0.00E+00	2.25E-01	1.29E-01	1.80E+01	7.50E-01	2.03E+03	1.78E+00	3.45E-01	1.01E+01	2.64E-08	2.56E+00	2.30E-02	6.89E-01	1.50E-02

Appendix A Nominal ILAW Inventory
TWRS/O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-196	12/30/20	164	17.1	0.24	1.90E-06	4.91E+02	9.17E+02	8.30E+02	6.46E+00	4.80E-01	7.00E-03	3.84E-05	2.00E-03	2.93E-04	4.24E-04	7.31E-04	4.10E-02	2.00E-01	8.20E-02
BATCH-197	1/1/21	157	16.4	0.24	1.28E-06	4.72E+02	8.45E+02	7.30E+02	5.54E+00	3.88E-01	8.00E-03	3.45E-05	2.00E-03	2.79E-04	3.97E-04	6.92E-04	3.80E-02	1.87E-01	7.70E-02
BATCH-198	1/16/21	177	18.5	0.24	9.46E-07	5.31E+02	1.20E+02	1.20E+02	8.59E+01	6.70E-02	4.70E-02	4.81E-06	3.00E-03	2.49E-04	1.49E-04	4.73E-04	1.20E-02	5.90E-02	2.00E-02
BATCH-199	1/18/21	177	18.4	0.24	9.45E-07	5.30E+02	1.20E+02	1.20E+02	8.59E+01	6.70E-02	4.70E-02	4.80E-06	3.00E-03	2.49E-04	1.49E-04	4.73E-04	1.20E-02	5.90E-02	2.00E-02
BATCH-200	2/4/21	145	15.1	0.24	7.75E-07	4.35E+02	9.89E+01	1.00E+02	7.07E+01	5.50E-02	3.80E-02	3.95E-06	2.00E-03	2.04E-04	1.22E-04	3.88E-04	1.00E-02	4.90E-02	1.60E-02
BATCH-201	2/6/21	148	15.5	0.24	7.92E-07	4.44E+02	1.01E+02	1.00E+02	7.22E+01	5.60E-02	3.90E-02	4.04E-06	2.00E-03	2.09E-04	1.25E-04	3.96E-04	1.00E-02	5.00E-02	1.60E-02
BATCH-202	2/20/21	162	16.9	0.24	8.64E-07	4.85E+02	1.10E+02	1.10E+02	7.88E+01	6.10E-02	4.30E-02	4.41E-06	3.00E-03	2.28E-04	1.36E-04	4.33E-04	1.10E-02	5.40E-02	1.80E-02
BATCH-203	2/21/21	155	16.1	0.24	8.26E-07	4.63E+02	1.05E+02	1.10E+02	7.52E+01	5.90E-02	4.10E-02	4.21E-06	3.00E-03	2.18E-04	1.30E-04	4.13E-04	1.00E-02	5.20E-02	1.70E-02
BATCH-204	3/9/21	130	13.5	0.24	5.80E-06	3.89E+02	5.27E+02	5.70E+02	4.08E+00	3.31E-01	1.80E-02	2.02E-05	2.00E-03	3.77E-04	3.10E-04	1.00E-03	3.60E-02	1.78E-01	5.20E-02
BATCH-205	3/10/21	129	13.5	0.24	6.60E-06	3.88E+02	5.96E+02	6.40E+02	4.63E+00	3.76E-01	1.50E-02	2.28E-05	2.00E-03	4.08E-04	3.41E-04	1.00E-03	4.00E-02	1.99E-01	5.80E-02
BATCH-206	3/22/21	106	11.1	0.24	5.41E-06	3.18E+02	4.89E+02	5.30E+02	3.79E+00	3.08E-01	1.20E-02	1.87E-05	2.00E-03	3.34E-04	2.80E-04	1.00E-03	3.30E-02	1.63E-01	4.70E-02
BATCH-207	3/24/21	108	11.3	0.24	5.53E-06	3.25E+02	5.00E+02	5.40E+02	3.88E+00	3.15E-01	1.30E-02	1.91E-05	2.00E-03	3.42E-04	2.86E-04	1.00E-03	3.40E-02	1.67E-01	4.80E-02
BATCH-208	4/3/21	118	12.3	0.24	6.04E-06	3.55E+02	5.45E+02	5.90E+02	4.23E+00	3.44E-01	1.40E-02	2.09E-05	2.00E-03	3.73E-04	3.12E-04	1.00E-03	3.70E-02	1.82E-01	5.30E-02
BATCH-209	4/4/21	113	11.8	0.24	5.77E-06	3.39E+02	5.22E+02	5.60E+02	4.05E+00	3.29E-01	1.30E-02	2.00E-05	2.00E-03	3.57E-04	2.98E-04	1.00E-03	3.50E-02	1.74E-01	5.10E-02
BATCH-210	4/15/21	111	11.6	0.24	5.68E-06	3.34E+02	5.13E+02	5.50E+02	3.98E+00	3.23E-01	1.30E-02	1.96E-05	2.00E-03	3.51E-04	2.94E-04	1.00E-03	3.40E-02	1.71E-01	5.00E-02
BATCH-211	4/16/21	100	10.4	0.24	3.62E-06	2.99E+02	4.22E+02	4.60E+02	3.24E+00	2.61E-01	2.70E-02	1.61E-05	2.00E-03	3.43E-04	2.61E-04	1.00E-03	3.00E-02	1.50E-01	4.10E-02
BATCH-212	4/27/21	94	9.8	0.24	5.84E-07	2.83E+02	1.28E+02	1.20E+02	8.92E+01	6.60E-02	7.00E-03	5.14E-06	5.91E-04	7.32E-05	7.14E-05	1.84E-04	7.00E-03	3.70E-02	1.30E-02
BATCH-213	4/27/21	75	7.8	0.24	5.67E-07	2.24E+02	2.61E+02	2.80E+02	1.95E+00	1.54E-01	4.30E-02	9.78E-06	2.00E-03	2.99E-04	1.93E-04	8.66E-04	2.10E-02	1.06E-01	2.60E-02
BATCH-214	5/5/21	82	8.5	0.24	6.19E-07	2.45E+02	2.85E+02	3.10E+02	2.13E+00	1.68E-01	4.70E-02	1.07E-05	3.00E-03	3.27E-04	2.11E-04	9.46E-04	2.30E-02	1.16E-01	2.90E-02
BATCH-215	5/7/21	78	8.2	0.24	5.93E-07	2.34E+02	2.73E+02	3.00E+02	2.04E+00	1.61E-01	4.50E-02	1.02E-05	3.00E-03	3.13E-04	2.02E-04	9.05E-04	2.20E-02	1.11E-01	2.70E-02
BATCH-216	5/14/21	77	8.0	0.24	5.80E-07	2.30E+02	2.67E+02	2.90E+02	2.00E+00	1.58E-01	4.40E-02	1.00E-05	3.00E-03	3.07E-04	1.98E-04	8.87E-04	2.20E-02	1.09E-01	2.70E-02
BATCH-217	5/15/21	77	8.0	0.24	5.83E-07	2.31E+02	2.68E+02	2.90E+02	2.01E+00	1.59E-01	4.40E-02	1.01E-05	3.00E-03	3.08E-04	1.98E-04	8.91E-04	2.20E-02	1.09E-01	2.70E-02
BATCH-218	5/22/21	100	10.4	0.24	6.03E-07	2.99E+02	1.38E+02	1.30E+02	9.65E+01	7.20E-02	8.00E-03	5.52E-06	6.83E-04	8.51E-05	7.94E-05	2.21E-04	8.00E-03	3.90E-02	1.40E-02
BATCH-219	5/23/21	54	5.6	0.24	3.01E-07	1.62E+02	6.62E+01	6.00E+01	4.61E+01	3.40E-02	4.00E-03	2.66E-06	3.05E-04	3.78E-05	3.69E-05	9.51E-05	4.00E-03	1.90E-02	7.00E-03
BATCH-220	5/29/21	74	7.8	0.24	5.60E-07	2.23E+02	2.59E+02	2.80E+02	1.94E+00	1.53E-01	4.20E-02	9.72E-06	2.00E-03	2.97E-04	1.92E-04	8.61E-04	2.10E-02	1.06E-01	2.60E-02
BATCH-221	6/1/21	71	7.4	0.24	5.36E-07	2.13E+02	2.48E+02	2.70E+02	1.86E+00	1.46E-01	4.10E-02	9.30E-06	2.00E-03	2.84E-04	1.83E-04	8.23E-04	2.00E-02	1.01E-01	2.50E-02
BATCH-222	6/6/21	99	10.3	0.24	1.05E-06	2.97E+02	1.11E+02	1.20E+02	8.51E+01	6.80E-02	1.00E-02	4.26E-06	8.08E-04	1.01E-04	7.46E-05	2.81E-04	8.00E-03	4.00E-02	1.20E-02
BATCH-223	6/9/21	98	10.2	0.24	8.76E-07	2.94E+02	9.43E+01	1.00E+02	7.19E+01	5.80E-02	1.00E-02	3.62E-06	7.80E-04	9.20E-05	6.64E-05	2.47E-04	7.00E-03	3.50E-02	1.00E-02
BATCH-224	6/17/21	18	1.9	0.24	7.24E-08	5.43E+01	1.59E+01	1.00E-03	1.11E-01	8.00E-03	8.70E-04	6.38E-07	7.33E-05	9.08E-06	8.86E-06	2.28E-05	9.14E-04	5.00E-03	2.00E-03
BATCH-225	6/19/21	57	6.0	0.24	3.15E-07	1.71E+02	7.23E+01	7.00E-03	5.05E-01	3.80E-02	4.00E-03	2.88E-06	3.57E-04	4.45E-05	4.15E-05	1.16E-04	4.00E-03	2.10E-02	7.00E-03
BATCH-226	6/19/21	98	10.3	0.24	6.14E-07	2.95E+02	1.17E+02	1.20E-02	8.40E-01	6.40E-02	1.00E-02	4.57E-06	7.64E-04	9.20E-05	7.40E-05	2.45E-04	8.00E-03	3.80E-02	1.20E-02
BATCH-227	6/25/21	108	11.3	0.24	6.59E-07	3.24E+02	1.43E+02	1.40E-02	1.02E+00	7.70E-02	1.00E-02	5.67E-06	8.26E-04	1.01E-04	8.67E-05	2.68E-04	9.00E-03	4.40E-02	1.40E-02
BATCH-228	6/30/21	54	5.6	0.24	5.17E-07	1.62E+02	5.48E+01	6.00E-03	4.19E-01	3.40E-02	5.00E-03	2.10E-06	3.98E-04	4.97E-05	3.68E-05	1.39E-04	4.00E-03	2.00E-02	6.00E-03
BATCH-229	7/6/21	56	5.8	0.24	4.52E-07	1.67E+02	4.86E+01	5.00E-03	3.71E-01	3.00E-02	5.00E-03	1.87E-06	4.02E-04	4.74E-05	3.42E-05	1.27E-04	4.00E-03	1.80E-02	5.00E-03
BATCH-230	7/7/21	134	14.0	0.24	9.82E-06	4.02E+02	5.27E+02	5.70E+02	3.91E+00	3.35E-01	7.58E+00	2.01E-05	4.00E-03	5.01E-04	3.57E-04	2.00E-03	3.80E-02	1.88E-01	5.10E-02
BATCH-231	7/12/21	20	2.1	0.24	8.54E-08	6.03E+01	1.96E+01	2.00E-03	1.37E-01	1.00E-02	1.00E-03	7.82E-07	9.68E-05	1.21E-05	1.13E-05	3.13E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-232	7/14/21	57	5.9	0.24	3.22E-07	1.70E+02	6.12E+01	6.00E-03	4.41E-01	3.40E-02	5.00E-03	2.40E-06	4.01E-04	4.83E-05	3.89E-05	1.29E-04	4.00E-03	2.00E-02	6.00E-03
BATCH-233	7/20/21	18	1.9	0.24	1.29E-07	5.52E+01	1.36E+01	1.00E-03	1.04E-01	8.00E-03	1.00E-03	5.23E-07	9.91E-05	1.24E-05	9.16E-06	3.45E-05	9.95E-04	5.00E-03	1.00E-03
BATCH-234	7/21/21	55	5.7	0.24	3.04E-07	1.65E+02	6.63E+01	6.00E-03	4.70E-01	3.50E-02	5.00E-03	2.62E-06	3.81E-04	4.68E-05	4.01E-05	1.24E-04	4.00E-03	2.00E-02	7.00E-03
BATCH-235	7/22/21	19	2.0	0.24	1.16E-07	5.74E+01	1.25E+01	1.00E-03	9.50E-02	8.00E-03	1.00E-03	4.80E-07	1.03E-04	1.22E-05	8.79E-06	3.26E-05	9.30E-04	5.00E-03	1.00E-03
BATCH-236	7/24/21	390	40.7	0.24	1.35E-04	1.17E+03	2.22E+03	2.33E+01	1.61E+01	1.66E+00	1.09E+02	8.81E-05	2.00E-03	1.00E-03	1.00E-03	4.00E-03	1.05E-01	5.22E-01	1.87E-01
BATCH-237	7/27/21	20	2.1	0.24	8.77E-08	6.01E+01	1.67E+01	2.00E-03	1.20E-01	9.00E-03	1.00E-03	6.53E-07	1.09E-04	1.31E-05	1.06E-05	3.50E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-238	7/29/21	341	35.6	0.24	1.08E-04	1.02E+03	1.94E+03	2.04E+01	1.40E+01	1.45E+00	9.52E+01	7.71E-05	2.00E-03	9.11E-04	1.00E-03	4.00E-03	9.20E-02	4.57E-01	1.64E-01
BATCH-239	9/3/21	390	40.6	0.24	1.35E-04	1.17E+03	2.22E+03	2.33E+01	1.60E+01	1.65E+00	1.09E+02	8.80E-05	2.00E-03	1.00E-03	1.00E-03	4.00E-03	1.05E-01	5.22E-01	1.87E-01
BATCH-240	9/3/21	390	40.6	0.24	1.35E-04	1.17E+03	2.22E+03	2.33E+01	1.60E+01	1.65E+00	1.09E+02	8.80E-05	2.00E-03	1.00E-03	1.00E-03	4.00E-03	1.05E-01	5.22E-01	1.87E-01
BATCH-241	10/14/21	19	2.0	0.24	7.98E-08	5.76E+01	1.74E+01	2.00E-03	1.23E-01	9.00E-03	1.00E-03	6.87E-07	1.00E-04	1.23E-05	1.05E-05	3.25E-05	1.00E-03	5.00E-03	2.00E-03
BATCH-242	10/14/21	389	40.6	0.24	1.35E-04	1.17E+03	2.22E+03	2.33E+01	1.60E+01	1.65E+00	1.09E+02	8.79E-05	2.00E-03	1.00E-03	1.00E-03	4.00E-03	1.05E-01	5.21E-01	1.87E-01
BATCH-243	10/16/21	288	30.1	0.24	1.08E-04	8.65E+02	1.65E+03	1.73E+01	1.19E+01	1.23E+00	8.02E+01	6.52E-05	2.00E-03	7.72E-04	8.74E-04	3.00E-03	7.80E-02	3.88E-01	1.39E-01
BATCH-244	11/15/21	101	10.6	0.24	8.86E-06	3.04E+02	9.20E+02	1.05E-01	6.93E+00	6.28E-01	4.49E+00	3.48E-05	1.00E-03	4.83E-04	1.00E-03	2.00E-03	5.60E-02	2.77E-01	7.10E-02

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-196	12/30/20	164	17.1	0.24	3.00E-03	2.00E-03	9.00E-03	9.50E-02	8.80E-02	4.39E+00	7.22E-01	5.04E+00	2.22E+00	3.63E-20	4.22E-05	1.59E-04	5.86E-04	4.00E-03	6.88E-07
BATCH-197	1/1/21	157	16.4	0.24	3.00E-03	2.00E-03	8.40E-03	8.80E-02	8.20E-02	4.20E+00	7.00E-01	4.71E+00	1.97E+00	7.19E-21	3.93E-05	1.47E-04	5.39E-04	4.00E-03	8.18E-07
BATCH-198	1/16/21	177	18.5	0.24	8.19E-04	4.47E-04	2.70E-02	2.10E-02	2.10E-02	4.21E+00	9.79E-01	1.87E+00	4.60E-01	3.07E-21	9.52E-06	2.63E-05	2.97E-04	2.00E-03	5.36E-06
BATCH-199	1/18/21	177	18.4	0.24	8.19E-04	4.47E-04	2.70E-02	2.10E-02	2.10E-02	4.21E+00	9.79E-01	1.87E+00	4.60E-01	3.07E-21	9.52E-06	2.63E-05	2.97E-04	2.00E-03	5.35E-06
BATCH-200	2/4/21	145	15.1	0.24	6.72E-04	3.67E-04	2.20E-02	1.70E-02	1.70E-02	3.45E+00	8.02E-01	1.53E+00	3.78E-01	2.52E-21	7.82E-06	2.16E-05	2.44E-04	2.00E-03	4.39E-06
BATCH-201	2/6/21	148	15.5	0.24	6.87E-04	3.75E-04	2.20E-02	1.70E-02	1.70E-02	3.53E+00	8.20E-01	1.57E+00	3.86E-01	2.57E-21	7.99E-06	2.21E-05	2.49E-04	2.00E-03	4.48E-06
BATCH-202	2/20/21	162	16.9	0.24	7.49E-04	4.09E-04	2.40E-02	1.90E-02	1.90E-02	3.85E+00	8.94E-01	1.71E+00	4.21E-01	2.81E-21	8.72E-06	2.41E-05	2.72E-04	2.00E-03	4.89E-06
BATCH-203	2/21/21	155	16.1	0.24	7.16E-04	3.91E-04	2.30E-02	1.80E-02	1.80E-02	3.68E+00	8.54E-01	1.63E+00	4.02E-01	2.68E-21	8.33E-06	2.30E-05	2.60E-04	2.00E-03	4.67E-06
BATCH-204	3/9/21	130	13.5	0.24	2.00E-03	2.00E-03	5.70E-02	9.50E-02	5.80E-02	4.58E+00	9.55E-01	4.31E+00	2.96E+00	7.42E-21	5.03E-05	2.31E-04	8.00E-03	1.23E-01	2.96E-06
BATCH-205	3/10/21	129	13.5	0.24	2.00E-03	2.00E-03	6.30E-02	1.07E-01	6.50E-02	4.81E+00	9.91E-01	4.78E+00	3.37E+00	8.23E-21	5.71E-05	2.64E-04	9.00E-03	1.42E-01	2.80E-06
BATCH-206	3/22/21	106	11.1	0.24	2.00E-03	2.00E-03	5.20E-02	8.80E-02	5.30E-02	3.95E+00	8.13E-01	3.91E+00	2.77E+00	6.74E-21	4.68E-05	2.16E-04	7.00E-03	1.16E-01	2.29E-06
BATCH-207	3/24/21	108	11.3	0.24	2.00E-03	2.00E-03	5.30E-02	9.00E-02	5.40E-02	4.03E+00	8.30E-01	4.00E+00	2.83E+00	6.89E-21	4.78E-05	2.21E-04	7.00E-03	1.19E-01	2.34E-06
BATCH-208	4/3/21	118	12.3	0.24	2.00E-03	2.00E-03	5.80E-02	9.80E-02	5.90E-02	4.40E+00	9.07E-01	4.37E+00	3.09E+00	7.52E-21	5.22E-05	2.41E-04	8.00E-03	1.30E-01	2.56E-06
BATCH-209	4/4/21	113	11.8	0.24	2.00E-03	2.00E-03	5.50E-02	9.40E-02	5.70E-02	4.21E+00	8.67E-01	4.18E+00	2.95E+00	7.20E-21	4.99E-05	2.31E-04	8.00E-03	1.24E-01	2.45E-06
BATCH-210	4/15/21	111	11.6	0.24	2.00E-03	2.00E-03	5.40E-02	9.20E-02	5.60E-02	4.14E+00	8.53E-01	4.11E+00	2.90E+00	7.08E-21	4.91E-05	2.27E-04	8.00E-03	1.22E-01	2.41E-06
BATCH-211	4/16/21	100	10.4	0.24	2.00E-03	1.00E-03	4.60E-02	7.00E-02	4.70E-02	3.09E+00	6.14E-01	3.12E+00	2.09E+00	5.45E-21	3.65E-05	1.60E-04	5.00E-03	7.30E-02	4.16E-06
BATCH-212	4/27/21	94	9.8	0.24	5.22E-04	3.77E-04	1.40E-02	1.70E-02	1.40E-02	1.04E+00	2.07E-01	8.98E-01	4.29E-01	1.44E-21	8.01E-06	3.21E-05	5.89E-04	9.00E-03	8.60E-07
BATCH-213	4/27/21	75	7.8	0.24	1.00E-03	7.40E-04	3.00E-02	3.50E-02	3.10E-02	1.41E+00	2.42E-01	1.52E+00	8.11E-01	2.78E-21	1.64E-05	5.62E-05	2.89E-04	2.00E-03	6.03E-06
BATCH-214	5/5/21	82	8.5	0.24	1.00E-03	8.08E-04	3.30E-02	3.80E-02	3.40E-02	1.54E+00	2.65E-01	1.66E+00	8.85E-01	3.04E-21	1.79E-05	6.13E-05	3.15E-04	2.00E-03	6.30E-06
BATCH-215	5/7/21	78	8.2	0.24	1.00E-03	7.74E-04	3.20E-02	3.70E-02	3.20E-02	1.47E+00	2.53E-01	1.59E+00	8.47E-01	2.91E-21	1.71E-05	5.87E-05	3.02E-04	2.00E-03	6.18E-06
BATCH-216	5/14/21	77	8.0	0.24	1.00E-03	7.58E-04	3.10E-02	3.60E-02	3.10E-02	1.44E+00	2.48E-01	1.56E+00	8.30E-01	2.86E-21	1.69E-05	5.78E-05	2.97E-04	2.00E-03	6.20E-06
BATCH-217	5/15/21	77	8.0	0.24	1.00E-03	7.61E-04	3.10E-02	3.60E-02	3.20E-02	1.45E+00	2.49E-01	1.57E+00	8.34E-01	2.86E-21	1.69E-05	5.78E-05	2.94E-04	9.00E-03	9.69E-07
BATCH-218	5/22/21	100	10.4	0.24	5.57E-04	4.02E-04	1.50E-02	1.80E-02	1.50E-02	1.09E+00	2.16E-01	9.55E-01	4.60E-01	1.55E-21	8.62E-06	3.42E-05	5.94E-04	9.00E-03	9.69E-07
BATCH-219	5/23/21	54	5.6	0.24	2.69E-04	1.95E-04	7.00E-03	9.00E-03	7.00E-03	5.36E-01	1.07E-01	4.63E-01	2.21E-01	7.45E-22	4.14E-06	1.66E-05	3.04E-04	4.00E-03	4.44E-07
BATCH-220	5/29/21	74	7.8	0.24	1.00E-03	7.35E-04	3.00E-02	3.50E-02	3.00E-02	1.40E+00	2.40E-01	1.51E+00	8.04E-01	2.76E-21	1.63E-05	5.57E-05	2.82E-04	2.00E-03	6.00E-06
BATCH-221	6/1/21	71	7.4	0.24	1.00E-03	7.03E-04	2.90E-02	3.30E-02	2.90E-02	1.34E+00	2.30E-01	1.45E+00	7.69E-01	2.64E-21	1.56E-05	5.33E-05	2.70E-04	2.00E-03	5.74E-06
BATCH-222	6/6/21	99	10.3	0.24	4.74E-04	3.80E-04	1.30E-02	1.90E-02	1.30E-02	1.20E+00	2.55E-01	9.51E-01	5.65E-01	1.63E-21	9.91E-06	4.28E-05	1.00E-03	2.00E-02	1.32E-06
BATCH-223	6/9/21	98	10.2	0.24	4.16E-04	3.23E-04	1.20E-02	1.60E-02	1.10E-02	1.14E+00	2.47E-01	8.42E-01	4.71E-01	1.44E-21	8.33E-06	3.53E-05	1.00E-03	1.60E-02	1.30E-06
BATCH-224	6/17/21	18	1.9	0.24	6.47E-05	4.68E-05	2.00E-03	2.00E-03	2.00E-03	1.29E-01	2.60E-02	1.11E-01	5.30E-02	1.79E-22	9.94E-07	3.98E-06	7.30E-05	1.00E-03	1.07E-07
BATCH-225	6/19/21	57	6.0	0.24	2.91E-04	2.10E-04	8.00E-03	9.00E-03	8.00E-03	5.71E-01	1.13E-01	4.99E-01	2.40E-01	8.10E-22	4.51E-06	1.79E-05	3.11E-04	5.00E-03	5.07E-07
BATCH-226	6/19/21	98	10.3	0.24	4.85E-04	3.53E-04	1.40E-02	1.60E-02	1.30E-02	1.03E+00	2.09E-01	8.55E-01	4.31E-01	1.43E-21	8.01E-06	3.18E-05	6.31E-04	9.00E-03	1.31E-06
BATCH-227	6/25/21	108	11.3	0.24	5.86E-04	4.23E-04	1.60E-02	1.90E-02	1.60E-02	1.17E+00	2.32E-01	1.01E+00	4.95E-01	1.66E-21	9.29E-06	3.66E-05	6.54E-04	1.00E-02	1.34E-06
BATCH-228	6/30/21	54	5.6	0.24	2.34E-04	1.87E-04	7.00E-03	9.00E-03	6.00E-03	5.90E-01	1.26E-01	4.69E-01	2.79E-01	8.05E-22	4.89E-06	2.11E-05	6.32E-04	1.00E-02	6.49E-07
BATCH-229	7/6/21	56	5.8	0.24	2.14E-04	1.67E-04	6.00E-03	8.00E-03	6.00E-03	5.88E-01	1.27E-01	4.34E-01	2.43E-01	7.42E-22	4.30E-06	1.82E-05	5.32E-04	8.00E-03	6.70E-07
BATCH-230	7/7/21	134	14.0	0.24	2.00E-03	1.00E-03	6.10E-02	7.00E-02	5.80E-02	3.27E+00	4.70E-01	4.50E+00	1.54E+00	6.84E-21	3.45E-05	2.14E-04	8.00E-03	9.00E-03	1.00E-03
BATCH-231	7/12/21	20	2.1	0.24	7.90E-05	5.69E-05	2.00E-03	3.00E-03	2.00E-03	1.55E-01	3.10E-02	1.35E-01	6.50E-02	2.20E-22	1.22E-06	4.84E-06	8.42E-05	1.00E-03	1.37E-07
BATCH-232	7/14/21	57	5.9	0.24	2.55E-04	1.85E-04	7.00E-03	9.00E-03	7.00E-03	5.42E-01	1.10E-01	4.49E-01	2.26E-01	7.50E-22	4.21E-06	1.67E-05	3.31E-04	5.00E-03	6.87E-07
BATCH-233	7/20/21	18	1.9	0.24	5.82E-05	4.66E-05	2.00E-03	2.00E-03	2.00E-03	1.47E-01	3.10E-02	1.17E-01	6.90E-02	2.00E-22	1.22E-06	5.25E-06	1.57E-04	2.00E-03	1.62E-07
BATCH-234	7/21/21	55	5.7	0.24	2.71E-04	1.95E-04	8.00E-03	9.00E-03	7.00E-03	5.39E-01	1.07E-01	4.64E-01	2.29E-01	7.67E-22	4.29E-06	1.69E-05	3.02E-04	4.00E-03	6.20E-07
BATCH-235	7/22/21	19	2.0	0.24	5.51E-05	4.28E-05	2.00E-03	2.00E-03	2.00E-03	1.51E-01	3.30E-02	1.11E-01	6.20E-02	1.91E-22	1.10E-06	4.67E-06	1.37E-04	2.00E-03	1.72E-07
BATCH-236	7/24/21	390	40.7	0.24	8.00E-03	6.00E-03	2.50E-01	2.88E-01	2.05E-01	1.81E+01	1.78E+00	3.36E+01	5.43E+00	4.14E-20	1.59E-04	2.00E-03	1.04E-01	8.80E-02	2.00E-02
BATCH-237	7/27/21	20	2.1	0.24	6.93E-05	5.04E-05	2.50E-03	2.00E-03	2.00E-03	1.47E-01	3.00E-02	1.22E-01	6.20E-02	2.04E-22	1.15E-06	4.54E-06	9.01E-05	1.00E-03	1.87E-07
BATCH-238	7/29/21	341	35.6	0.24	7.00E-03	5.00E-03	2.19E-01	2.52E-01	1.79E-01	1.58E+01	1.56E+00	2.94E+01	4.75E+00	3.62E-20	1.39E-04	2.00E-03	9.10E-02	7.70E-02	1.70E-02
BATCH-239	9/3/21	390	40.6	0.24	8.00E-03	6.00E-03	2.50E-01	2.88E-01	2.05E-01	1.81E+01	1.78E+00	3.36E+01	5.43E+00	4.13E-20	1.59E-04	2.00E-03	1.04E-01	8.80E-02	2.00E-02
BATCH-240	9/3/21	390	40.6	0.24	8.00E-03	6.00E-03	2.50E-01	2.87E-01	2.05E-01	1.81E+01	1.78E+00	3.36E+01	5.42E+00	4.13E-20	1.59E-04	2.00E-03	1.04E-01	8.80E-02	2.00E-02
BATCH-241	10/14/21	19	2.0	0.24	7.10E-05	5.12E-05	2.00E-03	2.00E-03	2.00E-03	1.41E-01	2.80E-02	1.22E-01	6.00E-02	2.01E-22	1.13E-06	4.43E-06	7.93E-05	1.00E-03	1.63E-07
BATCH-242	10/14/21	389	40.6	0.24	8.00E-03	6.00E-03	2.49E-01	2.87E-01	2.05E-01	1.80E+01	1.78E+00	3.35E+01	5.42E+00	4.12E-20	1.59E-04	2.00E-03	1.04E-01	8.80E-02	2.00E-02
BATCH-243	10/16/21	288	30.1	0.24	6.00E-03	5.00E-03	1.85E-01	2.13E-01	1.52E-01	1.34E+01	1.32E+00	2.49E+01	4.03E+00	3.20E-20	1.18E-04	1.00E-03	7.70E-02	6.50E-02	1.50E-02
BATCH-244	11/15/21	101	10.6	0.24	3.00E-03	2.00E-03	9.30E-02	1.52E-01	8.50E-02	5.37E+00	9.00E-01	1.36E+01	3.45E+00	1.61E-19	8.25E-05	8.25E-04	7.00E-03	3.30E-02	5.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses				0.24	6.00E-03	1.69E+02	1.72E-06	2.86E-04	1.59E-06	4.38E-20	3.60E-20	9.08E-01	1.64E-05	2.30E-02	2.46E+01	0.00E+00	6.20E-04	1.43E+01	4.05E-04
BATCH-196	12/30/20	164	17.1		5.00E-03	1.62E+02	1.69E-06	2.85E-04	1.84E-06	7.76E-20	3.30E-20	8.66E-01	1.79E-05	2.40E-02	2.38E+01	0.00E+00	7.08E-04	1.33E+01	4.32E-04
BATCH-197	1/1/21	157	16.4	0.24	4.00E-03	1.75E+02	3.13E-06	6.16E-04	1.10E-05	1.69E-20	7.00E-03	7.69E-01	8.01E-05	9.20E-02	3.30E+01	0.00E+00	6.81E-04	3.48E+00	1.75E-03
BATCH-198	1/16/21	177	18.5	0.24	4.00E-03	1.75E+02	3.13E-06	6.16E-04	1.09E-05	1.90E-20	7.00E-03	7.69E-01	8.00E-05	9.20E-02	3.30E+01	0.00E+00	6.79E-04	3.47E+00	1.75E-03
BATCH-199	1/18/21	177	18.4	0.24	4.00E-03	1.75E+02	3.13E-06	6.16E-04	8.97E-06	3.52E-27	6.00E-03	6.31E-01	6.56E-05	7.60E-02	2.70E+01	0.00E+00	1.82E-10	2.85E+00	1.43E-03
BATCH-200	2/4/21	145	15.1	0.24	2.08E-09	1.44E+02	2.57E-06	5.05E-04	9.16E-06	1.23E-26	6.00E-03	6.44E-01	6.70E-05	7.70E-02	2.76E+01	0.00E+00	2.09E-10	2.92E+00	1.46E-03
BATCH-201	2/6/21	148	15.5	0.24	2.39E-09	1.47E+02	2.62E-06	5.16E-04	1.00E-05	2.04E-23	7.00E-03	7.03E-01	7.31E-05	8.40E-02	3.01E+01	0.00E+00	2.88E-07	3.18E+00	1.59E-03
BATCH-202	2/20/21	162	16.9	0.24	2.68E-06	1.60E+02	2.86E-06	5.63E-04	9.55E-06	3.77E-23	6.00E-03	6.72E-01	6.98E-05	8.10E-02	2.88E+01	0.00E+00	3.44E-07	3.04E+00	1.54E-03
BATCH-203	2/21/21	155	16.1	0.24	2.21E-06	1.53E+02	2.73E-06	5.38E-04	5.05E-06	7.17E-24	1.20E-02	4.88E-01	4.74E-05	4.40E-02	2.46E+01	0.00E+00	2.89E-07	4.07E+00	9.71E-04
BATCH-204	3/9/21	130	13.5	0.24	1.86E-06	1.53E+02	1.45E-06	2.77E-04	4.57E-06	1.02E-23	1.40E-02	4.74E-01	4.55E-05	4.10E-02	2.46E+01	0.00E+00	3.65E-07	4.30E+00	9.17E-04
BATCH-205	3/10/21	129	13.5	0.24	2.35E-06	1.57E+02	1.31E-06	2.49E-04	3.74E-06	2.31E-30	1.10E-02	3.89E-01	3.73E-05	3.30E-02	2.01E+01	0.00E+00	1.19E-13	3.53E+00	7.55E-04
BATCH-206	3/22/21	106	11.1	0.24	1.37E-12	1.29E+02	1.08E-06	2.04E-04	3.83E-06	7.87E-30	1.10E-02	3.97E-01	3.81E-05	3.40E-02	2.06E+01	0.00E+00	1.34E-13	3.61E+00	7.82E-04
BATCH-207	3/24/21	108	11.3	0.24	1.54E-12	1.32E+02	1.10E-06	2.08E-04	4.18E-06	1.20E-26	1.20E-02	4.34E-01	4.16E-05	3.70E-02	2.25E+01	0.00E+00	1.69E-10	3.94E+00	8.36E-04
BATCH-208	4/3/21	118	12.3	0.24	1.57E-09	1.44E+02	1.20E-06	2.27E-04	4.18E-06	1.20E-26	1.20E-02	4.15E-01	3.98E-05	3.50E-02	2.15E+01	0.00E+00	2.11E-10	3.76E+00	8.09E-04
BATCH-209	4/4/21	113	11.8	0.24	1.36E-09	1.37E+02	1.15E-06	2.18E-04	4.00E-06	2.31E-26	1.20E-02	4.08E-01	3.91E-05	3.50E-02	2.11E+01	0.00E+00	1.80E-10	3.70E+00	8.09E-04
BATCH-210	4/15/21	111	11.6	0.24	1.16E-09	1.35E+02	1.13E-06	2.14E-04	3.93E-06	4.46E-27	1.20E-02	3.35E-01	5.93E-05	2.40E-02	1.63E+01	0.00E+00	2.03E-10	3.16E+00	1.32E-03
BATCH-211	4/16/21	100	10.4	0.24	1.31E-09	1.17E+02	1.77E-06	3.48E-04	7.35E-06	5.68E-27	1.20E-02	3.97E-01	1.34E-05	1.20E-02	6.57E+00	0.00E+00	2.83E-01	0.00E+00	2.97E-04
BATCH-212	4/27/21	94	9.8	0.24	2.29E+02	0.00E+00	5.36E-07	1.03E-04	1.70E-06	2.37E-21	1.20E-02	4.68E-01	7.97E-05	7.00E-03	8.38E+00	0.00E+00	1.00E-16	2.14E+00	1.86E-03
BATCH-213	4/27/21	75	7.8	0.24	1.15E-15	8.08E+01	2.42E-06	4.89E-04	1.11E-05	5.89E-33	1.20E-02	2.08E-01	7.97E-05	8.00E-03	9.15E+00	0.00E+00	1.16E-13	2.34E+00	2.02E-03
BATCH-214	5/5/21	82	8.5	0.24	1.08E-12	8.82E+01	2.65E-06	5.34E-04	1.21E-05	8.20E-30	1.30E-02	2.27E-01	8.71E-05	8.00E-03	8.76E+00	0.00E+00	1.51E-13	2.24E+00	1.94E-03
BATCH-215	5/7/21	78	8.2	0.24	9.71E-13	8.45E+01	2.53E-06	5.11E-04	1.16E-05	1.66E-29	1.20E-02	2.17E-01	8.33E-05	8.00E-03	8.58E+00	0.00E+00	1.48E-13	2.19E+00	1.91E-03
BATCH-216	5/14/21	77	8.0	0.24	9.54E-13	8.28E+01	2.48E-06	5.01E-04	1.14E-05	4.14E-30	1.20E-02	2.13E-01	8.17E-05	8.00E-03	8.62E+00	0.00E+00	1.31E-13	2.20E+00	1.91E-03
BATCH-217	5/15/21	77	8.0	0.24	8.41E-13	8.31E+01	2.49E-06	5.03E-04	1.14E-05	3.24E-30	1.20E-02	2.14E-01	8.20E-05	8.00E-03	8.62E+00	0.00E+00	2.90E+01	0.00E+00	3.24E-04
BATCH-218	5/22/21	100	10.4	0.24	2.50E+02	0.00E+00	6.13E-07	1.16E-04	1.87E-06	2.24E-21	1.30E-02	4.77E-01	1.47E-05	1.30E-02	6.80E+00	0.00E+00	1.46E+01	0.00E+00	1.62E-04
BATCH-219	5/23/21	54	5.6	0.24	1.18E+02	0.00E+00	2.77E-07	5.33E-05	8.75E-07	1.22E-21	6.00E-03	2.42E-01	6.92E-06	6.00E-03	3.39E+00	0.00E+00	8.72E-17	2.13E+00	1.83E-03
BATCH-220	5/29/21	74	7.8	0.24	8.10E-16	8.03E+01	2.41E-06	4.86E-04	1.10E-05	6.16E-33	1.10E-02	2.06E-01	7.93E-05	7.00E-03	8.32E+00	0.00E+00	1.19E-16	2.03E+00	1.75E-03
BATCH-221	6/1/21	71	7.4	0.24	7.62E-16	7.68E+01	2.31E-06	4.65E-04	1.06E-05	1.30E-32	1.10E-02	1.97E-01	7.58E-05	7.00E-03	7.96E+00	0.00E+00	1.34E+01	0.00E+00	4.32E-04
BATCH-222	6/6/21	99	10.3	0.24	2.53E+02	0.00E+00	6.58E-07	1.29E-04	2.46E-06	2.00E-21	1.30E-02	3.68E-01	1.96E-05	1.60E-02	7.38E+00	0.00E+00	1.29E+01	0.00E+00	4.32E-04
BATCH-223	6/9/21	98	10.2	0.24	2.57E+02	0.00E+00	6.68E-07	1.31E-04	2.47E-06	1.74E-21	1.40E-02	3.74E-01	1.93E-05	1.70E-02	7.35E+00	0.00E+00	3.51E+00	0.00E+00	2.70E-05
BATCH-224	6/17/21	18	1.9	0.24	2.84E+01	0.00E+00	6.65E-08	1.28E-05	2.10E-07	2.94E-22	1.00E-03	5.80E-02	1.66E-06	2.00E-03	8.14E-01	0.00E+00	1.52E+01	0.00E+00	1.62E-04
BATCH-225	6/19/21	57	6.0	0.24	1.31E+02	0.00E+00	3.20E-07	6.06E-05	9.79E-07	1.17E-21	7.00E-03	2.49E-01	7.70E-06	7.00E-03	3.56E+00	0.00E+00	2.26E+01	0.00E+00	4.32E-04
BATCH-226	6/19/21	98	10.3	0.24	2.51E+02	0.00E+00	6.95E-07	1.35E-04	2.49E-06	2.04E-21	1.20E-02	4.19E-01	1.90E-05	1.30E-02	6.54E+00	0.00E+00	2.35E+01	0.00E+00	4.32E-04
BATCH-227	6/25/21	108	11.3	0.24	2.63E+02	0.00E+00	7.51E-07	1.45E-04	2.56E-06	6.32E-21	1.40E-02	4.53E-01	1.97E-05	1.40E-02	7.31E+00	0.00E+00	6.63E+00	0.00E+00	2.16E-04
BATCH-228	6/30/21	54	5.6	0.24	1.25E+02	0.00E+00	3.25E-07	6.36E-05	1.21E-06	9.85E-22	7.00E-03	1.82E-01	9.64E-06	8.00E-03	3.64E+00	0.00E+00	6.67E+00	0.00E+00	2.16E-04
BATCH-229	7/6/21	56	5.8	0.24	1.32E+02	0.00E+00	3.44E-07	6.75E-05	1.27E-06	8.97E-22	7.00E-03	1.93E-01	9.95E-06	9.00E-03	3.79E+00	0.00E+00	5.17E-04	4.81E+00	1.37E-02
BATCH-230	7/7/21	134	14.0	0.24	4.00E-03	1.55E+02	1.00E-03	5.00E-03	4.15E-04	4.33E-26	1.70E-02	3.96E-01	1.00E-03	1.20E-02	1.69E+01	0.00E+00	4.11E+00	0.00E+00	5.39E-05
BATCH-231	7/12/21	20	2.1	0.24	3.55E+01	0.00E+00	8.68E-08	1.64E-05	2.65E-07	3.17E-22	2.00E-03	6.80E-02	2.09E-06	2.00E-03	9.64E-01	0.00E+00	1.19E+01	0.00E+00	2.16E-04
BATCH-232	7/14/21	57	5.9	0.24	1.32E+02	0.00E+00	3.65E-07	7.08E-05	1.31E-06	1.07E-21	7.00E-03	2.20E-01	9.98E-06	7.00E-03	3.44E+00	0.00E+00	1.19E+01	0.00E+00	5.39E-05
BATCH-233	7/20/21	18	1.9	0.24	3.10E+01	0.00E+00	8.08E-08	1.58E-05	3.02E-07	2.45E-22	2.00E-03	4.50E-02	2.40E-06	2.00E-03	9.06E-01	0.00E+00	1.65E+00	0.00E+00	2.16E-04
BATCH-234	7/21/21	55	5.7	0.24	1.21E+02	0.00E+00	3.47E-07	6.67E-05	1.18E-06	2.92E-21	6.00E-03	2.09E-01	9.10E-06	6.00E-03	3.38E+00	0.00E+00	1.09E+01	0.00E+00	5.39E-05
BATCH-235	7/22/21	19	2.0	0.24	3.40E+01	0.00E+00	8.85E-08	1.73E-05	3.27E-07	2.30E-22	2.00E-03	4.90E-02	2.56E-06	2.00E-03	9.73E-01	0.00E+00	1.71E+00	0.00E+00	5.39E-05
BATCH-236	7/24/21	390	40.7	0.24	6.00E-03	5.61E+02	1.50E-02	6.10E-02	6.00E-03	5.78E-26	1.40E-02	1.43E+00	1.40E-02	1.80E-02	7.16E+01	0.00E+00	7.49E-04	2.53E+01	1.60E-01
BATCH-237	7/27/21	20	2.1	0.24	3.59E+01	0.00E+00	9.92E-08	1.93E-05	3.55E-07	2.92E-22	2.00E-03	6.00E-02	2.72E-06	2.00E-03	9.35E-01	0.00E+00	3.23E+00	0.00E+00	5.39E-05
BATCH-238	7/29/21	341	35.6	0.24	2.19E-06	4.91E+02	1.30E-02	5.30E-02	5.00E-03	2.26E-29	1.20E-02	1.25E+00	1.20E-02	1.60E-02	6.26E+01	0.00E+00	2.70E-07	2.21E+01	1.40E-01
BATCH-239	9/3/21	390	40.6	0.24	5.00E-03	5.61E+02	1.50E-02	6.10E-02	6.00E-03	3.95E-26	1.40E-02	1.43E+00	1.40E-02	1.80E-02	7.15E+01	0.00E+00	2.89E-04	2.53E+01	1.60E-01
BATCH-240	9/3/21	390	40.6	0.24	6.00E-03	5.60E+02	1.50E-02	6.10E-02	6.00E-03	3.89E-26	1.40E-02	1.42E+00	1.40E-02	1.80E-02	7.15E+01	0.00E+00	2.85E+00	0.00E+00	5.39E-05
BATCH-241	10/14/21	19	2.0	0.24	3.18E+01	0.00E+00	9.10E-08	1.75E-05	3.10E-07	7.65E-22	2.00E-03	5.50E-02	2.39E-06	2.00E-03	8.86E-01	0.00E+00	5.91E-04	2.52E+01	1.60E-01
BATCH-242	10/14/21	389	40.6	0.24	7.00E-03	5.60E+02	1.50E-02	6.10E-02	6.00E-03	5.34E-26	1.40E-02	1.42E+00	1.40E-02	1.80E-02	7.14E+01	0.00E+00	1.49E-10	1.87E+01	1.19E-01
BATCH-243	10/16/21	288	30.1	0.24	1.21E-09	4.15E+02	1.10E-02	4.50E-02	4.00E-03	1.25E-32	1.10E-02	1.05E+00	1.00E-02	1.30E-02	5.30E+01	0.00E+00	1.49E-10	1.87E+01	5.52E-02
BATCH-244	11/15/21	101	10.6	0.24	3.45E-06	1.37E+02	1.00E-02	2.40E-02	5.00E-03	3.06E-29	1.50E-02	3.53E-01	3.00E-03	3.00E-03	2.34E+01	0.00E+00	3.99E-07	5.38E+00	5.38E+00

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-196	12/30/20	164	17.1	0.24	3.05E-07	9.67E+01	7.46E-01	0.00E+00	0.00E+00	6.00E-04	9.65E+00	3.23E-06	1.65E-05	6.31E-05	3.86E-01	1.79E-06	2.80E+03	0.00E+00	2.02E+00
BATCH-197	1/1/21	157	16.4	0.24	4.64E-07	9.27E+01	7.56E-01	0.00E+00	0.00E+00	6.00E-04	9.39E+00	3.13E-06	1.89E-05	6.13E-05	3.60E-01	3.19E-06	2.69E+03	0.00E+00	1.98E+00
BATCH-198	1/16/21	177	18.5	0.24	5.34E-06	9.83E+01	1.97E+00	0.00E+00	0.00E+00	1.40E-03	1.39E+01	4.17E-06	1.06E-04	8.88E-05	9.20E-02	4.51E-05	3.02E+03	0.00E+00	3.41E+00
BATCH-199	1/18/21	177	18.4	0.24	5.34E-06	9.83E+01	1.97E+00	0.00E+00	0.00E+00	1.40E-03	1.39E+01	4.17E-06	1.06E-04	8.87E-05	9.20E-02	4.51E-05	3.02E+03	0.00E+00	3.41E+00
BATCH-200	2/4/21	145	15.1	0.24	4.37E-06	8.06E+01	1.61E+00	0.00E+00	0.00E+00	1.00E-03	1.14E+01	3.42E-06	8.70E-05	7.27E-05	7.70E-02	3.77E-05	2.53E+03	0.00E+00	2.85E+00
BATCH-201	2/6/21	148	15.5	0.24	4.47E-06	8.23E+01	1.65E+00	0.00E+00	0.00E+00	1.20E-03	1.17E+01	3.49E-06	8.89E-05	7.43E-05	8.11E-05	8.40E-02	4.12E-05	2.76E+03	0.00E+00	3.11E+00
BATCH-202	2/20/21	162	16.9	0.24	4.87E-06	8.98E+01	1.80E+00	0.00E+00	0.00E+00	1.20E-03	1.27E+01	3.81E-06	9.70E-05	8.11E-05	8.40E-02	4.12E-05	2.76E+03	0.00E+00	2.98E+00
BATCH-203	2/21/21	155	16.1	0.24	4.66E-06	8.58E+01	1.72E+00	0.00E+00	0.00E+00	1.20E-03	1.22E+01	3.64E-06	9.26E-05	7.75E-05	8.00E-02	3.94E-05	2.64E+03	0.00E+00	2.98E+00
BATCH-204	3/9/21	130	13.5	0.24	2.77E-06	9.28E+01	1.13E+00	0.00E+00	0.00E+00	8.00E-04	1.66E+01	8.43E-05	5.64E-05	6.71E-05	1.66E-01	2.27E-05	2.22E+03	0.00E+00	2.21E+00
BATCH-205	3/10/21	129	13.5	0.24	2.58E-06	9.60E+01	1.07E+00	0.00E+00	0.00E+00	8.00E-04	1.76E+01	9.71E-05	5.28E-05	6.72E-05	1.82E-01	2.10E-05	2.21E+03	0.00E+00	2.16E+00
BATCH-206	3/22/21	106	11.1	0.24	2.12E-06	7.86E+01	8.79E-01	0.00E+00	0.00E+00	6.00E-04	1.45E+01	7.96E-05	4.33E-05	5.51E-05	1.49E-01	1.72E-05	1.81E+03	0.00E+00	1.77E+00
BATCH-207	3/24/21	108	11.3	0.24	2.16E-06	8.04E+01	8.98E-01	0.00E+00	0.00E+00	6.00E-04	1.48E+01	8.13E-05	4.42E-05	5.63E-05	1.52E-01	1.76E-05	1.85E+03	0.00E+00	1.81E+00
BATCH-208	4/3/21	118	12.3	0.24	2.36E-06	8.77E+01	9.80E-01	0.00E+00	0.00E+00	6.00E-04	1.61E+01	8.88E-05	4.83E-05	6.15E-05	1.66E-01	1.92E-05	2.02E+03	0.00E+00	1.98E+00
BATCH-209	4/4/21	113	11.8	0.24	2.26E-06	8.39E+01	9.37E-01	0.00E+00	0.00E+00	6.00E-04	1.54E+01	8.49E-05	4.62E-05	5.88E-05	1.59E-01	1.83E-05	1.93E+03	0.00E+00	1.89E+00
BATCH-210	4/15/21	111	11.6	0.24	2.22E-06	8.25E+01	9.22E-01	0.00E+00	0.00E+00	6.00E-04	1.52E+01	8.35E-05	4.54E-05	5.78E-05	1.56E-01	1.80E-05	1.90E+03	0.00E+00	1.86E+00
BATCH-211	4/16/21	100	10.4	0.24	4.05E-06	7.19E+01	9.56E-01	0.00E+00	0.00E+00	4.00E-04	1.31E+01	5.15E-05	7.84E-05	6.13E-05	1.30E-01	3.37E-05	1.71E+03	0.00E+00	2.29E+00
BATCH-212	4/27/21	94	9.8	0.24	8.29E-07	2.38E+01	6.08E-01	0.00E+00	0.00E+00	2.00E-04	3.20E+00	6.31E-06	1.71E-05	1.79E-05	5.50E-02	6.91E-06	1.61E+03	0.00E+00	6.29E-01
BATCH-213	4/27/21	75	7.8	0.24	6.03E-06	5.09E+01	9.07E-01	0.00E+00	0.00E+00	1.06E-04	9.16E+00	4.65E-06	1.14E-04	5.98E-05	8.20E-02	5.09E-05	1.28E+03	0.00E+00	2.62E+00
BATCH-214	5/5/21	82	8.5	0.24	6.59E-06	5.56E+01	9.90E-01	0.00E+00	0.00E+00	1.16E-04	1.00E+01	5.08E-06	1.24E-04	6.53E-05	8.90E-02	5.56E-05	1.40E+03	0.00E+00	2.86E+00
BATCH-215	5/7/21	78	8.2	0.24	6.30E-06	5.32E+01	9.48E-01	0.00E+00	0.00E+00	1.11E-04	9.58E+00	4.86E-06	1.19E-04	6.25E-05	8.60E-02	5.32E-05	1.34E+03	0.00E+00	2.74E+00
BATCH-216	5/14/21	77	8.0	0.24	6.18E-06	5.22E+01	9.29E-01	0.00E+00	0.00E+00	1.09E-04	9.39E+00	4.74E-06	1.17E-04	6.13E-05	8.40E-02	5.22E-05	1.31E+03	0.00E+00	2.69E+00
BATCH-217	5/15/21	77	8.0	0.24	6.20E-06	5.24E+01	9.33E-01	0.00E+00	0.00E+00	1.09E-04	9.43E+00	4.78E-06	1.17E-04	6.15E-05	8.40E-02	5.24E-05	1.31E+03	0.00E+00	2.70E+00
BATCH-218	5/22/21	100	10.4	0.24	9.21E-07	2.49E+01	6.88E-01	0.00E+00	0.00E+00	2.00E-04	3.49E+00	6.36E-06	1.90E-05	1.99E-05	5.70E-02	7.66E-06	1.70E+03	0.00E+00	7.21E-01
BATCH-219	5/23/21	54	5.6	0.24	4.28E-07	1.23E+01	3.14E-01	0.00E+00	0.00E+00	1.07E-04	1.65E+00	3.26E-06	8.80E-06	9.21E-06	2.80E-02	3.57E-06	9.24E+02	0.00E+00	3.25E-01
BATCH-220	5/29/21	74	7.8	0.24	6.00E-06	5.06E+01	9.01E-01	0.00E+00	0.00E+00	1.05E-04	9.11E+00	4.57E-06	1.13E-04	5.95E-05	8.10E-02	5.06E-05	1.27E+03	0.00E+00	2.61E+00
BATCH-221	6/1/21	71	7.4	0.24	5.74E-06	4.84E+01	8.62E-01	0.00E+00	0.00E+00	1.01E-04	8.71E+00	4.37E-06	1.08E-04	5.69E-05	7.80E-02	4.84E-05	1.22E+03	0.00E+00	2.49E+00
BATCH-222	6/6/21	99	10.3	0.24	1.29E-06	2.67E+01	7.60E-01	0.00E+00	0.00E+00	2.00E-04	4.47E+00	1.42E-05	2.54E-05	2.23E-05	4.00E-02	1.07E-05	1.69E+03	0.00E+00	8.17E-01
BATCH-223	6/9/21	98	10.2	0.24	1.27E-06	2.57E+01	7.67E-01	0.00E+00	0.00E+00	2.00E-04	4.19E+00	1.15E-05	2.52E-05	2.18E-05	3.60E-02	1.07E-05	1.67E+03	0.00E+00	8.07E-01
BATCH-224	6/17/21	18	1.9	0.24	1.03E-07	2.95E+00	7.50E-02	0.00E+00	0.00E+00	2.57E-05	3.97E-01	7.82E-07	2.12E-06	2.21E-06	7.00E-03	8.57E-07	3.09E+02	0.00E+00	7.80E-02
BATCH-225	6/19/21	57	6.0	0.24	4.82E-07	1.30E+01	3.60E-01	0.00E+00	0.00E+00	1.09E-04	1.83E+00	3.33E-06	9.95E-06	1.04E-05	3.00E-02	4.01E-06	9.75E+02	0.00E+00	3.77E-01
BATCH-226	6/19/21	98	10.3	0.24	1.28E-06	2.46E+01	7.35E-01	0.00E+00	0.00E+00	2.00E-04	3.75E+00	6.98E-06	2.53E-05	2.13E-05	4.60E-02	1.07E-05	1.68E+03	0.00E+00	8.07E-01
BATCH-227	6/25/21	108	11.3	0.24	1.30E-06	2.76E+01	7.70E-01	0.00E+00	0.00E+00	2.00E-04	4.06E+00	7.15E-06	2.61E-05	2.33E-05	5.70E-02	1.09E-05	1.85E+03	0.00E+00	8.73E-01
BATCH-228	6/30/21	54	5.6	0.24	6.33E-07	1.32E+01	3.74E-01	0.00E+00	0.00E+00	1.25E-04	2.20E+00	6.99E-06	1.25E-05	1.10E-05	2.00E-02	5.29E-06	9.24E+02	0.00E+00	4.03E-01
BATCH-229	7/6/21	56	5.8	0.24	6.57E-07	1.33E+01	3.96E-01	0.00E+00	0.00E+00	1.34E-04	2.16E+00	5.91E-06	1.30E-05	1.12E-05	1.90E-02	5.50E-06	9.51E+02	0.00E+00	4.16E-01
BATCH-230	7/7/21	134	14.0	0.24	1.11E-05	7.97E+01	1.33E+00	0.00E+00	0.00E+00	4.00E-04	1.72E+01	3.27E-04	5.44E-04	1.40E-02	1.77E-01	2.49E-04	2.29E+03	0.00E+00	3.79E+00
BATCH-231	7/12/21	20	2.1	0.24	1.31E-07	3.53E+00	9.80E-02	0.00E+00	0.00E+00	2.96E-05	4.95E-01	9.02E-07	2.70E-06	2.82E-06	8.00E-03	1.09E-06	3.44E+02	0.00E+00	1.02E-01
BATCH-232	7/14/21	57	5.9	0.24	6.70E-07	1.29E+01	3.86E-01	0.00E+00	0.00E+00	1.08E-04	1.97E+00	3.66E-06	1.33E-05	1.12E-05	2.40E-02	5.61E-06	9.67E+02	0.00E+00	4.24E-01
BATCH-233	7/20/21	18	1.9	0.24	1.58E-07	3.28E+00	9.30E-02	0.00E+00	0.00E+00	3.10E-05	5.48E-01	1.74E-06	3.11E-06	2.73E-06	5.00E-03	1.32E-06	3.15E+02	0.00E+00	1.00E-01
BATCH-234	7/21/21	55	5.7	0.24	6.00E-07	1.28E+01	3.55E-01	0.00E+00	0.00E+00	1.03E-04	1.88E+00	3.30E-06	1.20E-05	1.08E-05	2.60E-02	5.01E-06	9.39E+02	0.00E+00	4.03E-01
BATCH-235	7/22/21	19	2.0	0.24	1.69E-07	3.41E+00	1.02E-01	0.00E+00	0.00E+00	3.45E-05	5.54E-01	1.52E-06	3.33E-06	2.89E-06	5.00E-03	1.41E-06	3.27E+02	0.00E+00	1.07E-01
BATCH-236	7/24/21	390	40.7	0.24	3.59E-05	9.76E+01	3.99E-01	0.00E+00	0.00E+00	2.80E-03	5.82E+01	5.00E-03	6.00E-03	1.98E-01	8.70E-01	3.00E-03	6.67E+03	0.00E+00	3.87E-01
BATCH-237	7/27/21	20	2.1	0.24	1.82E-07	3.52E+00	1.05E-01	0.00E+00	0.00E+00	2.94E-05	5.35E-01	9.97E-07	3.62E-06	3.04E-06	7.00E-03	1.53E-06	3.42E+02	0.00E+00	1.15E-01
BATCH-238	7/29/21	341	35.6	0.24	3.14E-05	8.54E+01	3.50E-01	0.00E+00	0.00E+00	2.40E-03	5.09E+01	4.00E-03	5.00E-03	1.73E-01	7.61E-01	2.00E-03	5.83E+03	0.00E+00	3.40E-01
BATCH-239	9/3/21	390	40.6	0.24	3.58E-05	9.75E+01	3.99E-01	0.00E+00	0.00E+00	2.80E-03	5.82E+01	5.00E-03	6.00E-03	1.98E-01	8.69E-01	3.00E-03	6.66E+03	0.00E+00	3.86E-01
BATCH-240	9/3/21	390	40.6	0.24	3.58E-05	9.74E+01	3.99E-01	0.00E+00	0.00E+00	2.80E-03	5.81E+01	5.00E-03	6.00E-03	1.98E-01	8.69E-01	3.00E-03	6.66E+03	0.00E+00	3.86E-01
BATCH-241	10/14/21	19	2.0	0.24	1.57E-07	3.35E+00	9.30E-02	0.00E+00	0.00E+00	2.70E-05	4.92E-01	8.66E-07	3.16E-06	2.83E-06	7.00E-03	1.32E-06	3.28E+02	0.00E+00	1.06E-01
BATCH-242	10/14/21	389	40.6	0.24	3.58E-05	9.73E+01	3.99E-01	0.00E+00	0.00E+00	2.80E-03	5.80E+01	5.00E-03	6.00E-03	1.98E-01	8.67E-01	3.00E-03	6.65E+03	0.00E+00	3.85E-01
BATCH-243	10/16/21	288	30.1	0.24	2.68E-05	7.20E+01	2.96E-01	0.00E+00	0.00E+00	2.00E-03	4.31E+01	3.00E-03	4.00E-03	1.49E-01	6.43E-01	2.00E-03	4.93E+03	0.00E+00	2.86E-01
BATCH-244	11/15/21	101	10.6	0.24	4.05E-05	1.34E+01	1.10E-01	0.00E+00	0.00E+00	8.00E-04	2.30E+01	2.00E-03	3.00E-03	2.68E-01	2.51E-01	8.66E-04	1.73E+03	0.00E+00	1.58E-01

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Tc+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-196	12/30/20	164	17.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	1.08E+02	1.88E-07	1.50E+01	7.31E+01	2.60E-02	2.40E-07	0.00E+00	1.48E-01	4.00E-03	3.70E-02
BATCH-197	1/1/21	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.02E+02	1.83E-07	1.46E+01	6.98E+01	2.60E-02	3.84E-07	0.00E+00	1.37E-01	3.00E-03	3.70E-02
BATCH-198	1/16/21	177	18.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	6.70E+01	2.72E-07	2.40E+01	6.54E+01	5.60E-02	4.79E-06	0.00E+00	3.00E-03	8.38E-04	8.60E-02
BATCH-199	1/16/21	177	18.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	6.70E+01	2.72E-07	2.40E+01	6.53E+01	5.60E-02	4.79E-06	0.00E+00	3.00E-03	8.37E-04	8.60E-02
BATCH-200	2/4/21	145	15.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.49E+01	2.23E-07	1.97E+01	5.36E+01	4.60E-02	3.92E-06	0.00E+00	3.00E-03	6.88E-04	7.00E-02
BATCH-201	2/6/21	148	15.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.61E+01	2.28E-07	2.01E+01	5.47E+01	4.70E-02	4.01E-06	0.00E+00	3.00E-03	7.03E-04	7.20E-02
BATCH-202	2/20/21	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.12E+01	2.49E-07	2.20E+01	5.97E+01	5.10E-02	4.38E-06	0.00E+00	3.00E-03	7.66E-04	7.80E-02
BATCH-203	2/21/21	155	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.85E+01	2.38E-07	2.10E+01	5.71E+01	4.90E-02	4.18E-06	0.00E+00	3.00E-03	7.32E-04	7.50E-02
BATCH-204	3/9/21	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.74E+01	9.76E-08	1.59E+01	4.77E+01	4.00E-02	2.33E-06	0.00E+00	2.00E-03	4.02E-04	4.06E-01
BATCH-205	3/10/21	129	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.55E+01	8.11E-08	1.56E+01	4.76E+01	3.90E-02	2.13E-06	0.00E+00	2.00E-03	3.67E-04	4.60E-01
BATCH-206	3/22/21	106	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.91E+01	6.65E-08	1.28E+01	3.90E+01	3.20E-02	1.75E-06	0.00E+00	2.00E-03	3.01E-04	3.77E-01
BATCH-207	3/24/21	108	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.97E+01	6.79E-08	1.31E+01	3.99E+01	3.30E-02	1.79E-06	0.00E+00	2.00E-03	3.07E-04	3.85E-01
BATCH-208	4/3/21	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.25E+01	7.41E-08	1.43E+01	4.35E+01	3.60E-02	1.95E-06	0.00E+00	2.00E-03	3.36E-04	4.21E-01
BATCH-209	4/4/21	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.10E+01	7.09E-08	1.36E+01	4.16E+01	3.40E-02	1.87E-06	0.00E+00	2.00E-03	3.21E-04	4.02E-01
BATCH-210	4/15/21	111	11.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	3.05E+01	6.97E-08	1.34E+01	4.09E+01	3.40E-02	1.83E-06	0.00E+00	2.00E-03	3.16E-04	3.96E-01
BATCH-211	4/16/21	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	2.57E+01	1.11E-07	1.48E+01	4.24E+01	3.60E-02	3.48E-06	0.00E+00	3.00E-03	4.70E-04	2.43E-01
BATCH-212	4/27/21	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.31E+01	4.62E-08	6.70E+01	1.65E+01	9.00E-03	7.31E-07	0.00E+00	1.50E-02	4.29E-04	3.70E-02
BATCH-213	4/27/21	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.69E+01	1.55E-07	1.50E+01	4.00E+01	3.60E-02	5.28E-06	0.00E+00	6.00E-03	6.25E-04	2.00E-02
BATCH-214	5/5/21	82	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.85E+01	1.69E-07	1.64E+01	4.37E+01	3.90E-02	5.77E-06	0.00E+00	6.00E-03	6.82E-04	2.20E-02
BATCH-215	5/7/21	78	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.77E+01	1.62E-07	1.57E+01	4.18E+01	3.70E-02	5.52E-06	0.00E+00	6.00E-03	6.53E-04	2.10E-02
BATCH-216	5/14/21	77	8.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.73E+01	1.59E-07	1.54E+01	4.10E+01	3.60E-02	5.41E-06	0.00E+00	6.00E-03	6.40E-04	2.00E-02
BATCH-217	5/15/21	77	8.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.74E+01	1.59E-07	1.55E+01	4.12E+01	3.70E-02	5.43E-06	0.00E+00	6.00E-03	6.42E-04	2.00E-02
BATCH-218	5/22/21	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.68E+01	5.21E-08	7.22E+01	1.79E+01	1.10E-02	8.07E-07	0.00E+00	1.60E-02	4.37E-04	3.80E-02
BATCH-219	5/23/21	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.71E+01	2.39E-08	3.46E+01	8.53E+00	5.00E-03	3.77E-07	0.00E+00	8.00E-03	2.21E-04	1.90E-02
BATCH-220	5/29/21	74	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.68E+01	1.54E-07	1.50E+01	3.98E+01	3.50E-02	5.25E-06	0.00E+00	5.00E-03	5.94E-04	1.90E-02
BATCH-221	6/1/21	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.61E+01	1.47E-07	1.43E+01	3.81E+01	3.40E-02	5.02E-06	0.00E+00	5.00E-03	5.94E-04	1.90E-02
BATCH-222	6/6/21	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.32E+01	4.93E-08	7.13E+01	1.75E+01	1.30E-02	1.12E-06	0.00E+00	2.00E-03	1.77E-04	7.40E-02
BATCH-223	6/9/21	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.29E+01	5.16E-08	6.96E+01	1.71E+01	1.30E-02	1.12E-06	0.00E+00	2.00E-03	1.79E-04	6.30E-02
BATCH-224	6/17/21	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.89E-04	4.11E+00	5.73E-09	8.30E+00	2.05E+00	1.00E-03	9.06E-08	0.00E+00	2.00E-03	5.32E-05	5.00E-03
BATCH-225	6/19/21	57	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.92E+01	2.72E-08	3.77E+01	9.36E+00	6.00E-03	4.22E-07	0.00E+00	9.00E-03	2.28E-04	2.00E-02
BATCH-226	6/19/21	98	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.65E+01	5.45E-08	7.20E+01	1.79E+01	1.20E-02	1.12E-06	0.00E+00	1.00E-02	3.25E-04	4.00E-02
BATCH-227	6/25/21	108	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.03E+01	6.04E-08	7.97E+01	2.02E+01	1.30E-02	1.14E-06	0.00E+00	1.40E-02	4.28E-04	4.10E-02
BATCH-228	6/30/21	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.84E-04	1.64E+01	2.43E-08	3.52E+01	8.61E+00	7.00E-03	5.52E-07	0.00E+00	8.53E-04	8.72E-05	3.60E-02
BATCH-229	7/6/21	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.22E-04	1.70E+01	2.66E-08	3.59E+01	8.84E+00	7.00E-03	5.75E-07	0.00E+00	8.26E-04	9.24E-05	3.20E-02
BATCH-230	7/7/21	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.19E+01	5.02E-06	2.27E+01	6.45E+01	5.10E-02	9.45E-06	0.00E+00	1.70E-02	5.00E-02	3.90E-02
BATCH-231	7/12/21	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.84E-04	5.22E+00	7.38E-09	1.02E+01	2.54E+00	2.00E-03	1.14E-07	0.00E+00	2.00E-03	6.19E-05	5.00E-03
BATCH-232	7/14/21	57	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.22E-04	1.92E+01	2.86E-08	3.78E+01	9.41E+00	7.00E-03	5.87E-07	0.00E+00	5.00E-03	1.71E-04	2.10E-02
BATCH-233	7/20/21	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-04	4.08E+00	6.05E-09	8.75E+00	2.14E+00	2.00E-03	1.37E-07	0.00E+00	2.12E-04	2.17E-05	9.00E-03
BATCH-234	7/21/21	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.70E-04	1.86E+01	2.79E-08	3.68E+01	9.33E+00	6.00E-03	5.26E-07	0.00E+00	6.00E-03	1.98E-04	1.90E-02
BATCH-235	7/22/21	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-04	4.36E+00	6.83E-09	9.22E+00	2.27E+00	2.00E-03	1.48E-07	0.00E+00	2.12E-04	2.37E-05	8.00E-03
BATCH-236	7/24/21	390	40.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	1.11E+02	6.95E-05	1.62E+01	1.04E+02	6.00E-03	2.72E-05	0.00E+00	1.39E-01	7.09E-01	1.54E-01
BATCH-237	7/27/21	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.51E-04	5.22E+00	7.79E-09	1.03E+01	2.56E+00	2.00E-03	1.60E-07	0.00E+00	1.00E-03	4.66E-05	6.00E-03
BATCH-238	7/29/21	341	35.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-02	9.72E+01	6.07E-05	1.42E+01	9.07E+01	5.00E-03	2.37E-05	0.00E+00	1.21E-01	6.20E-01	1.35E-01
BATCH-239	9/3/21	390	40.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	1.11E+02	6.94E-05	1.62E+01	1.04E+02	6.00E-03	2.71E-05	0.00E+00	1.38E-01	7.08E-01	1.54E-01
BATCH-240	9/3/21	390	40.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	1.11E+02	6.93E-05	1.62E+01	1.03E+02	6.00E-03	2.71E-05	0.00E+00	1.38E-01	7.08E-01	1.54E-01
BATCH-241	10/14/21	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-04	4.88E+00	7.32E-09	9.66E+00	2.45E+00	2.00E-03	1.38E-07	0.00E+00	2.00E-03	5.19E-05	5.00E-03
BATCH-242	10/14/21	389	40.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	1.11E+02	6.93E-05	1.61E+01	1.03E+02	6.00E-03	2.71E-05	0.00E+00	1.38E-01	7.07E-01	1.53E-01
BATCH-243	10/16/21	288	30.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.90E-02	8.20E+01	5.15E-05	1.20E+01	7.67E+01	5.00E-03	2.01E-05	0.00E+00	1.02E-01	5.23E-01	1.14E-01
BATCH-244	11/15/21	101	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	1.17E+01	3.80E-05	8.24E+00	3.80E+01	1.70E-02	8.44E-06	0.00E+00	3.00E-02	9.90E-02	5.20E-02

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-245	11/24/21	101	10.6	0.24	0.00E+00	0.00E+00	2.25E-01	1.29E-01	1.80E+01	7.50E-01	2.03E+03	1.78E+00	3.45E-01	1.01E+01	2.64E-08	2.56E+00	2.30E-02	6.89E-01	1.50E-02
BATCH-246	11/26/21	101	10.6	0.24	0.00E+00	0.00E+00	2.24E-01	1.28E-01	1.80E+01	7.49E-01	2.03E+03	1.78E+00	3.44E-01	1.01E+01	2.64E-08	2.56E+00	2.30E-02	6.89E-01	1.50E-02
BATCH-247	12/5/21	112	11.7	0.24	0.00E+00	0.00E+00	2.49E-01	1.42E-01	2.00E+01	8.31E-01	2.25E+03	1.98E+00	3.82E-01	1.12E+01	2.89E-08	2.84E+00	2.60E-02	7.64E-01	1.65E-02
BATCH-248	12/7/21	76	7.9	0.24	0.00E+00	0.00E+00	1.68E-01	9.60E-02	1.35E+01	5.61E-01	1.52E+03	1.33E+00	2.58E-01	7.56E+00	1.98E-08	1.92E+00	1.70E-02	5.15E-01	1.13E-02
BATCH-249	12/15/21	101	10.5	0.24	0.00E+00	0.00E+00	2.24E-01	1.28E-01	1.79E+01	7.46E-01	2.02E+03	1.78E+00	3.43E-01	1.01E+01	2.63E-08	2.55E+00	2.30E-02	6.86E-01	1.50E-02
BATCH-250	12/16/21	138	14.4	0.24	0.00E+00	0.00E+00	1.12E-01	5.50E-02	8.94E+00	4.31E-01	2.76E+03	9.55E-01	1.53E-01	1.38E+01	6.35E-09	1.97E+00	1.00E-02	2.52E-01	1.30E-02
BATCH-251	12/26/21	154	16.1	0.24	0.00E+00	0.00E+00	7.70E-02	3.30E-02	6.19E+00	3.38E-01	3.08E+03	7.08E-01	9.50E-02	1.53E+01	1.51E-11	1.83E+00	6.00E-03	1.14E-01	1.25E-02
BATCH-252	12/31/21	154	16.1	0.24	0.00E+00	0.00E+00	7.70E-02	3.30E-02	6.19E+00	3.38E-01	3.08E+03	7.08E-01	9.50E-02	1.53E+01	1.51E-11	1.83E+00	6.00E-03	1.14E-01	1.25E-02
BATCH-253	1/11/22	115	12.0	0.24	0.00E+00	0.00E+00	5.80E-02	2.10E-02	4.61E+00	2.54E-01	2.31E+03	5.31E-01	6.70E-02	1.15E+01	7.39E-12	1.31E+00	4.00E-03	8.60E-02	9.50E-03
BATCH-254	1/16/22	171	17.8	0.24	0.00E+00	0.00E+00	8.60E-02	3.20E-02	6.82E+00	3.75E-01	3.42E+03	7.85E-01	1.00E-01	1.70E+01	7.60E-12	1.94E+00	5.00E-03	1.27E-01	1.40E-02
BATCH-255	1/23/22	154	16.0	0.24	0.00E+00	0.00E+00	7.70E-02	2.90E-02	6.13E+00	3.38E-01	3.07E+03	7.06E-01	9.00E-02	1.53E+01	7.57E-12	1.74E+00	5.00E-03	1.14E-01	1.25E-02
BATCH-256	2/3/22	134	14.0	0.24	0.00E+00	0.00E+00	6.70E-02	2.50E-02	5.35E+00	2.94E-01	2.68E+03	6.16E-01	7.80E-02	1.34E+01	2.60E-12	1.52E+00	4.00E-03	9.90E-02	1.10E-02
BATCH-257	2/9/22	94	9.8	0.24	0.00E+00	0.00E+00	1.74E-01	8.90E-02	1.38E+01	3.78E-01	1.87E+03	1.02E+00	1.98E-01	9.32E+00	3.26E-10	2.17E+00	1.10E-02	4.09E-01	2.03E-02
BATCH-258	2/18/22	91	9.5	0.24	0.00E+00	0.00E+00	1.85E-01	9.60E-02	1.47E+01	3.89E-01	1.82E+03	1.06E+00	2.10E-01	9.07E+00	3.57E-10	2.25E+00	1.20E-02	4.40E-01	2.13E-02
BATCH-259	2/19/22	115	12.0	0.24	0.00E+00	0.00E+00	8.10E-02	3.80E-02	6.42E+00	3.19E-01	2.30E+03	6.73E-01	1.20E-01	1.15E+01	3.69E-08	9.24E-01	7.00E-03	2.32E-01	7.75E-03
BATCH-260	2/27/22	101	10.5	0.24	0.00E+00	0.00E+00	2.06E-01	1.06E-01	1.63E+01	4.32E-01	2.02E+03	1.18E+00	2.34E-01	1.01E+01	3.96E-10	2.50E+00	1.40E-02	4.88E-01	2.38E-02
BATCH-261	3/3/22	91	9.5	0.24	0.00E+00	0.00E+00	1.85E-01	9.50E-02	1.47E+01	3.89E-01	1.82E+03	1.06E+00	2.10E-01	9.06E+00	3.57E-10	2.25E+00	1.20E-02	4.39E-01	2.13E-02
BATCH-262	3/10/22	80	8.3	0.24	0.00E+00	0.00E+00	1.62E-01	8.40E-02	1.28E+01	3.39E-01	1.59E+03	9.29E-01	1.84E-01	7.93E+00	3.12E-10	1.96E+00	1.10E-02	3.84E-01	1.85E-02
BATCH-263	3/13/22	78	8.1	0.24	0.00E+00	0.00E+00	1.58E-01	8.20E-02	1.26E+01	3.32E-01	1.55E+03	9.07E-01	1.80E-01	7.74E+00	3.05E-10	1.92E+00	1.00E-02	3.75E-01	1.83E-02
BATCH-264	3/19/22	78	8.2	0.24	0.00E+00	0.00E+00	1.59E-01	8.20E-02	1.26E+01	3.34E-01	1.56E+03	9.13E-01	1.81E-01	7.79E+00	3.07E-10	1.93E+00	1.10E-02	3.78E-01	1.83E-02
BATCH-265	3/21/22	64	6.7	0.24	0.00E+00	0.00E+00	4.10E-02	1.90E-02	3.28E+00	1.63E-01	1.27E+03	3.45E-01	6.10E-02	6.37E+00	1.89E-08	4.73E-01	3.00E-03	1.19E-01	4.00E-03
BATCH-266	3/27/22	87	9.0	0.24	0.00E+00	0.00E+00	1.76E-01	9.10E-02	1.40E+01	3.70E-01	1.73E+03	1.01E+00	2.00E-01	8.64E+00	3.40E-10	2.14E+00	1.20E-02	4.19E-01	2.03E-02
BATCH-267	3/28/22	100	10.5	0.24	0.00E+00	0.00E+00	1.57E-01	1.59E-01	1.25E+01	3.68E-01	2.01E+03	1.21E+00	2.16E-01	1.00E+01	4.13E-10	1.93E+00	1.30E-02	4.04E-01	2.15E-02
BATCH-268	4/5/22	116	12.1	0.24	0.00E+00	0.00E+00	6.20E-02	3.00E-02	4.95E+00	2.27E-01	2.26E+03	4.97E-01	8.80E-02	9.74E+00	1.83E-08	7.82E-01	5.00E-03	1.71E-01	6.50E-03
BATCH-269	4/8/22	126	13.1	0.24	0.00E+00	0.00E+00	6.90E-02	3.40E-02	5.45E+00	2.31E-01	2.49E+03	5.18E-01	9.40E-02	9.87E+00	1.83E-08	8.51E-01	5.00E-03	1.84E-01	7.50E-03
BATCH-270	4/17/22	124	12.9	0.24	0.00E+00	0.00E+00	7.00E-02	3.40E-02	5.52E+00	2.30E-01	2.48E+03	5.18E-01	9.40E-02	9.76E+00	1.81E-08	8.49E-01	5.00E-03	1.87E-01	7.50E-03
BATCH-271	4/21/22	22	2.3	0.24	0.00E+00	0.00E+00	1.10E-02	5.00E-03	8.98E-01	4.50E-02	3.47E+02	9.40E-02	1.70E-02	1.93E+00	5.16E-09	1.29E-01	9.27E-04	3.20E-02	1.00E-03
BATCH-272	4/23/22	107	11.2	0.24	0.00E+00	0.00E+00	4.80E-02	2.30E-02	3.78E+00	1.26E-01	1.93E+03	3.15E-01	5.60E-02	5.25E+00	4.50E-10	6.51E-01	3.00E-03	1.11E-01	5.50E-03
BATCH-273	5/1/22	116	12.1	0.24	0.00E+00	0.00E+00	6.70E-02	3.80E-02	5.29E+00	2.23E-01	2.31E+03	5.18E-01	9.30E-02	9.67E+00	1.76E-08	8.15E-01	5.00E-03	1.81E-01	7.50E-03
BATCH-274	5/5/22	65	6.8	0.24	0.00E+00	0.00E+00	3.30E-02	1.60E-02	2.58E+00	1.18E-01	1.18E+03	2.59E-01	4.60E-02	5.07E+00	9.54E-09	4.08E-01	3.00E-03	8.90E-02	3.50E-03
BATCH-275	5/12/22	68	7.1	0.24	0.00E+00	0.00E+00	3.40E-02	1.70E-02	2.72E+00	1.15E-01	1.24E+03	2.58E-01	4.70E-02	4.92E+00	9.13E-09	4.24E-01	3.00E-03	9.20E-02	3.75E-03
BATCH-276	5/13/22	163	17.0	0.24	0.00E+00	0.00E+00	2.50E-01	2.63E-01	1.99E+01	5.90E-01	3.25E+03	1.96E+00	3.49E-01	1.62E+01	6.71E-10	3.07E+00	2.20E-02	6.46E-01	3.48E-02
BATCH-277	5/19/22	68	7.1	0.24	0.00E+00	0.00E+00	3.50E-02	1.70E-02	2.80E+00	1.16E-01	1.27E+03	2.63E-01	4.80E-02	4.96E+00	9.21E-09	4.31E-01	3.00E-03	9.50E-02	3.75E-03
BATCH-278	5/26/22	55	5.7	0.24	0.00E+00	0.00E+00	2.20E-02	1.10E-02	1.74E+00	5.85E-02	8.89E+02	1.45E-01	2.60E-02	2.42E+00	2.08E-10	3.00E-01	1.00E-03	5.10E-02	2.50E-03
BATCH-279	5/30/22	23	2.4	0.24	0.00E+00	0.00E+00	9.00E-03	4.00E-03	7.32E-01	3.33E-02	3.34E+02	7.30E-02	1.30E-02	1.44E+00	2.70E-09	1.16E-01	7.26E-04	2.50E-02	1.00E-03
BATCH-280	6/1/22	67	7.0	0.24	0.00E+00	0.00E+00	3.60E-02	2.00E-02	2.85E+00	1.21E-01	1.26E+03	2.79E-01	5.00E-02	5.21E+00	9.48E-09	4.39E-01	3.00E-03	9.80E-02	4.00E-03
BATCH-281	6/2/22	24	2.5	0.24	0.00E+00	0.00E+00	1.00E-02	5.00E-03	7.71E-01	3.24E-02	3.52E+02	7.30E-02	1.30E-02	1.40E+00	2.59E-09	1.20E-01	7.45E-04	2.60E-02	1.00E-03
BATCH-282	6/4/22	24	2.5	0.24	0.00E+00	0.00E+00	1.00E-02	5.00E-03	7.95E-01	3.33E-02	3.60E+02	7.50E-02	1.40E-02	1.41E+00	2.61E-09	1.22E-01	7.66E-04	2.70E-02	1.00E-03
BATCH-283	6/7/22	142	14.9	0.24	0.00E+00	0.00E+00	2.19E-01	2.30E-01	1.74E+01	5.16E-01	2.85E+03	1.72E+00	3.05E-01	1.42E+01	5.87E-10	2.69E+00	1.90E-02	5.66E-01	3.05E-02
BATCH-284	6/8/22	18	1.9	0.24	0.00E+00	0.00E+00	5.00E-03	3.00E-03	4.14E-01	1.35E-02	2.11E+02	3.40E-02	6.00E-03	5.74E-01	4.93E-11	7.10E-02	3.52E-04	1.20E-02	5.00E-04
BATCH-285	6/10/22	162	16.9	0.24	0.00E+00	0.00E+00	2.49E-01	2.62E-01	1.98E+01	5.89E-01	3.25E+03	1.96E+00	3.48E-01	1.62E+01	6.70E-10	3.07E+00	2.20E-02	6.45E-01	3.48E-02
BATCH-286	6/22/22	162	16.9	0.24	0.00E+00	0.00E+00	2.49E-01	2.62E-01	1.98E+01	5.88E-01	3.24E+03	1.96E+00	3.48E-01	1.62E+01	6.69E-10	3.07E+00	2.20E-02	6.44E-01	3.48E-02
BATCH-287	6/27/22	24	2.5	0.24	0.00E+00	0.00E+00	1.00E-02	6.00E-03	8.25E-01	3.51E-02	3.65E+02	8.10E-02	1.50E-02	1.51E+00	2.74E-09	1.27E-01	8.27E-04	2.80E-02	1.25E-03
BATCH-288	6/30/22	162	16.9	0.24	0.00E+00	0.00E+00	2.49E-01	2.62E-01	1.98E+01	5.87E-01	3.24E+03	1.96E+00	3.47E-01	1.61E+01	6.68E-10	3.06E+00	2.20E-02	6.43E-01	3.48E-02
BATCH-289	7/9/22	178	18.5	0.24	0.00E+00	0.00E+00	1.33E-01	6.80E-02	1.06E+01	4.77E-01	3.55E+03	1.07E+00	1.82E-01	1.77E+01	8.36E-11	2.19E+00	9.00E-03	2.27E-01	1.95E-02
BATCH-290	7/17/22	140	14.6	0.24	0.00E+00	0.00E+00	9.10E-02	3.10E-02	7.22E+00	3.58E-01	2.79E+03	7.32E-01	1.24E-01	1.39E+01	1.34E-12	1.61E+00	6.00E-03	1.31E-01	1.35E-02
BATCH-291	7/28/22	159	16.6	0.24	0.00E+00	0.00E+00	1.04E-01	3.60E-02	8.24E+00	4.09E-01	3.18E+03	8.35E-01	1.41E-01	1.59E+01	1.48E-12	1.84E+00	7.00E-03	1.49E-01	1.53E-02
BATCH-292	8/1/22	182	18.9	0.24	0.00E+00	0.00E+00	1.18E-01	4.10E-02	9.39E+00	4.66E-01	3.63E+03	9.51E-01	1.61E-01	1.81E+01	1.84E-12	2.09E+00	8.00E-03	1.70E-01	1.75E-02
BATCH-293	8/14/22	159	16.6	0.24	0.00E+00	0.00E+00	1.04E-01	3.60E-02	8.23E+00	4.09E-01	3.18E+03	8.34E-01	1.41E-01	1.58E+01	1.48E-12	1.83E+00	7.00E-03	1.49E-01	1.53E-02

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-245	11/24/21	101	10.6	0.24	8.86E-06	3.04E-02	9.20E+02	1.05E-01	6.93E+00	6.28E-01	4.49E+00	3.48E-05	1.00E-03	4.83E-04	1.00E-03	2.00E-03	5.60E-02	2.77E-01	7.10E-02
BATCH-246	11/26/21	101	10.6	0.24	8.85E-06	3.04E-02	9.19E+02	1.05E-01	6.93E+00	6.28E-01	4.48E+00	3.48E-05	1.00E-03	4.83E-04	1.00E-03	2.00E-03	5.60E-02	2.77E-01	7.10E-02
BATCH-247	12/5/21	112	11.7	0.24	9.76E-06	3.37E+02	1.02E+03	1.17E-01	7.68E+00	6.96E-01	4.91E+00	3.86E-05	1.00E-03	5.36E-04	1.00E-03	2.00E-03	6.20E-02	3.08E-01	7.80E-02
BATCH-248	12/7/21	76	7.9	0.24	6.64E-06	2.28E+02	6.88E+02	7.90E-02	5.18E+00	4.70E-01	3.37E+00	2.61E-05	1.00E-03	3.62E-04	7.82E-04	2.00E-03	4.20E-02	2.07E-01	5.30E-02
BATCH-249	12/15/21	101	10.5	0.24	8.82E-06	3.03E+02	9.16E+02	1.05E-01	6.90E+00	6.25E-01	4.47E+00	3.47E-05	1.00E-03	4.81E-04	1.00E-03	2.00E-03	5.50E-02	2.76E-01	7.00E-02
BATCH-250	12/16/21	138	14.4	0.24	2.87E-06	4.14E+02	3.75E+02	4.20E-02	2.81E+00	2.40E-01	1.08E+00	1.42E-05	8.37E-04	2.21E-04	3.69E-04	8.90E-04	2.40E-02	1.20E-01	3.10E-02
BATCH-251	12/26/21	154	16.1	0.24	9.90E-07	4.62E+02	2.05E+02	2.20E-02	1.53E+00	1.19E-01	2.00E-03	7.76E-06	6.94E-04	1.40E-04	1.56E-04	5.37E-04	1.40E-02	7.10E-02	1.80E-02
BATCH-252	12/31/21	154	16.1	0.24	9.89E-07	4.62E+02	2.05E+02	2.20E-02	1.53E+00	1.19E-01	2.00E-03	7.75E-06	6.94E-04	1.40E-04	1.56E-04	5.37E-04	1.40E-02	7.10E-02	1.80E-02
BATCH-253	1/11/22	115	12.0	0.24	5.31E-07	3.46E+02	1.53E+02	1.60E-02	1.06E+00	7.80E-02	2.00E-03	5.63E-06	4.69E-04	1.05E-04	1.17E-04	4.03E-04	1.10E-02	5.30E-02	1.40E-02
BATCH-254	1/16/22	171	17.8	0.24	7.84E-07	5.12E+02	2.26E+02	2.30E-02	1.56E+00	1.15E-01	2.00E-03	8.33E-06	6.95E-04	1.56E-04	1.74E-04	5.96E-04	1.60E-02	7.90E-02	2.00E-02
BATCH-255	1/23/22	154	16.0	0.24	7.06E-07	4.61E+02	2.03E+02	2.10E-02	1.41E+00	1.03E-01	2.00E-03	7.49E-06	6.25E-04	1.40E-04	1.56E-04	5.36E-04	1.40E-02	7.10E-02	1.80E-02
BATCH-256	2/3/22	134	14.0	0.24	6.14E-07	4.02E+02	1.77E+02	1.80E-02	1.23E+00	9.00E-02	6.32E-04	6.53E-06	5.45E-04	1.22E-04	1.36E-04	4.67E-04	1.20E-02	6.20E-02	1.60E-02
BATCH-257	2/9/22	94	9.8	0.24	3.22E-06	2.81E+02	5.48E+02	4.90E-02	2.66E+00	3.27E-01	1.09E-01	2.18E-05	1.00E-03	1.93E-04	2.51E-04	7.10E-04	1.60E-02	8.20E-02	3.80E-02
BATCH-258	2/18/22	91	9.5	0.24	3.48E-06	2.73E+02	5.85E+02	5.20E-02	2.81E+00	3.50E-01	1.20E-01	2.34E-05	1.00E-03	2.01E-04	2.64E-04	7.38E-04	1.70E-02	8.40E-02	4.10E-02
BATCH-259	2/19/22	115	12.0	0.24	1.08E-05	3.46E+02	3.11E+02	3.20E-02	2.11E+00	1.96E-01	1.25E+01	1.19E-05	5.55E-04	1.72E-04	1.86E-04	6.57E-04	1.60E-02	8.20E-02	2.70E-02
BATCH-260	2/27/22	101	10.5	0.24	3.86E-06	3.03E+02	6.51E+02	5.70E-02	3.12E+00	3.89E-01	1.33E-01	2.60E-05	1.00E-03	2.24E-04	2.93E-04	8.20E-04	1.90E-02	9.40E-02	4.50E-02
BATCH-261	3/3/22	91	9.5	0.24	3.48E-06	2.73E+02	5.85E+02	5.20E-02	2.81E+00	3.50E-01	1.20E-01	2.33E-05	1.00E-03	2.01E-04	2.64E-04	7.38E-04	1.70E-02	8.40E-02	4.10E-02
BATCH-262	3/10/22	80	8.3	0.24	3.04E-06	2.39E+02	5.12E+02	4.50E-02	2.46E+00	3.06E-01	1.05E-01	2.04E-05	9.40E-04	1.76E-04	2.31E-04	6.45E-04	1.50E-02	7.40E-02	3.60E-02
BATCH-263	3/13/22	78	8.1	0.24	2.97E-06	2.33E+02	5.00E+02	4.40E-02	2.40E+00	2.99E-01	1.02E-01	1.99E-05	9.18E-04	1.72E-04	2.25E-04	6.30E-04	1.40E-02	7.20E-02	3.50E-02
BATCH-264	3/19/22	78	8.2	0.24	2.99E-06	2.34E+02	5.03E+02	4.40E-02	2.42E+00	3.01E-01	1.03E-01	2.01E-05	9.24E-04	1.73E-04	2.27E-04	6.34E-04	1.50E-02	7.30E-02	3.50E-02
BATCH-265	3/21/22	64	6.7	0.24	5.53E-06	1.92E+02	1.59E+02	1.60E-02	1.08E+00	1.00E-01	6.38E+00	6.11E-06	2.84E-04	8.78E-05	9.49E-05	3.36E-04	8.00E-03	4.20E-02	1.40E-02
BATCH-266	3/27/22	87	9.0	0.24	3.31E-06	2.60E+02	5.58E+02	4.90E-02	2.68E+00	3.34E-01	1.14E-01	2.23E-05	1.00E-03	1.92E-04	2.51E-04	7.03E-04	1.60E-02	8.00E-02	3.90E-02
BATCH-267	3/28/22	100	10.5	0.24	3.71E-06	3.01E+02	6.32E+02	6.30E-02	3.23E+00	4.14E-01	1.39E-01	2.45E-05	9.35E-04	3.05E-04	3.19E-04	1.00E-03	2.70E-02	1.34E-01	4.10E-02
BATCH-268	4/5/22	116	12.1	0.24	5.74E-06	3.49E+02	2.31E+02	2.30E-02	1.49E+00	1.43E-01	6.18E+00	8.87E-06	3.22E-04	1.12E-04	1.53E-04	4.48E-04	1.10E-02	5.70E-02	1.90E-02
BATCH-269	4/8/22	126	13.1	0.24	5.89E-06	3.78E+02	2.47E+02	2.40E-02	1.52E+00	1.52E-01	6.18E+00	9.57E-06	3.56E-04	1.12E-04	1.44E-04	4.43E-04	1.10E-02	5.50E-02	2.00E-02
BATCH-270	4/17/22	124	12.9	0.24	5.88E-06	3.72E+02	2.50E+02	2.40E-02	1.52E+00	1.55E-01	6.13E+00	9.71E-06	3.59E-04	1.12E-04	1.44E-04	4.42E-04	1.10E-02	5.50E-02	2.00E-02
BATCH-271	4/21/22	22	2.3	0.24	1.51E-06	6.62E+01	4.36E+01	4.00E-03	2.95E-01	2.70E-02	1.74E+00	1.67E-06	7.77E-05	2.40E-05	2.60E-05	9.19E-05	2.00E-03	1.10E-02	4.00E-03
BATCH-272	4/23/22	107	11.2	0.24	8.79E-07	3.21E+02	1.52E+02	1.40E-02	8.34E-01	8.90E-02	1.52E-01	5.93E-06	2.92E-04	6.45E-05	9.38E-05	2.47E-04	6.00E-03	3.00E-02	1.10E-02
BATCH-273	5/1/22	116	12.1	0.24	5.74E-06	3.47E+02	2.49E+02	2.50E-02	1.52E+00	1.56E-01	5.94E+00	9.62E-06	3.45E-04	1.16E-04	1.44E-04	4.58E-04	1.10E-02	5.60E-02	1.90E-02
BATCH-274	5/5/22	65	6.8	0.24	2.99E-06	1.96E+02	1.20E+02	1.20E-02	7.77E-01	7.40E-02	3.22E+00	4.62E-06	1.68E-04	5.81E-05	7.96E-05	2.33E-04	6.00E-03	2.90E-02	1.00E-02
BATCH-275	5/12/22	68	7.1	0.24	2.94E-06	2.03E+02	1.23E+02	1.20E-02	7.55E-01	7.60E-02	3.08E+00	4.77E-06	1.78E-04	5.59E-05	7.16E-05	2.21E-04	5.00E-03	2.70E-02	1.00E-02
BATCH-276	5/13/22	163	17.0	0.24	5.99E-06	4.87E+02	1.02E+03	1.02E-01	5.25E+00	6.72E-01	2.25E-01	3.95E-05	1.00E-03	5.02E-04	5.19E-04	2.00E-03	4.40E-02	2.21E-01	6.70E-02
BATCH-277	5/19/22	68	7.1	0.24	2.99E-06	2.03E+02	1.27E+02	1.20E-02	7.72E-01	7.90E-02	3.11E+00	4.93E-06	1.82E-04	5.68E-05	7.30E-05	2.24E-04	6.00E-03	2.80E-02	1.00E-02
BATCH-278	5/26/22	55	5.7	0.24	4.05E-07	1.64E+02	7.02E+01	7.00E-03	3.85E-01	4.10E-02	7.00E-02	2.74E-06	1.34E-04	2.97E-05	4.33E-05	1.14E-04	3.00E-03	1.40E-02	5.00E-03
BATCH-279	5/30/22	23	2.4	0.24	8.48E-07	6.89E+01	3.41E+01	3.00E-03	2.20E-01	2.10E-02	9.13E-01	1.31E-06	4.75E-05	1.65E-05	2.26E-05	6.62E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-280	6/1/22	67	7.0	0.24	3.09E-06	2.01E+02	1.34E+02	1.30E-02	8.17E-01	8.40E-02	3.20E+00	5.18E-06	1.86E-04	6.26E-05	7.78E-05	2.47E-04	6.00E-03	3.00E-02	1.00E-02
BATCH-281	6/2/22	24	2.5	0.24	8.34E-07	7.09E+01	3.49E+01	3.00E-03	2.14E-01	2.20E-02	8.75E-01	1.36E-06	5.04E-05	1.59E-05	2.03E-05	6.28E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-282	6/4/22	24	2.5	0.24	8.47E-07	7.10E+01	3.60E+01	3.00E-03	2.19E-01	2.20E-02	8.82E-01	1.40E-06	5.17E-05	1.61E-05	2.07E-05	6.37E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-283	6/7/22	142	14.9	0.24	5.25E-06	4.27E+02	8.95E+02	9.00E-02	4.60E+00	5.89E-01	1.97E-01	3.46E-05	1.00E-03	4.40E-04	4.55E-04	2.00E-03	3.90E-02	1.93E-01	5.80E-02
BATCH-284	6/8/22	18	1.9	0.24	9.61E-08	5.49E+01	1.67E+01	2.00E-03	9.10E-02	1.00E-02	1.70E-02	6.49E-07	3.19E-05	7.06E-06	1.03E-05	2.70E-05	6.67E-04	3.00E-03	1.00E-03
BATCH-285	6/10/22	162	16.9	0.24	5.98E-06	4.87E+02	1.02E+03	1.02E-01	5.24E+00	6.71E-01	2.25E-01	3.95E-05	1.00E-03	5.02E-04	5.18E-04	2.00E-03	4.40E-02	2.20E-01	6.70E-02
BATCH-286	6/22/22	162	16.9	0.24	5.97E-06	4.86E+02	1.02E+03	1.02E-01	5.23E+00	6.71E-01	2.25E-01	3.95E-05	1.00E-03	5.01E-04	5.18E-04	2.00E-03	4.40E-02	2.20E-01	6.70E-02
BATCH-287	6/27/22	24	2.5	0.24	8.95E-07	7.13E+01	3.88E+01	4.00E-03	2.37E-01	2.40E-02	9.27E-01	1.50E-06	5.38E-05	1.81E-05	2.25E-05	7.15E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-288	6/30/22	162	16.9	0.24	5.97E-06	4.86E+02	1.02E+03	1.02E-01	5.23E+00	6.70E-01	2.24E-01	3.94E-05	1.00E-03	5.00E-04	5.17E-04	2.00E-03	4.40E-02	2.20E-01	6.70E-02
BATCH-289	7/9/22	178	18.5	0.24	1.99E-06	5.32E+02	3.90E+02	3.90E+02	2.39E+00	2.12E-01	2.80E-02	1.50E-05	9.10E-04	2.07E-04	2.43E-04	6.99E-04	2.10E-02	1.07E-01	3.10E-02
BATCH-290	7/17/22	140	14.6	0.24	1.27E-06	4.19E+02	2.34E+02	2.30E-02	1.55E+00	1.15E-01	1.26E-04	8.97E-06	6.45E-04	1.29E-04	1.59E-04	4.16E-04	1.40E-02	7.10E-02	2.00E-02
BATCH-291	7/28/22	159	16.6	0.24	1.27E-06	4.78E+02	2.67E+02	2.70E-02	1.77E+00	1.31E-01	1.27E-04	1.02E-05	7.35E-04	1.47E-04	1.82E-04	4.75E-04	1.60E-02	8.10E-02	2.30E-02
BATCH-292	8/1/22	182	18.9	0.24	1.44E-06	5.45E+02	3.04E+02	3.10E-02	2.01E+00	1.50E-01	1.98E-04	1.17E-05	8.38E-04	1.67E-04	2.07E-04	5.41E-04	1.80E-02	9.20E-02	2.60E-02
BATCH-293	8/14/22	159	16.6	0.24	1.27E-06	4.77E+02	2.67E+02	2.70E-02	1.76E+00	1.31E-01	1.27E-04	1.02E-05	7.34E-04	1.47E-04	1.81E-04	4.74E-04	1.60E-02	8.00E-02	2.30E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-245	11/24/21	101	10.6	0.24	3.00E-03	2.00E-03	9.30E-02	1.52E-01	8.40E-02	5.37E+00	8.99E-01	1.36E+01	3.45E+00	1.61E-19	8.25E-05	8.25E-04	7.00E-03	3.30E-02	5.00E-03
BATCH-246	11/26/21	101	10.6	0.24	3.00E-03	2.00E-03	9.30E-02	1.52E-01	8.40E-02	5.36E+00	8.99E-01	1.36E+01	3.44E+00	1.61E-19	8.24E-05	8.24E-04	7.00E-03	3.30E-02	5.00E-03
BATCH-247	12/5/21	112	11.7	0.24	3.00E-03	3.00E-03	1.03E-01	1.68E-01	9.40E-02	5.95E+00	9.97E-01	1.51E+01	3.82E+00	1.78E-19	9.14E-05	9.14E-04	7.00E-03	3.70E-02	5.00E-03
BATCH-248	12/7/21	76	7.9	0.24	2.00E-03	2.00E-03	7.00E-02	1.14E-01	6.30E-02	4.02E+00	6.73E-01	1.02E+01	2.58E+00	1.20E-19	6.17E-05	6.17E-04	5.00E-03	2.50E-02	4.00E-03
BATCH-249	12/15/21	101	10.5	0.24	3.00E-03	2.00E-03	9.30E-02	1.51E-01	8.40E-02	5.34E+00	8.96E-01	1.36E+01	3.43E+00	1.60E-19	8.21E-05	8.21E-04	7.00E-03	3.30E-02	5.00E-03
BATCH-250	12/16/21	138	14.4	0.24	1.00E-03	9.63E-04	4.40E-02	5.60E-02	3.70E-02	5.35E+00	1.16E+00	5.27E+00	1.28E+00	4.23E-20	2.89E-05	2.33E-04	2.00E-03	1.00E-02	1.00E-03
BATCH-251	12/26/21	154	16.1	0.24	7.38E-04	5.37E-04	2.90E-02	2.60E-02	2.20E-02	5.49E+00	1.28E+00	2.66E+00	6.03E-01	4.46E-21	1.21E-05	4.39E-05	3.19E-04	2.00E-03	5.72E-06
BATCH-252	12/31/21	154	16.1	0.24	7.38E-04	5.36E-04	2.90E-02	2.60E-02	2.20E-02	5.48E+00	1.28E+00	2.66E+00	6.03E-01	4.45E-21	1.21E-05	4.39E-05	3.19E-04	2.00E-03	5.72E-06
BATCH-253	1/11/22	115	12.0	0.24	5.53E-04	4.02E-04	2.20E-02	2.00E-02	1.60E-02	4.11E+00	9.57E-01	1.99E+00	4.31E-01	7.13E-22	9.06E-06	3.30E-05	2.34E-04	1.00E-03	4.89E-06
BATCH-254	1/16/22	171	17.8	0.24	8.18E-04	5.95E-04	3.30E-02	2.90E-02	2.40E-02	6.09E+00	1.42E+00	2.94E+00	6.37E-01	1.05E-21	1.34E-05	4.87E-05	3.45E-04	2.00E-03	6.08E-06
BATCH-255	1/23/22	154	16.0	0.24	7.36E-04	5.35E-04	2.90E-02	2.60E-02	2.20E-02	5.47E+00	1.27E+00	2.64E+00	5.73E-01	9.44E-22	1.21E-05	4.38E-05	3.11E-04	2.00E-03	5.70E-06
BATCH-256	2/3/22	134	14.0	0.24	6.42E-04	4.67E-04	2.60E-02	2.30E-02	1.90E-02	4.78E+00	1.11E+00	2.31E+00	4.99E-01	8.14E-22	1.05E-05	3.80E-05	2.69E-04	2.00E-03	3.55E-06
BATCH-257	2/9/22	94	9.8	0.24	2.00E-03	1.00E-03	7.30E-02	5.80E-02	4.00E-02	4.24E+00	4.62E-01	2.84E+01	1.37E+00	8.41E-22	2.80E-05	1.76E-04	7.93E-04	9.00E-03	3.99E-05
BATCH-258	2/18/22	91	9.5	0.24	2.00E-03	1.00E-03	7.80E-02	6.20E-02	4.20E-02	4.23E+00	4.12E-01	3.09E+01	1.46E+00	8.53E-22	2.97E-05	1.89E-04	8.46E-04	9.00E-03	4.35E-05
BATCH-259	2/19/22	115	12.0	0.24	1.00E-03	8.75E-04	3.60E-02	4.10E-02	3.00E-02	2.68E+00	3.31E-01	4.42E+00	7.77E-01	1.76E-21	2.23E-05	2.45E-04	1.20E-02	1.10E-02	2.00E-03
BATCH-260	2/27/22	101	10.5	0.24	2.00E-03	1.00E-03	8.60E-02	6.90E-02	4.70E-02	4.70E+00	4.58E-01	3.44E+01	1.62E+00	9.47E-22	3.31E-05	2.10E-04	9.40E-04	1.00E-02	4.83E-05
BATCH-261	3/3/22	91	9.5	0.24	2.00E-03	1.00E-03	7.80E-02	6.20E-02	4.20E-02	4.23E+00	4.12E-01	3.09E+01	1.46E+00	8.52E-22	2.97E-05	1.89E-04	8.46E-04	9.00E-03	4.35E-05
BATCH-262	3/10/22	80	8.3	0.24	1.00E-03	1.00E-03	6.80E-02	5.40E-02	3.70E-02	3.70E+00	3.60E-01	2.70E+01	1.28E+00	7.45E-22	2.60E-05	1.65E-04	7.40E-04	8.00E-03	3.80E-05
BATCH-263	3/13/22	78	8.1	0.24	1.00E-03	1.00E-03	6.60E-02	5.30E-02	3.60E-02	3.61E+00	3.51E-01	2.64E+01	1.25E+00	7.28E-22	2.54E-05	1.62E-04	7.23E-04	8.00E-03	3.71E-05
BATCH-264	3/19/22	78	8.2	0.24	1.00E-03	1.00E-03	6.70E-02	5.30E-02	3.60E-02	3.63E+00	3.53E-01	2.66E+01	1.26E+00	7.32E-22	2.56E-05	1.63E-04	7.27E-04	8.00E-03	3.74E-05
BATCH-265	3/21/22	64	6.7	0.24	5.59E-04	4.48E-04	1.80E-02	2.10E-02	1.50E-02	1.37E+00	1.69E-01	2.26E+00	3.98E-01	9.02E-22	1.14E-05	1.25E-04	6.00E-03	5.00E-03	1.00E-03
BATCH-266	3/27/22	87	9.0	0.24	2.00E-03	1.00E-03	7.40E-02	5.90E-02	4.00E-02	4.03E+00	3.92E-01	2.95E+01	1.39E+00	8.12E-22	2.83E-05	1.80E-04	8.06E-04	9.00E-03	4.14E-05
BATCH-267	3/28/22	100	10.5	0.24	2.00E-03	1.00E-03	8.70E-02	7.00E-02	4.60E-02	2.61E+00	4.42E-01	7.56E+00	1.59E+00	1.17E-21	3.20E-05	1.17E-04	9.64E-04	1.40E-02	2.73E-04
BATCH-268	4/5/22	116	12.1	0.24	7.61E-04	6.15E-04	2.70E-02	3.00E-02	2.10E-02	2.20E+00	3.22E-01	5.00E+00	6.16E-01	2.33E-21	1.63E-05	1.65E-04	6.00E-03	7.00E-03	1.00E-03
BATCH-269	4/8/22	126	13.1	0.24	7.99E-04	6.45E-04	3.00E-02	3.10E-02	2.20E-02	2.28E+00	3.09E-01	6.73E+00	6.30E-01	1.55E-21	1.62E-05	1.59E-04	6.00E-03	7.00E-03	1.00E-03
BATCH-270	4/17/22	124	12.9	0.24	8.05E-04	6.51E-04	3.00E-02	3.10E-02	2.20E-02	2.24E+00	2.93E-01	7.09E+00	6.37E-01	1.54E-21	1.63E-05	1.60E-04	6.00E-03	7.00E-03	1.00E-03
BATCH-271	4/21/22	22	2.3	0.24	1.53E-04	1.23E-04	5.00E-03	6.00E-03	4.00E-03	3.75E-01	4.60E-02	6.18E-01	1.09E-01	2.46E-22	3.12E-06	3.43E-05	2.00E-03	1.00E-03	3.25E-04
BATCH-272	4/23/22	107	11.2	0.24	4.57E-04	3.63E-04	2.00E-02	1.80E-02	1.20E-02	1.47E+00	2.30E-01	6.20E+00	4.17E-01	1.25E-21	8.98E-06	6.26E-05	3.76E-04	3.00E-03	1.48E-04
BATCH-273	5/1/22	116	12.1	0.24	7.90E-04	6.46E-04	3.00E-02	3.10E-02	2.10E-02	2.09E+00	2.88E-01	5.53E+00	6.33E-01	1.51E-21	1.61E-05	1.51E-04	6.00E-03	7.00E-03	1.00E-03
BATCH-274	5/5/22	65	6.8	0.24	3.96E-04	3.20E-04	1.40E-02	1.60E-02	1.15E-02	1.68E-01	2.61E+00	3.21E-01	1.22E-21	8.49E-06	8.61E-05	3.00E-03	4.00E-03	6.84E-04	
BATCH-275	5/12/22	68	7.1	0.24	3.98E-04	3.22E-04	1.50E-02	1.50E-02	1.10E-02	1.14E+00	1.54E-01	3.36E+00	3.14E-01	7.75E-22	8.10E-06	7.93E-05	3.00E-03	3.00E-03	6.08E-04
BATCH-276	5/13/22	163	17.0	0.24	3.00E-03	2.00E-03	1.40E-01	1.13E-01	7.50E-02	4.02E+00	7.15E-01	9.61E+00	2.56E+00	1.92E-21	5.17E-05	1.81E-04	2.00E-03	2.40E-02	4.63E-04
BATCH-277	5/19/22	68	7.1	0.24	4.09E-04	3.31E-04	1.50E-02	1.60E-02	1.10E-02	1.14E+00	1.49E-01	3.60E+00	3.23E-01	7.81E-22	8.30E-06	8.11E-05	3.00E-03	4.00E-03	6.14E-04
BATCH-278	5/26/22	55	5.7	0.24	2.11E-04	1.67E-04	9.00E-03	8.00E-03	6.00E-03	6.79E-01	1.06E-01	2.86E+00	1.92E-01	5.77E-22	4.14E-06	2.88E-05	1.73E-04	1.00E-03	6.81E-05
BATCH-279	5/30/22	23	2.4	0.24	1.12E-04	9.08E-05	4.00E-03	5.00E-03	3.00E-03	3.25E-01	4.80E-02	7.39E-01	9.10E-02	3.45E-22	2.41E-06	2.44E-05	8.55E-04	1.00E-03	1.94E-04
BATCH-280	6/1/22	67	7.0	0.24	4.26E-04	3.48E-04	1.60E-02	1.70E-02	1.20E-02	1.13E+00	1.55E-01	2.98E+00	3.41E-01	8.15E-22	8.70E-06	8.14E-05	3.00E-03	4.00E-03	6.39E-04
BATCH-281	6/2/22	24	2.5	0.24	1.13E-04	9.13E-05	4.00E-03	4.00E-03	3.00E-03	3.23E-01	4.40E-02	9.53E-01	8.90E-02	2.20E-22	2.30E-06	2.25E-05	8.46E-04	9.87E-04	1.73E-04
BATCH-282	6/4/22	24	2.5	0.24	1.16E-04	9.38E-05	4.00E-03	4.00E-03	3.00E-03	3.23E-01	4.20E-02	1.02E+00	9.20E-02	2.22E-22	2.35E-06	2.30E-05	8.54E-04	1.00E-03	1.74E-04
BATCH-283	6/7/22	142	14.9	0.24	2.00E-03	2.00E-03	1.23E-01	9.90E-02	6.50E-02	3.52E+00	6.26E-01	8.42E+00	2.25E+00	1.68E-21	4.53E-05	1.59E-04	1.00E-03	2.10E-02	4.06E-04
BATCH-284	6/8/22	18	1.9	0.24	5.00E-05	3.97E-05	2.00E-03	2.00E-03	1.00E-03	1.61E-01	2.50E-02	6.78E-01	4.60E-02	1.37E-22	9.82E-07	6.84E-06	4.11E-05	3.05E-04	1.62E-05
BATCH-285	6/10/22	162	16.9	0.24	3.00E-03	2.00E-03	1.40E-01	1.13E-01	7.50E-02	4.01E+00	7.14E-01	9.60E+00	2.56E+00	1.92E-21	5.16E-05	1.81E-04	2.00E-03	2.40E-02	4.63E-04
BATCH-286	6/22/22	162	16.9	0.24	3.00E-03	2.00E-03	1.40E-01	1.13E-01	7.50E-02	4.01E+00	7.13E-01	9.59E+00	2.56E+00	1.92E-21	5.16E-05	1.81E-04	2.00E-03	2.40E-02	4.62E-04
BATCH-287	6/27/22	24	2.5	0.24	1.23E-04	1.01E-04	5.00E-03	5.00E-03	3.00E-03	3.26E-01	4.50E-02	8.63E-01	9.90E-02	2.36E-22	2.52E-06	2.36E-05	8.99E-04	1.00E-03	1.85E-04
BATCH-288	6/30/22	162	16.9	0.24	3.00E-03	2.00E-03	1.40E-01	1.12E-01	7.40E-02	4.00E+00	7.12E-01	9.58E+00	2.55E+00	1.92E-21	5.15E-05	1.80E-04	2.00E-03	2.40E-02	4.62E-04
BATCH-289	7/9/22	178	18.5	0.24	1.00E-03	9.76E-04	5.40E-02	4.80E-02	3.50E-02	2.03E+00	3.55E-01	2.73E+00	1.04E+00	1.60E-21	2.17E-05	7.78E-05	6.72E-04	7.00E-03	5.70E-05
BATCH-290	7/17/22	140	14.6	0.24	8.12E-04	6.10E-04	3.30E-02	3.00E-02	2.30E-02	1.36E+00	2.37E-01	1.38E+00	6.44E-01	1.21E-21	1.36E-05	4.93E-05	4.25E-04	3.00E-03	2.36E-07
BATCH-291	7/28/22	159	16.6	0.24	9.26E-04	6.96E-04	3.80E-02	3.40E-02	2.70E-02	1.55E+00	2.70E-01	1.57E+00	7.34E-01	1.38E-21	1.55E-05	5.62E-05	4.85E-04	4.00E-03	2.36E-07
BATCH-292	8/1/22	182	18.9	0.24	1.00E-03	7.93E-04	4.30E-02	3.90E-02	3.00E-02	1.77E+00	3.08E-01	1.78E+00	8.36E-01	1.57E-21	1.77E-05	6.40E-05	5.53E-04	4.00E-03	3.83E-08
BATCH-293	8/14/22	159	16.6	0.24	9.25E-04	6.95E-04	3.80E-02	3.40E-02	2.70E-02	1.55E+00	2.70E-01	1.57E+00	7.33E-01	1.37E-21	1.55E-05	5.61E-05	4.85E-04	4.00E-03	2.36E-07

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-245	11/24/21	101	10.6	0.24	2.67E-06	1.37E+02	1.00E-02	2.40E-02	5.00E-03	2.11E-29	1.50E-02	3.53E-01	3.00E-03	2.34E+01	0.00E+00	0.00E+00	1.42E-07	5.38E+00	5.52E-02
BATCH-246	11/26/21	101	10.6	0.24	3.06E-06	1.37E+02	1.00E-02	2.40E-02	5.00E-03	2.08E-29	1.50E-02	3.53E-01	3.00E-03	2.34E+01	0.00E+00	0.00E+00	1.54E-07	5.37E+00	5.51E-02
BATCH-247	12/5/21	112	11.7	0.24	6.00E-03	1.52E+02	1.10E-02	2.70E-02	5.00E-03	1.40E-25	1.60E-02	3.91E-01	3.00E-03	2.59E+01	0.00E+00	0.00E+00	5.20E-04	5.95E+00	6.11E-02
BATCH-248	12/7/21	76	7.9	0.24	8.57E-13	1.02E+02	7.00E-03	1.80E-02	4.00E-03	8.87E-36	1.10E-02	2.64E-01	2.00E-03	1.75E+01	0.00E+00	0.00E+00	1.06E-13	4.02E+00	4.13E-02
BATCH-249	12/15/21	101	10.5	0.24	3.51E-06	1.36E+02	1.00E-02	2.40E-02	5.00E-03	2.85E-29	1.40E-02	3.51E-01	3.00E-03	2.33E+01	0.00E+00	0.00E+00	3.15E-07	5.35E+00	5.49E-02
BATCH-250	12/16/21	138	14.4	0.24	1.71E-09	1.59E+02	2.00E-03	6.00E-03	1.00E-03	1.53E-32	1.00E-02	6.99E-01	7.12E-04	5.70E-02	3.67E+01	0.00E+00	1.98E-10	3.33E+00	1.34E-02
BATCH-251	12/26/21	154	16.1	0.24	1.35E-09	1.71E+02	2.11E-05	1.24E-05	8.87E-06	1.07E-32	9.00E-03	8.33E-01	2.41E-05	7.70E-02	4.21E+01	0.00E+00	7.20E-11	2.75E+00	5.39E-05
BATCH-252	12/31/21	154	16.1	0.24	1.56E-09	1.70E+02	2.11E-05	1.24E-05	8.86E-06	1.05E-32	9.00E-03	8.32E-01	2.41E-05	7.70E-02	4.21E+01	0.00E+00	7.83E-11	2.75E+00	5.39E-05
BATCH-253	1/11/22	115	12.0	0.24	5.80E-16	1.28E+02	1.71E-05	1.24E-05	7.24E-06	6.00E-39	7.00E-03	6.24E-01	1.84E-05	5.70E-02	3.15E+01	0.00E+00	2.37E-07	3.05E+00	8.09E-05
BATCH-254	1/16/22	171	17.8	0.24	2.65E-06	1.89E+02	2.29E-05	1.24E-05	9.57E-06	6.38E-29	1.00E-02	9.24E-01	2.65E-05	8.50E-02	4.67E+01	0.00E+00	1.60E-10	2.74E+00	5.39E-05
BATCH-255	1/23/22	154	16.0	0.24	1.78E-09	1.70E+02	2.11E-05	1.24E-05	8.84E-06	1.45E-32	9.00E-03	8.30E-01	2.40E-05	7.60E-02	4.20E+01	0.00E+00	1.15E-13	2.39E+00	2.70E-05
BATCH-256	2/3/22	134	14.0	0.24	9.91E-13	1.48E+02	1.54E-05	3.45E-06	6.30E-06	8.86E-36	8.00E-03	7.25E-01	2.01E-05	6.70E-02	3.67E+01	0.00E+00	3.53E-14	4.76E+00	5.88E-03
BATCH-257	2/9/22	94	9.8	0.24	6.64E-13	9.22E+01	2.09E-05	2.10E-02	1.46E-05	5.24E-36	6.00E-03	1.08E+00	1.52E-04	1.30E-02	1.76E+01	0.00E+00	4.69E-14	5.01E+00	6.45E-03
BATCH-258	2/18/22	91	9.5	0.24	9.31E-13	8.83E+01	2.17E-05	2.30E-02	1.55E-05	6.30E-36	6.00E-03	1.13E+00	1.65E-04	9.00E-03	1.61E+01	0.00E+00	2.18E+01	0.00E+00	1.94E-02
BATCH-259	2/19/22	115	12.0	0.24	2.47E+02	0.00E+00	2.00E-03	7.00E-03	7.46E-04	3.55E-27	5.00E-03	6.75E-01	2.00E-03	8.00E-03	1.23E+01	0.00E+00	1.28E-10	5.56E+00	7.17E-03
BATCH-260	2/27/22	101	10.5	0.24	1.43E-09	9.81E+01	2.42E-05	2.60E-02	1.72E-05	3.43E-32	7.00E-03	1.25E+00	1.83E-04	1.00E-02	1.79E+01	0.00E+00	9.57E-14	5.00E+00	6.45E-03
BATCH-261	3/3/22	91	9.5	0.24	1.07E-12	8.83E+01	2.17E-05	2.30E-02	1.55E-05	8.65E-36	6.00E-03	1.13E+00	1.65E-04	9.00E-03	1.61E+01	0.00E+00	7.85E-17	4.38E+00	5.64E-03
BATCH-262	3/10/22	80	8.3	0.24	6.77E-16	7.72E+01	1.90E-05	2.10E-02	1.35E-05	6.05E-39	5.00E-03	9.83E-01	1.44E-04	8.00E-03	1.38E+01	0.00E+00	2.47E-17	4.27E+00	5.50E-03
BATCH-263	3/13/22	78	8.1	0.24	4.64E-16	7.53E+01	1.86E-05	2.00E-02	1.32E-05	3.67E-39	5.00E-03	9.60E-01	1.41E-04	8.00E-03	1.38E+01	0.00E+00	3.25E-17	4.30E+00	5.56E-03
BATCH-264	3/19/22	78	8.2	0.24	6.46E-16	7.58E+01	1.87E-05	2.00E-02	1.33E-05	4.38E-39	5.00E-03	9.66E-01	1.42E-04	8.00E-03	1.38E+01	0.00E+00	1.11E+01	0.00E+00	9.95E-03
BATCH-265	3/21/22	64	6.7	0.24	1.26E+02	0.00E+00	9.92E-04	4.00E-03	3.82E-04	1.82E-27	3.00E-03	3.45E-01	8.30E-04	4.00E-03	6.29E+00	0.00E+00	7.99E-14	4.77E+00	6.15E-03
BATCH-266	3/27/22	87	9.0	0.24	8.92E-13	8.41E+01	2.07E-05	2.20E-02	1.48E-05	2.15E-35	6.00E-03	1.07E+00	1.57E-04	9.00E-03	1.53E+01	0.00E+00	5.56E-17	2.98E+00	4.42E-03
BATCH-267	3/28/22	100	10.5	0.24	6.19E-16	1.17E+02	2.85E-05	3.70E-02	2.99E-05	5.03E-39	7.00E-03	7.07E-01	3.38E-04	1.30E-02	2.14E+01	0.00E+00	1.93E+01	0.00E+00	1.19E-02
BATCH-268	4/5/22	116	12.1	0.24	2.97E+02	0.00E+00	1.00E-03	6.00E-03	5.51E-04	3.16E-27	6.00E-03	7.03E-01	9.05E-04	1.00E-02	1.12E+01	0.00E+00	2.06E+01	0.00E+00	1.12E-02
BATCH-269	4/8/22	126	13.1	0.24	2.93E+02	0.00E+00	1.00E-03	7.00E-03	4.42E-04	2.20E-27	5.00E-03	7.42E-01	8.59E-04	1.00E-02	1.11E+01	0.00E+00	2.06E+01	0.00E+00	1.12E-02
BATCH-270	4/17/22	124	12.9	0.24	2.87E+02	0.00E+00	1.00E-03	7.00E-03	4.38E-04	2.15E-27	5.00E-03	7.38E-01	8.53E-04	9.00E-03	1.06E+01	0.00E+00	3.05E+00	0.00E+00	2.72E-03
BATCH-271	4/21/22	22	2.3	0.24	3.45E+01	0.00E+00	2.71E-04	1.00E-03	1.04E-04	4.96E-28	7.28E-04	9.40E-02	2.27E-04	1.00E-03	1.72E+00	0.00E+00	1.55E+01	0.00E+00	2.78E-03
BATCH-272	4/23/22	107	11.2	0.24	2.72E+02	0.00E+00	3.00E-04	5.00E-03	1.43E-04	3.71E-27	5.00E-03	6.03E-01	1.16E-04	1.00E-02	7.86E+00	0.00E+00	2.22E+01	0.00E+00	1.07E-02
BATCH-273	5/1/22	116	12.1	0.24	2.73E+02	0.00E+00	1.00E-03	8.00E-03	4.25E-04	2.86E-27	5.00E-03	7.41E-01	8.39E-04	9.00E-03	1.07E+01	0.00E+00	1.01E+01	0.00E+00	6.23E-03
BATCH-274	5/5/22	65	6.8	0.24	1.55E+02	0.00E+00	6.98E-04	3.00E-03	2.87E-04	1.65E-27	3.00E-03	3.66E-01	4.72E-04	6.00E-03	5.83E+00	0.00E+00	1.03E+01	0.00E+00	5.58E-03
BATCH-275	5/12/22	68	7.1	0.24	1.46E+02	0.00E+00	5.54E-04	4.00E-03	2.21E-04	1.10E-27	2.00E-03	3.70E-01	4.28E-04	5.00E-03	5.53E+00	0.00E+00	4.57E+00	0.00E+00	6.93E-03
BATCH-276	5/13/22	163	17.0	0.24	6.00E-03	1.91E+02	4.66E-05	6.20E-02	4.97E-05	9.09E-32	1.10E-02	1.09E+00	5.63E-04	2.20E-02	3.50E+01	0.00E+00	5.58E-04	4.57E+00	5.66E-03
BATCH-277	5/19/22	68	7.1	0.24	1.46E+02	0.00E+00	5.59E-04	4.00E-03	2.23E-04	1.09E-27	2.00E-03	3.75E-01	4.33E-04	5.00E-03	5.37E+00	0.00E+00	1.04E+01	0.00E+00	1.29E-03
BATCH-278	5/26/22	55	5.7	0.24	1.25E+02	0.00E+00	1.38E-04	2.00E-03	6.57E-05	1.71E-27	2.00E-03	2.78E-01	5.34E-05	4.00E-03	3.62E+00	0.00E+00	7.15E+00	0.00E+00	1.75E-03
BATCH-279	5/30/22	23	2.4	0.24	4.39E+01	0.00E+00	1.98E-04	9.13E-04	8.14E-05	4.67E-28	8.15E-04	1.04E-01	1.34E-04	2.00E-03	1.65E+00	0.00E+00	2.85E+00	0.00E+00	5.77E-03
BATCH-280	6/1/22	67	7.0	0.24	1.47E+02	0.00E+00	5.75E-04	4.00E-03	2.29E-04	1.54E-27	3.00E-03	3.99E-01	4.52E-04	5.00E-03	5.75E+00	0.00E+00	1.19E+01	0.00E+00	5.77E-03
BATCH-281	6/2/22	24	2.5	0.24	4.15E+01	0.00E+00	1.57E-04	1.00E-03	6.26E-05	3.11E-28	7.04E-04	1.05E-01	1.22E-04	1.00E-03	1.57E+00	0.00E+00	2.92E+00	0.00E+00	1.59E-03
BATCH-282	6/4/22	24	2.5	0.24	4.13E+01	0.00E+00	1.59E-04	1.00E-03	6.31E-05	3.10E-28	6.90E-04	1.06E-01	1.23E-04	1.00E-03	1.52E+00	0.00E+00	2.96E+00	0.00E+00	1.62E-03
BATCH-283	6/7/22	142	14.9	0.24	3.21E-06	1.67E+02	4.08E-05	5.40E-02	4.35E-05	4.62E-35	9.00E-03	9.56E-01	4.93E-04	1.90E-02	3.06E+01	0.00E+00	2.83E-07	4.00E+00	6.07E-03
BATCH-284	6/8/22	18	1.9	0.24	2.98E+01	0.00E+00	3.28E-05	5.38E-04	1.56E-05	4.06E-28	5.05E-04	6.60E-02	1.27E-05	1.00E-03	8.60E-01	0.00E+00	1.70E+00	0.00E+00	2.97E-04
BATCH-285	6/10/22	162	16.9	0.24	8.00E-03	1.90E+02	4.65E-05	6.20E-02	4.96E-05	8.97E-32	1.10E-02	1.09E+00	5.62E-04	2.20E-02	3.49E+01	0.00E+00	5.48E-04	4.56E+00	6.90E-03
BATCH-286	6/22/22	162	16.9	0.24	8.00E-03	1.90E+02	4.65E-05	6.20E-02	4.96E-05	5.98E-32	1.10E-02	1.09E+00	5.61E-04	2.20E-02	3.49E+01	0.00E+00	5.61E-04	4.56E+00	6.90E-03
BATCH-287	6/27/22	24	2.5	0.24	4.27E+01	0.00E+00	1.67E-04	1.00E-03	6.64E-05	4.47E-28	7.59E-04	1.16E-01	1.31E-04	1.00E-03	1.67E+00	0.00E+00	3.46E+00	0.00E+00	1.67E-03
BATCH-288	6/30/22	162	16.9	0.24	8.00E-03	1.90E+02	4.64E-05	6.10E-02	4.95E-05	5.94E-32	1.10E-02	1.09E+00	5.60E-04	2.20E-02	3.48E+01	0.00E+00	5.69E-04	4.55E+00	6.88E-03
BATCH-289	7/9/22	178	18.5	0.24	3.00E-03	1.86E+02	5.73E-06	8.00E-03	6.12E-06	4.69E-32	9.00E-03	5.56E-01	7.61E-05	8.30E-02	4.59E+01	0.00E+00	1.96E-04	5.29E+00	8.90E-04
BATCH-290	7/17/22	140	14.6	0.24	1.86E-09	1.44E+02	2.40E-08	3.15E-05	2.65E-08	2.67E-38	7.00E-03	3.74E-01	6.38E-06	7.10E-02	3.69E+01	0.00E+00	1.64E-10	4.19E+00	5.39E-05
BATCH-291	7/28/22	159	16.6	0.24	4.28E-06	1.64E+02	2.40E-08	3.15E-05	2.67E-08	4.55E-35	7.00E-03	4.27E-01	7.24E-06	8.10E-02	4.21E+01	0.00E+00	2.78E-07	4.78E+00	5.39E-05
BATCH-292	8/1/22	182	18.9	0.24	8.00E-03	1.87E+02	3.35E-08	4.90E-07	1.49E-08	8.84E-32	9.00E-03	4.87E-01	7.96E-06	9.20E-02	4.80E+01	0.00E+00	6.84E-04	5.45E+00	5.39E-05
BATCH-293	8/14/22	159	16.6	0.24	4.04E-06	1.64E+02	2.40E-08	3.14E-05	2.67E-08	3.03E-35	7.00E-03	4.27E-01	7.23E-06	8.10E-02	4.20E+01	0.00E+00	2.85E-07	4.77E+00	5.39E-05

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-245	11/24/21	101	10.6	0.24	4.05E-05	1.34E+01	1.10E-01	0.00E+00	0.00E+00	8.00E-04	2.30E+01	2.00E-03	3.00E-03	2.68E-01	2.51E-01	8.66E-04	1.73E+03	0.00E+00	1.58E-01
BATCH-246	11/26/21	101	10.6	0.24	4.05E-05	1.34E+01	1.10E-01	0.00E+00	0.00E+00	8.00E-04	2.30E+01	2.00E-03	3.00E-03	2.68E-01	2.50E-01	8.65E-04	1.73E+03	0.00E+00	1.57E-01
BATCH-247	12/5/21	112	11.7	0.24	4.49E-05	1.48E+01	1.22E-01	0.00E+00	0.00E+00	1.00E-03	2.55E+01	2.00E-03	4.00E-03	2.97E-01	2.78E-01	9.59E-04	1.92E+03	0.00E+00	1.75E-01
BATCH-248	12/7/21	76	7.9	0.24	3.03E-05	1.00E+01	8.20E-02	0.00E+00	0.00E+00	6.00E-04	1.72E+01	1.00E-03	2.00E-03	2.00E-01	1.88E-01	6.48E-04	1.30E+03	0.00E+00	1.18E-01
BATCH-249	12/15/21	101	10.5	0.24	4.03E-05	1.34E+01	1.09E-01	0.00E+00	0.00E+00	8.00E-04	2.29E+01	2.00E-03	3.00E-03	2.67E-01	2.50E-01	8.62E-04	1.73E+03	0.00E+00	1.57E-01
BATCH-250	12/16/21	138	14.4	0.24	9.88E-06	3.14E+01	8.51E-01	0.00E+00	0.00E+00	4.00E-04	1.52E+01	4.03E-04	8.54E-04	6.60E-02	9.10E-02	2.11E-04	2.36E+03	0.00E+00	1.57E-01
BATCH-251	12/26/21	154	16.1	0.24	4.71E-08	3.82E+01	1.12E+00	0.00E+00	0.00E+00	1.73E-04	1.31E+01	2.20E-06	8.78E-05	1.00E-03	4.20E-02	4.40E-07	2.63E+03	0.00E+00	1.61E-01
BATCH-252	12/31/21	154	16.1	0.24	4.71E-08	3.82E+01	1.12E+00	0.00E+00	0.00E+00	1.73E-04	1.31E+01	2.20E-06	8.77E-05	1.00E-03	4.10E-02	4.39E-07	2.63E+03	0.00E+00	1.61E-01
BATCH-253	1/11/22	115	12.0	0.24	4.04E-08	2.86E+01	8.37E-01	0.00E+00	0.00E+00	1.30E-04	9.79E+00	1.86E-06	6.61E-05	8.15E-04	3.10E-02	4.39E-07	1.97E+03	0.00E+00	1.20E-01
BATCH-254	1/16/22	171	17.8	0.24	5.00E-08	4.24E+01	1.24E+00	0.00E+00	0.00E+00	1.92E-04	1.45E+01	2.35E-06	9.72E-05	1.00E-03	4.60E-02	4.38E-07	2.92E+03	0.00E+00	1.78E-01
BATCH-255	1/23/22	154	16.0	0.24	4.70E-08	3.81E+01	1.12E+00	0.00E+00	0.00E+00	1.73E-04	1.30E+01	2.20E-06	8.75E-05	1.00E-03	4.10E-02	4.38E-07	2.63E+03	0.00E+00	1.60E-01
BATCH-256	2/3/22	134	14.0	0.24	2.89E-08	3.32E+01	9.74E-01	0.00E+00	0.00E+00	1.51E-04	1.14E+01	1.42E-06	7.54E-05	8.28E-04	3.60E-02	1.22E-07	2.29E+03	0.00E+00	1.40E-01
BATCH-257	2/9/22	94	9.8	0.24	5.01E-07	3.18E+01	1.36E+00	0.00E+00	0.00E+00	2.00E-04	1.78E+01	1.00E-03	2.01E-04	1.90E-02	6.43E-01	5.00E-03	1.56E+03	0.00E+00	4.74E-01
BATCH-258	2/18/22	91	9.5	0.24	5.47E-07	3.20E+01	1.41E+00	0.00E+00	0.00E+00	2.00E-04	1.85E+01	1.00E-03	2.14E-04	2.80E-02	1.16E-01	3.11E-04	1.97E+03	0.00E+00	3.66E-01
BATCH-259	2/19/22	115	12.0	0.24	5.54E-06	1.98E+01	4.57E-01	0.00E+00	0.00E+00	4.00E-04	8.97E+00	5.59E-04	7.07E-04	2.20E-02	7.15E-01	6.00E-03	1.73E+03	0.00E+00	5.27E-01
BATCH-260	2/27/22	101	10.5	0.24	6.08E-07	3.55E+01	1.56E+00	0.00E+00	0.00E+00	2.00E-04	2.06E+01	2.00E-03	2.37E-04	2.14E-04	1.90E-02	6.43E-01	5.00E-03	1.56E+03	0.00E+00	4.74E-01
BATCH-261	3/3/22	91	9.5	0.24	5.47E-07	3.20E+01	1.41E+00	0.00E+00	0.00E+00	2.00E-04	1.85E+01	1.00E-03	2.14E-04	1.90E-02	6.43E-01	5.00E-03	1.56E+03	0.00E+00	4.74E-01
BATCH-262	3/10/22	80	8.3	0.24	4.78E-07	2.80E+01	1.23E+00	0.00E+00	0.00E+00	2.00E-04	1.62E+01	1.00E-03	1.87E-04	1.70E-02	5.62E-01	5.00E-03	1.36E+03	0.00E+00	4.15E-01
BATCH-263	3/13/22	78	8.1	0.24	4.67E-07	2.73E+01	1.20E+00	0.00E+00	0.00E+00	2.00E-04	1.58E+01	1.00E-03	1.83E-04	1.70E-02	5.49E-01	5.00E-03	1.33E+03	0.00E+00	4.05E-01
BATCH-264	3/19/22	78	8.2	0.24	4.70E-07	2.75E+01	1.21E+00	0.00E+00	0.00E+00	2.00E-04	1.59E+01	1.00E-03	1.84E-04	1.70E-02	5.53E-01	5.00E-03	1.34E+03	0.00E+00	4.08E-01
BATCH-265	3/21/22	64	6.7	0.24	2.84E-06	1.01E+01	2.34E-01	0.00E+00	0.00E+00	1.84E-04	4.59E+00	2.86E-04	3.62E-04	1.40E-02	5.90E-02	1.59E-04	1.09E+03	0.00E+00	1.87E-01
BATCH-266	3/27/22	87	9.0	0.24	5.21E-07	3.05E+01	1.34E+00	0.00E+00	0.00E+00	2.00E-04	1.77E+01	1.00E-03	2.04E-04	1.90E-02	6.13E-01	5.00E-03	1.48E+03	0.00E+00	4.52E-01
BATCH-267	3/28/22	100	10.5	0.24	6.47E-06	2.85E+01	2.50E-01	0.00E+00	0.00E+00	1.71E-04	2.28E+01	2.00E-03	1.00E-03	1.80E-02	1.80E-01	6.00E-03	1.72E+03	0.00E+00	2.36E-01
BATCH-268	4/5/22	116	12.1	0.24	4.00E-06	1.28E+01	5.62E-01	0.00E+00	0.00E+00	2.00E-04	7.17E+00	4.35E-04	4.88E-04	2.60E-02	1.10E-01	5.65E-04	1.99E+03	0.00E+00	8.10E-02
BATCH-269	4/8/22	126	13.1	0.24	3.09E-06	1.41E+01	6.42E-01	0.00E+00	0.00E+00	2.00E-04	7.70E+00	4.95E-04	4.26E-04	2.00E-02	1.47E-01	9.12E-04	2.15E+03	0.00E+00	1.07E-01
BATCH-270	4/17/22	124	12.9	0.24	3.07E-06	1.38E+01	6.42E-01	0.00E+00	0.00E+00	2.00E-04	7.70E+00	5.12E-04	4.24E-04	2.10E-02	1.55E-01	9.84E-04	2.12E+03	0.00E+00	1.11E-01
BATCH-271	4/21/22	22	2.3	0.24	7.75E-07	2.77E+00	6.40E-02	0.00E+00	0.00E+00	5.04E-05	1.26E+00	7.82E-05	9.89E-05	4.00E-03	1.60E-02	4.35E-05	3.77E+02	0.00E+00	5.10E-02
BATCH-272	4/23/22	107	11.2	0.24	1.29E-06	1.00E+01	7.10E-01	0.00E+00	0.00E+00	8.51E-05	5.32E+00	3.03E-04	1.43E-04	1.10E-02	1.27E-01	9.99E-04	1.83E+03	0.00E+00	1.06E-01
BATCH-273	5/1/22	116	12.1	0.24	3.35E-06	1.34E+01	5.27E-01	0.00E+00	0.00E+00	2.00E-04	7.85E+00	5.37E-04	4.67E-04	2.00E-02	1.24E-01	1.00E-03	1.98E+03	0.00E+00	9.50E-02
BATCH-274	5/5/22	65	6.8	0.24	2.09E-06	6.65E+00	2.93E-01	0.00E+00	0.00E+00	1.21E-04	3.74E+00	2.27E-04	2.54E-04	1.30E-02	5.70E-02	2.95E-04	1.12E+03	0.00E+00	4.20E-02
BATCH-275	5/12/22	68	7.1	0.24	1.54E-06	7.02E+00	3.20E-01	0.00E+00	0.00E+00	1.14E-04	3.84E+00	2.47E-04	2.13E-04	1.00E-02	7.40E-02	4.55E-04	1.16E+03	0.00E+00	5.30E-02
BATCH-276	5/13/22	163	17.0	0.24	1.10E-05	4.54E+01	2.77E-01	0.00E+00	0.00E+00	2.00E-04	3.72E+01	3.00E-03	2.00E-03	2.80E-02	2.40E-01	1.00E-02	2.78E+03	0.00E+00	3.53E-01
BATCH-277	5/19/22	68	7.1	0.24	1.56E-06	7.02E+00	3.26E-01	0.00E+00	0.00E+00	1.16E-04	3.91E+00	2.60E-04	2.16E-04	1.00E-02	7.90E-02	5.00E-04	1.16E+03	0.00E+00	5.60E-02
BATCH-278	5/26/22	55	5.7	0.24	5.97E-07	4.61E+00	3.27E-01	0.00E+00	0.00E+00	3.92E-05	2.45E+00	1.40E-04	6.58E-05	5.00E-03	5.80E-02	4.60E-04	9.32E+02	0.00E+00	4.90E-02
BATCH-279	5/30/22	23	2.4	0.24	5.91E-07	1.89E+00	8.30E-02	0.00E+00	0.00E+00	3.44E-05	1.06E+00	6.44E-05	7.20E-05	4.00E-03	1.60E-02	8.35E-05	3.93E+02	0.00E+00	1.20E-02
BATCH-280	6/1/22	67	7.0	0.24	1.81E-06	7.19E+00	2.84E-01	0.00E+00	0.00E+00	1.17E-04	4.23E+00	2.89E-04	2.51E-04	1.10E-02	6.70E-02	5.57E-04	1.15E+03	0.00E+00	5.10E-02
BATCH-281	6/2/22	24	2.5	0.24	4.37E-07	1.99E+00	9.10E-02	0.00E+00	0.00E+00	3.24E-05	1.09E+00	7.01E-05	6.03E-05	3.00E-03	2.10E-02	1.29E-04	4.04E+02	0.00E+00	1.50E-02
BATCH-282	6/4/22	24	2.5	0.24	4.42E-07	1.99E+00	9.20E-02	0.00E+00	0.00E+00	3.28E-05	1.11E+00	7.37E-05	6.11E-05	3.00E-03	2.20E-02	1.42E-04	4.05E+02	0.00E+00	1.60E-02
BATCH-283	6/7/22	142	14.9	0.24	9.67E-06	3.98E+01	2.43E-01	0.00E+00	0.00E+00	2.00E-04	3.26E+01	3.00E-03	2.00E-03	2.50E-02	2.10E-01	9.00E-03	2.43E+03	0.00E+00	3.09E-01
BATCH-284	6/8/22	18	1.9	0.24	1.42E-07	1.09E+00	7.80E-02	0.00E+00	0.00E+00	9.30E-06	5.82E-01	3.32E-05	1.56E-05	1.00E-03	1.40E-02	1.09E-04	3.13E+02	0.00E+00	1.20E-02
BATCH-285	6/10/22	162	16.9	0.24	1.10E-05	4.54E+01	2.77E-01	0.00E+00	0.00E+00	2.00E-04	3.71E+01	3.00E-03	2.00E-03	2.80E-02	2.40E-01	1.00E-02	2.77E+03	0.00E+00	3.53E-01
BATCH-286	6/22/22	162	16.9	0.24	1.10E-05	4.53E+01	2.76E-01	0.00E+00	0.00E+00	2.00E-04	3.71E+01	3.00E-03	2.00E-03	2.80E-02	2.39E-01	1.00E-02	2.77E+03	0.00E+00	3.52E-01
BATCH-287	6/27/22	24	2.5	0.24	5.23E-07	2.08E+00	8.20E-02	0.00E+00	0.00E+00	3.39E-05	1.22E+00	8.37E-05	7.28E-05	3.00E-03	1.90E-02	1.61E-04	4.06E+02	0.00E+00	1.50E-02
BATCH-288	6/30/22	162	16.9	0.24	1.10E-05	4.53E+01	2.76E-01	0.00E+00	0.00E+00	2.00E-04	3.70E+01	3.00E-03	2.00E-03	2.80E-02	2.39E-01	1.00E-02	2.77E+03	0.00E+00	3.52E-01
BATCH-289	7/9/22	178	18.5	0.24	1.36E-06	5.47E+01	2.84E-01	0.00E+00	0.00E+00	2.00E-04	1.73E+01	3.88E-04	2.20E-04	3.00E-03	8.90E-02	1.00E-03	3.03E+03	0.00E+00	1.30E-01
BATCH-290	7/17/22	140	14.6	0.24	6.68E-09	4.35E+01	2.22E-01	0.00E+00	0.00E+00	1.69E-04	1.13E+01	1.76E-06	9.46E-07	3.15E-05	5.30E-02	5.09E-06	2.72E+03	0.00E+00	7.60E-02
BATCH-291	7/28/22	159	16.6	0.24	6.82E-09	4.96E+01	2.53E-01	0.00E+00	0.00E+00	1.93E-04	1.28E+01	1.78E-06	9.50E-07	3.40E-05	6.10E-02	5.09E-06	2.72E+03	0.00E+00	8.70E-02
BATCH-292	8/1/22	182	18.9	0.24	1.51E-09	5.66E+01	2.88E-01	0.00E+00	0.00E+00	2.00E-04	1.46E+01	2.23E-07	6.56E-08	2.32E-05	6.90E-02	3.81E-06	3.10E+03	0.00E+00	9.90E-02
BATCH-293	8/14/22	159	16.6	0.24	6.82E-09	4.95E+01	2.53E-01	0.00E+00	0.00E+00	1.93E-04	1.28E+01	1.77E-06	9.50E-07	3.39E-05	6.10E-02	5.09E-06	2.72E+03	0.00E+00	8.70E-02

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUN kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-245	11/24/21	101	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	1.17E+01	3.80E-05	8.24E+00	3.80E+01	1.70E-02	8.44E-06	0.00E+00	3.00E-02	9.90E-02	5.20E-02
BATCH-246	11/26/21	101	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	1.17E+01	3.80E-05	8.24E+00	3.79E+01	1.70E-02	8.43E-06	0.00E+00	3.00E-02	9.90E-02	5.20E-02
BATCH-247	12/5/21	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	1.29E+01	4.21E-05	9.14E+00	4.21E+01	1.90E-02	9.35E-06	0.00E+00	3.40E-02	1.09E-01	5.70E-02
BATCH-248	12/7/21	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	8.78E+00	2.84E-05	6.16E+00	2.84E+01	1.30E-02	6.31E-06	0.00E+00	2.30E-02	7.40E-02	3.90E-02
BATCH-249	12/15/21	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	1.17E+01	3.78E-05	8.20E+00	3.78E+01	1.70E-02	8.40E-06	0.00E+00	3.00E-02	9.80E-02	5.20E-02
BATCH-250	12/16/21	138	14.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.30E+01	9.25E-06	3.58E+00	4.19E+01	1.80E-02	2.05E-06	0.00E+00	1.50E-02	2.40E-02	2.20E-02
BATCH-251	12/26/21	154	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.09E+01	1.93E-08	2.15E+00	4.44E+01	1.90E-02	4.28E-09	0.00E+00	1.10E-02	1.76E-04	1.30E-02
BATCH-252	12/31/21	154	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.09E+01	1.93E-08	2.14E+00	4.44E+01	1.90E-02	4.28E-09	0.00E+00	1.10E-02	1.76E-04	1.30E-02
BATCH-253	1/11/22	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.06E+01	1.93E-08	1.61E+00	3.33E+01	1.40E-02	4.27E-09	0.00E+00	8.00E-03	1.44E-04	9.00E-03
BATCH-254	1/16/22	171	17.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.53E+01	1.93E-08	2.38E+00	4.93E+01	2.10E-02	4.27E-09	0.00E+00	1.20E-02	1.90E-04	1.40E-02
BATCH-255	1/23/22	154	16.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.08E+01	1.92E-08	2.14E+00	4.43E+01	1.90E-02	4.27E-09	0.00E+00	1.10E-02	1.76E-04	1.30E-02
BATCH-256	2/3/22	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.56E+01	5.37E-09	1.87E+00	3.87E+01	1.60E-02	1.19E-09	0.00E+00	9.00E-03	1.24E-04	1.10E-02
BATCH-257	2/9/22	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.90E-02	4.73E+01	4.08E-06	4.71E+00	3.07E+01	6.00E-03	7.96E-04	0.00E+00	5.40E-02	4.10E-02	2.40E-02
BATCH-258	2/18/22	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-02	4.88E+01	4.47E-06	5.00E+00	3.03E+01	5.00E-03	8.71E-04	0.00E+00	5.90E-02	4.40E-02	2.60E-02
BATCH-259	2/19/22	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	2.89E+01	8.62E-06	4.57E+01	2.13E+01	6.00E-03	3.86E-06	0.00E+00	1.90E-02	8.20E-02	2.20E-02
BATCH-260	2/27/22	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-01	5.42E+01	4.97E-06	5.55E+00	3.37E+01	5.00E-03	9.68E-04	0.00E+00	6.50E-02	4.90E-02	2.80E-02
BATCH-261	3/3/22	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-02	4.88E+01	4.47E-06	5.00E+00	3.03E+01	5.00E-03	8.71E-04	0.00E+00	5.90E-02	4.40E-02	2.60E-02
BATCH-262	3/10/22	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-02	4.27E+01	3.91E-06	4.37E+00	2.65E+01	4.00E-03	7.62E-04	0.00E+00	5.10E-02	3.90E-02	2.20E-02
BATCH-263	3/13/22	78	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	4.17E+01	3.82E-06	4.27E+00	2.59E+01	4.00E-03	7.44E-04	0.00E+00	5.00E-02	3.80E-02	2.20E-02
BATCH-264	3/19/22	78	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-02	4.19E+01	3.84E-06	4.29E+00	2.61E+01	4.00E-03	7.49E-04	0.00E+00	5.10E-02	3.80E-02	2.20E-02
BATCH-265	3/21/22	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.48E+01	4.41E-06	2.34E+01	1.09E+01	3.00E-03	1.98E-06	0.00E+00	1.00E-02	4.20E-02	1.10E-02
BATCH-266	3/27/22	87	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.30E-02	4.65E+01	4.26E-06	4.76E+00	2.89E+01	5.00E-03	8.31E-04	0.00E+00	5.60E-02	4.20E-02	2.40E-02
BATCH-267	3/28/22	100	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.74E+01	5.95E-06	4.46E+00	3.03E+01	1.30E-02	7.73E-04	0.00E+00	5.00E-02	4.20E-02	2.80E-02
BATCH-268	4/5/22	116	12.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	2.19E+01	5.99E-06	1.61E+01	1.59E+01	4.00E-03	6.33E-05	0.00E+00	1.80E-02	4.70E-02	1.40E-02
BATCH-269	4/8/22	126	13.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	2.42E+01	5.43E-06	2.02E+01	1.65E+01	3.00E-03	1.22E-04	0.00E+00	2.00E-02	4.80E-02	1.50E-02
BATCH-270	4/17/22	124	12.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	2.40E+01	5.45E-06	2.06E+01	1.61E+01	3.00E-03	1.33E-04	0.00E+00	2.00E-02	4.80E-02	1.50E-02
BATCH-271	4/21/22	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.05E+00	1.21E-06	6.40E+00	2.99E+00	8.94E-04	5.41E-07	0.00E+00	3.00E-03	1.20E-02	3.00E-03
BATCH-272	4/23/22	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	1.90E+01	1.92E-06	1.98E+01	1.19E+01	3.00E-03	1.56E-04	0.00E+00	1.50E-02	1.10E-02	7.00E-03
BATCH-273	5/1/22	116	12.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	2.28E+01	5.40E-06	1.62E+01	1.58E+01	4.00E-03	1.28E-04	0.00E+00	2.00E-02	4.70E-02	1.50E-02
BATCH-274	5/5/22	65	6.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.14E+01	3.12E-06	8.38E+00	8.27E+00	2.00E-03	3.30E-05	0.00E+00	8.00E-03	2.40E-02	7.00E-03
BATCH-275	5/12/22	68	7.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.21E+01	2.71E-06	1.01E+01	8.24E+00	2.00E-03	6.07E-05	0.00E+00	1.00E-02	2.40E-02	7.00E-03
BATCH-276	5/13/22	163	17.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	5.89E+01	9.74E-06	7.12E+00	4.87E+01	2.10E-02	1.00E-03	0.00E+00	7.90E-02	6.70E-02	4.50E-02
BATCH-277	5/19/22	68	7.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.22E+01	2.77E-06	1.05E+01	8.20E+00	2.00E-03	6.77E-05	0.00E+00	1.00E-02	2.40E-02	7.00E-03
BATCH-278	5/26/22	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	8.75E+00	8.85E-07	9.12E+00	5.51E+00	2.00E-03	7.20E-05	0.00E+00	7.00E-03	5.00E-03	3.00E-03
BATCH-279	5/30/22	23	2.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.24E+00	8.85E-07	2.38E+00	2.35E+00	5.50E-04	9.35E-06	0.00E+00	2.00E-03	7.00E-03	2.00E-03
BATCH-280	6/1/22	67	7.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.23E+01	2.91E-06	8.72E+00	8.52E+00	2.00E-03	6.90E-05	0.00E+00	1.10E-02	2.50E-02	8.00E-03
BATCH-281	6/2/22	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.42E+00	7.68E-07	2.86E+00	2.34E+00	4.72E-04	1.72E-05	0.00E+00	3.00E-03	7.00E-03	2.00E-03
BATCH-282	6/4/22	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.45E+00	7.84E-07	2.97E+00	2.32E+00	4.45E-04	1.92E-05	0.00E+00	3.00E-03	7.00E-03	2.00E-03
BATCH-283	6/7/22	142	14.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	5.16E+01	8.53E-06	6.23E+00	4.27E+01	1.80E-02	1.00E-03	0.00E+00	7.00E-02	5.80E-02	4.00E-02
BATCH-284	6/8/22	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.08E+00	2.10E-07	2.17E+00	1.31E+00	3.58E-04	1.71E-05	0.00E+00	2.00E-03	1.00E-03	8.06E-04
BATCH-285	6/10/22	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	5.88E+01	9.73E-06	7.11E+00	4.86E+01	2.10E-02	1.00E-03	0.00E+00	7.90E-02	6.70E-02	4.50E-02
BATCH-286	6/22/22	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	5.88E+01	9.72E-06	7.10E+00	4.86E+01	2.10E-02	1.00E-03	0.00E+00	7.90E-02	6.70E-02	4.50E-02
BATCH-287	6/27/22	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.56E+00	8.42E-07	2.52E+00	2.47E+00	5.48E-04	2.00E-05	0.00E+00	3.00E-03	7.00E-03	2.00E-03
BATCH-288	6/30/22	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	5.87E+01	9.70E-06	7.09E+00	4.85E+01	2.10E-02	1.00E-03	0.00E+00	7.90E-02	6.60E-02	4.50E-02
BATCH-289	7/9/22	178	18.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.59E+01	1.20E-06	6.25E+00	5.19E+01	1.90E-02	1.52E-04	0.00E+00	3.20E-02	8.00E-03	2.00E-02
BATCH-290	7/17/22	140	14.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.31E+01	4.95E-09	4.76E+00	4.06E+01	1.40E-02	6.25E-07	0.00E+00	1.90E-02	5.70E-05	1.30E-02
BATCH-291	7/28/22	159	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.92E+01	4.94E-09	5.43E+00	4.64E+01	1.60E-02	6.24E-07	0.00E+00	2.20E-02	6.02E-05	1.50E-02
BATCH-292	8/1/22	182	18.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.61E+01	1.81E-10	6.19E+00	5.29E+01	1.90E-02	4.60E-09	0.00E+00	2.50E-02	3.16E-05	1.70E-02
BATCH-293	8/14/22	159	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.91E+01	4.94E-09	5.43E+00	4.63E+01	1.60E-02	6.24E-07	0.00E+00	2.20E-02	6.02E-05	1.50E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H Ci	14-C Ci	59-Ni Ci	60-Co Ci	63-Ni Ci	79-Se Ci	90-Sr Ci	93-Zr Ci	93m-Nb Ci	99-Tc Ci	106-Ru Ci	113m-Cd Ci	125-Sb Ci	126-Sn Ci	129-I Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-294	8/20/22	159	16.6	0.24	0.00E+00	0.00E+00	1.04E-01	3.60E-02	8.22E+00	4.08E-01	3.18E+03	8.33E-01	1.41E-01	1.58E+01	1.48E-12	1.83E+00	7.00E-03	1.49E-01	1.53E-02
BATCH-295	8/31/22	111	11.6	0.24	0.00E+00	0.00E+00	1.11E-01	6.20E-02	8.83E+00	3.72E-01	2.22E+03	1.08E+00	1.93E-01	1.11E+01	1.66E-12	1.57E+00	1.00E-02	2.41E-01	1.23E-02
BATCH-296	9/6/22	68	7.1	0.24	0.00E+00	0.00E+00	9.40E-02	6.30E-02	7.50E+00	2.86E-01	1.36E+03	9.95E-01	1.83E-01	6.80E+00	1.55E-12	1.16E+00	9.00E-03	2.39E-01	8.75E-03
BATCH-297	9/11/22	78	8.1	0.24	0.00E+00	0.00E+00	1.07E-01	7.20E-02	8.55E+00	3.27E-01	1.56E+03	1.14E+00	2.08E-01	7.75E+00	1.76E-12	1.32E+00	1.10E-02	2.73E-01	1.00E-02
BATCH-298	9/13/22	89	9.3	0.24	0.00E+00	0.00E+00	1.23E-01	8.30E-02	9.76E+00	3.73E-01	1.78E+03	1.30E+00	2.38E-01	8.85E+00	2.01E-12	1.51E+00	1.20E-02	3.12E-01	1.13E-02
BATCH-299	9/20/22	78	8.1	0.24	0.00E+00	0.00E+00	1.07E-01	7.20E-02	8.54E+00	3.26E-01	1.56E+03	1.13E+00	2.08E-01	7.75E+00	1.76E-12	1.32E+00	1.10E-02	2.73E-01	1.00E-02
BATCH-300	9/22/22	78	8.1	0.24	0.00E+00	0.00E+00	1.07E-01	7.20E-02	8.54E+00	3.26E-01	1.55E+03	1.13E+00	2.08E-01	7.74E+00	1.76E-12	1.32E+00	1.10E-02	2.73E-01	1.00E-02
BATCH-301	9/28/22	79	8.2	0.24	0.00E+00	0.00E+00	1.09E-01	7.40E-02	8.69E+00	3.31E-01	1.58E+03	1.15E+00	2.12E-01	7.88E+00	1.79E-12	1.34E+00	1.10E-02	2.77E-01	1.00E-02
BATCH-302	10/1/22	71	7.4	0.24	0.00E+00	0.00E+00	7.90E-02	5.00E-02	6.31E+00	2.66E-01	1.42E+03	8.84E-01	1.67E-01	7.08E+00	1.25E-12	9.64E-01	8.00E-03	2.00E-01	8.25E-03
BATCH-303	10/7/22	104	10.8	0.24	0.00E+00	0.00E+00	6.60E-02	2.90E-02	5.19E+00	3.02E-01	2.08E+03	8.82E-01	1.82E-01	1.04E+01	8.73E-13	7.53E-01	8.00E-03	1.62E-01	9.75E-03
BATCH-304	10/8/22	119	12.4	0.24	0.00E+00	0.00E+00	7.50E-02	3.30E-02	5.93E+00	3.44E-01	2.37E+03	1.01E+00	2.08E-01	1.18E+01	9.96E-13	8.60E-01	9.00E-03	1.84E-01	1.13E-02
BATCH-305	10/18/22	104	10.8	0.24	0.00E+00	0.00E+00	6.60E-02	2.90E-02	5.19E+00	3.02E-01	2.08E+03	8.81E-01	1.82E-01	1.03E+01	8.73E-13	7.53E-01	8.00E-03	1.61E-01	9.75E-03
BATCH-306	10/21/22	104	10.8	0.24	0.00E+00	0.00E+00	6.60E-02	2.90E-02	5.19E+00	3.02E-01	2.08E+03	8.81E-01	1.82E-01	1.03E+01	8.72E-13	7.53E-01	8.00E-03	1.61E-01	9.75E-03
BATCH-307	10/29/22	106	11.0	0.24	0.00E+00	0.00E+00	6.70E-02	3.00E-02	5.28E+00	3.07E-01	2.11E+03	8.97E-01	1.85E-01	1.05E+01	8.88E-13	7.66E-01	8.00E-03	1.64E-01	1.00E-02
BATCH-308	11/1/22	89	9.2	0.24	0.00E+00	0.00E+00	4.40E-02	4.00E-02	3.50E+00	1.18E-01	1.56E+03	3.60E-01	6.40E-02	5.56E+00	8.80E-11	5.76E-01	4.00E-03	1.06E-01	6.00E-03
BATCH-309	11/9/22	98	10.3	0.24	0.00E+00	0.00E+00	6.20E-02	2.70E-02	4.91E+00	2.85E-01	1.97E+03	8.34E-01	1.72E-01	9.79E+00	8.25E-13	7.12E-01	7.00E-03	1.53E-01	9.25E-03
BATCH-310	11/10/22	112	11.7	0.24	0.00E+00	0.00E+00	7.10E-02	3.10E-02	5.59E+00	3.25E-01	2.24E+03	9.49E-01	1.96E-01	1.12E+01	9.39E-13	8.11E-01	8.00E-03	1.74E-01	1.05E-02
BATCH-311	11/20/22	102	10.7	0.24	0.00E+00	0.00E+00	5.90E-02	2.60E-02	4.68E+00	2.84E-01	2.04E+03	8.24E-01	1.73E-01	1.02E+01	1.10E-10	6.66E-01	7.00E-03	1.45E-01	9.50E-03
BATCH-312	11/22/22	104	10.9	0.24	0.00E+00	0.00E+00	5.90E-02	2.50E-02	4.66E+00	2.86E-01	2.08E+03	8.29E-01	1.74E-01	1.04E+01	1.41E-10	6.61E-01	7.00E-03	1.44E-01	9.50E-03
BATCH-313	12/1/22	106	11.1	0.24	0.00E+00	0.00E+00	6.00E-02	2.60E-02	4.74E+00	2.92E-01	2.12E+03	8.45E-01	1.78E-01	1.06E+01	1.44E-10	6.73E-01	8.00E-03	1.47E-01	9.75E-03
BATCH-314	12/3/22	56	5.8	0.24	0.00E+00	0.00E+00	2.50E-02	2.30E-02	2.00E+00	6.66E-02	8.88E+02	2.06E-01	3.60E-02	3.17E+00	5.02E-11	3.29E-01	2.00E-03	6.10E-02	3.50E-03
BATCH-315	12/9/22	99	10.3	0.24	0.00E+00	0.00E+00	5.60E-02	2.40E-02	4.41E+00	2.71E-01	1.97E+03	7.85E-01	1.65E-01	9.83E+00	1.34E-10	6.26E-01	7.00E-03	1.37E-01	9.00E-03
BATCH-316	12/12/22	113	11.7	0.24	0.00E+00	0.00E+00	6.40E-02	2.80E-02	5.03E+00	3.09E-01	2.25E+03	8.96E-01	1.89E-01	1.12E+01	1.52E-10	7.14E-01	8.00E-03	1.56E-01	1.03E-02
BATCH-317	12/20/22	98	10.2	0.24	0.00E+00	0.00E+00	5.50E-02	2.40E-02	4.37E+00	2.68E-01	1.95E+03	7.77E-01	1.64E-01	9.73E+00	1.32E-10	6.19E-01	7.00E-03	1.35E-01	9.00E-03
BATCH-318	12/24/22	98	10.2	0.24	0.00E+00	0.00E+00	5.50E-02	2.40E-02	4.38E+00	2.69E-01	1.96E+03	7.80E-01	1.64E-01	9.76E+00	1.33E-10	6.21E-01	7.00E-03	1.36E-01	9.00E-03
BATCH-319	12/30/22	19	2.0	0.24	0.00E+00	0.00E+00	6.00E-03	6.00E-03	5.01E-01	1.71E-02	2.23E+02	5.20E-02	9.00E-03	7.95E-01	1.26E-11	8.20E-02	5.34E-04	1.50E-02	7.50E-04
BATCH-320	1/1/23	100	10.4	0.24	0.00E+00	0.00E+00	5.60E-02	2.10E-02	4.42E+00	2.74E-01	1.99E+03	7.93E-01	1.59E-01	9.93E+00	6.79E-11	6.03E-01	6.00E-03	1.38E-01	9.25E-03
BATCH-321	1/3/23	81	8.4	0.24	0.00E+00	0.00E+00	6.60E-02	2.70E-02	5.19E+00	2.72E-01	1.62E+03	7.55E-01	1.35E-01	8.06E+00	4.87E-11	7.29E-01	5.00E-03	1.68E-01	8.50E-03
BATCH-322	1/12/23	85	8.9	0.24	0.00E+00	0.00E+00	8.80E-02	3.70E-02	6.91E+00	3.30E-01	1.70E+03	8.96E-01	1.47E-01	8.46E+00	4.52E-11	9.86E-01	6.00E-03	2.28E-01	1.00E-02
BATCH-323	1/12/23	74	7.7	0.24	0.00E+00	0.00E+00	7.60E-02	3.20E-02	6.00E+00	2.87E-01	1.47E+03	7.78E-01	1.28E-01	7.34E+00	3.92E-11	8.56E-01	5.00E-03	1.98E-01	8.75E-03
BATCH-324	1/20/23	119	12.4	0.24	0.00E+00	0.00E+00	1.23E-01	5.20E-02	9.69E+00	4.64E-01	2.38E+03	1.26E+00	2.07E-01	1.19E+01	6.33E-11	1.38E+00	9.00E-03	3.19E-01	1.40E-02
BATCH-325	1/21/23	74	7.7	0.24	0.00E+00	0.00E+00	7.60E-02	3.30E-02	6.02E+00	2.88E-01	1.48E+03	7.80E-01	1.28E-01	7.37E+00	3.94E-11	8.59E-01	5.00E-03	1.98E-01	8.75E-03
BATCH-326	1/29/23	81	8.5	0.24	0.00E+00	0.00E+00	3.20E-02	2.10E-02	2.51E+00	1.02E-01	1.36E+03	2.93E-01	5.10E-02	5.03E+00	2.57E-11	4.04E-01	2.00E-03	7.40E-02	4.50E-03
BATCH-327	2/2/23	75	7.9	0.24	0.00E+00	0.00E+00	7.80E-02	3.30E-02	6.13E+00	2.93E-01	1.51E+03	7.95E-01	1.31E-01	7.51E+00	4.01E-11	8.75E-01	5.00E-03	2.02E-01	9.00E-03
BATCH-328	2/7/23	80	8.3	0.24	0.00E+00	0.00E+00	3.20E-02	2.10E-02	2.49E+00	1.01E-01	1.32E+03	2.88E-01	5.00E-02	4.96E+00	2.58E-11	4.02E-01	2.00E-03	7.30E-02	4.50E-03
BATCH-329	2/10/23	82	8.5	0.24	0.00E+00	0.00E+00	8.40E-02	3.60E-02	6.65E+00	3.18E-01	1.63E+03	8.62E-01	1.42E-01	8.14E+00	4.35E-11	9.49E-01	6.00E-03	2.19E-01	9.75E-03
BATCH-330	2/15/23	79	8.2	0.24	0.00E+00	0.00E+00	3.10E-02	2.10E-02	2.45E+00	9.90E-02	1.29E+03	2.83E-01	4.90E-02	4.88E+00	2.62E-11	3.95E-01	2.00E-03	7.20E-02	4.25E-03
BATCH-331	2/19/23	115	11.9	0.24	0.00E+00	0.00E+00	1.18E-01	5.00E-02	9.31E+00	4.46E-01	2.29E+03	1.21E+00	1.99E-01	1.14E+01	6.09E-11	1.33E+00	8.00E-03	3.07E-01	1.35E-02
BATCH-332	2/24/23	56	5.9	0.24	0.00E+00	0.00E+00	2.00E-02	1.30E-02	1.58E+00	6.39E-02	8.53E+02	1.85E-01	3.20E-02	3.17E+00	1.62E-11	2.55E-01	1.00E-03	4.60E-02	2.75E-03
BATCH-333	3/2/23	59	6.1	0.24	0.00E+00	0.00E+00	3.50E-02	1.70E-02	2.78E+00	1.90E-01	1.17E+03	4.13E-01	6.80E-02	5.85E+00	6.65E-12	4.31E-01	3.00E-03	9.00E-02	4.50E-03
BATCH-334	3/3/23	56	5.8	0.24	0.00E+00	0.00E+00	2.00E-02	1.30E-02	1.59E+00	6.39E-02	8.38E+02	1.83E-01	3.20E-02	3.16E+00	1.64E-11	2.56E-01	1.00E-03	4.70E-02	2.75E-03
BATCH-335	3/8/23	64	6.6	0.24	0.00E+00	0.00E+00	3.80E-02	1.80E-02	2.98E+00	2.05E-01	1.27E+03	4.44E-01	7.30E-02	6.33E+00	6.81E-12	4.63E-01	3.00E-03	9.60E-02	4.75E-03
BATCH-336	3/9/23	56	5.8	0.24	0.00E+00	0.00E+00	2.00E-02	1.30E-02	1.59E+00	6.39E-02	8.39E+02	1.83E-01	3.20E-02	3.16E+00	1.70E-11	2.56E-01	1.00E-03	4.70E-02	2.75E-03
BATCH-337	3/15/23	20	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.00E-03	4.33E-01	1.80E-02	2.34E+02	5.10E-02	9.00E-03	8.68E-01	4.43E-12	7.00E-02	3.83E-04	1.30E-02	7.50E-04
BATCH-338	3/15/23	89	9.3	0.24	0.00E+00	0.00E+00	5.30E-02	2.50E-02	4.18E+00	2.88E-01	1.78E+03	6.23E-01	1.03E-01	8.88E+00	9.55E-12	6.49E-01	4.00E-03	1.35E-01	6.75E-03
BATCH-339	3/17/23	101	10.5	0.24	0.00E+00	0.00E+00	3.10E-02	1.50E-02	2.42E+00	1.16E-01	1.78E+03	2.99E-01	5.20E-02	6.48E+00	1.37E-11	4.17E-01	2.00E-03	6.50E-02	4.25E-03
BATCH-340	3/24/23	20	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.00E-03	4.30E-01	1.71E-02	2.27E+02	5.00E-02	9.00E-03	8.55E-01	4.44E-12	6.90E-02	3.76E-04	1.30E-02	7.50E-04
BATCH-341	3/26/23	85	8.8	0.24	0.00E+00	0.00E+00	2.20E-02	9.00E-03	1.76E+00	9.36E-02	1.49E+03	2.35E-01	4.10E-02	5.55E+00	4.33E-12	3.00E-01	2.00E-03	4.70E-02	3.00E-03
BATCH-342	3/28/23	20	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.00E-03	4.31E-01	1.71E-02	2.27E+02	5.00E-02	9.00E-03	8.57E-01	4.61E-12	6.90E-02	3.77E-04	1.30E-02	7.50E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-294	8/20/22	159	16.6	0.24	1.26E-06	4.76E+02	2.66E+02	2.70E-02	1.76E+00	1.31E-01	1.27E-04	1.02E-05	7.33E-04	1.46E-04	1.81E-04	4.74E-04	1.60E-02	8.00E-02	2.30E-02
BATCH-295	8/31/22	111	11.6	0.24	8.17E-07	3.33E+02	4.45E+02	4.70E-02	3.11E+00	2.32E-01	3.68E-05	1.64E-05	7.85E-04	2.65E-04	2.61E-04	1.00E-03	2.70E-02	1.37E-01	3.10E-02
BATCH-296	9/6/22	68	7.1	0.24	4.58E-07	2.05E-02	4.47E+02	4.80E-02	3.17E+00	2.37E-01	2.45E-05	1.63E-05	6.65E-04	2.72E-04	2.51E-04	1.00E-03	2.80E-02	1.39E-01	3.00E-02
BATCH-297	9/11/22	78	8.1	0.24	5.22E-07	2.34E+02	5.10E+02	5.40E-02	3.61E+00	2.71E-01	2.80E-05	1.86E-05	7.59E-04	3.11E-04	2.86E-04	1.00E-03	3.10E-02	1.58E-01	3.40E-02
BATCH-298	9/13/22	89	9.3	0.24	5.96E-07	2.66E+02	5.82E+02	6.20E-02	4.12E+00	3.09E-01	3.19E-05	2.12E-05	8.66E-04	3.54E-04	3.27E-04	1.00E-03	3.60E-02	1.80E-01	3.80E-02
BATCH-299	9/20/22	78	8.1	0.24	5.22E-07	2.33E+02	5.10E+02	5.40E-02	3.61E+00	2.70E-01	2.79E-05	1.86E-05	7.58E-04	3.10E-04	2.86E-04	1.00E-03	3.10E-02	1.58E-01	3.40E-02
BATCH-300	9/22/22	78	8.1	0.24	5.22E-07	2.33E+02	5.10E+02	5.40E-02	3.61E+00	2.70E-01	2.79E-05	1.86E-05	7.58E-04	3.10E-04	2.86E-04	1.00E-03	3.10E-02	1.58E-01	3.40E-02
BATCH-301	9/28/22	79	8.2	0.24	5.30E-07	2.37E+02	5.18E+02	5.50E-02	3.67E+00	2.75E-01	2.84E-05	1.89E-05	7.71E-04	3.16E-04	2.91E-04	1.00E-03	3.20E-02	1.61E-01	3.40E-02
BATCH-302	10/1/22	71	7.4	0.24	3.91E-07	2.13E+02	3.73E+02	3.80E-02	2.59E+00	1.90E-01	1.95E-05	1.37E-05	5.15E-04	2.08E-04	2.24E-04	8.59E-04	2.20E-02	1.09E-01	2.50E-02
BATCH-303	10/7/22	104	10.8	0.24	3.43E-07	3.12E+02	2.97E+02	2.60E-02	1.90E+00	1.26E-01	1.27E-05	1.11E-05	2.75E-04	1.03E-04	2.25E-04	4.23E-04	1.30E-02	6.40E-02	2.30E-02
BATCH-304	10/8/22	119	12.4	0.24	3.91E-07	3.56E+02	3.39E+02	3.00E-02	2.17E+00	1.44E-01	1.44E-05	1.26E-05	3.14E-04	1.17E-04	2.56E-04	4.82E-04	1.50E-02	7.30E-02	2.60E-02
BATCH-305	10/18/22	104	10.8	0.24	3.43E-07	3.12E+02	2.97E+02	2.60E-02	1.90E+00	1.26E-01	1.26E-05	1.11E-05	2.75E-04	1.03E-04	2.25E-04	4.22E-04	1.30E-02	6.40E-02	2.30E-02
BATCH-306	10/21/22	104	10.8	0.24	3.43E-07	3.12E+02	2.97E+02	2.60E-02	1.90E+00	1.26E-01	1.26E-05	1.11E-05	2.75E-04	1.03E-04	2.25E-04	4.22E-04	1.30E-02	6.40E-02	2.30E-02
BATCH-307	10/29/22	106	11.0	0.24	3.49E-07	3.17E+02	3.03E+02	2.70E-02	1.93E+00	1.29E-01	1.29E-05	1.13E-05	2.80E-04	1.05E-04	2.29E-04	4.30E-04	1.30E-02	6.50E-02	2.30E-02
BATCH-308	11/1/22	89	9.2	0.24	8.87E-07	2.65E+02	1.73E+02	1.70E-02	9.58E-01	1.08E-01	2.90E-02	6.65E-06	2.74E-04	8.87E-05	9.22E-05	3.32E-04	8.00E-03	4.10E-02	1.20E-02
BATCH-309	11/9/22	98	10.3	0.24	3.24E-07	2.95E+02	2.81E+02	2.50E-02	1.79E+00	1.19E-01	1.20E-05	1.05E-05	2.60E-04	9.69E-05	2.12E-04	3.99E-04	1.20E-02	6.00E-02	2.20E-02
BATCH-310	11/10/22	112	11.7	0.24	3.69E-07	3.36E+02	3.20E+02	2.80E-02	2.04E+00	1.36E-01	1.36E-05	1.19E-05	2.96E-04	1.10E-04	2.42E-04	4.54E-04	1.40E-02	6.90E-02	2.50E-02
BATCH-311	11/20/22	102	10.7	0.24	3.93E-07	3.06E+02	2.68E+02	2.20E-02	1.69E+00	1.11E-01	2.80E-02	1.00E-05	2.08E-04	7.63E-05	2.08E-04	3.04E-04	1.00E-02	5.10E-02	2.10E-02
BATCH-312	11/22/22	104	10.9	0.24	4.16E-07	3.12E+02	2.67E+02	2.20E-02	1.68E+00	1.09E-01	3.60E-02	1.00E-05	1.96E-04	7.13E-05	2.09E-04	2.81E-04	1.00E-02	4.90E-02	2.10E-02
BATCH-313	12/1/22	106	11.1	0.24	4.24E-07	3.18E+02	2.72E+02	2.30E-02	1.71E+00	1.11E-01	3.70E-02	1.02E-05	2.00E-04	7.26E-05	2.13E-04	2.86E-04	1.00E-02	5.00E-02	2.10E-02
BATCH-314	12/3/22	56	5.8	0.24	5.06E-07	1.67E+02	9.89E+01	1.00E-02	5.47E-01	6.20E-02	1.70E-02	3.79E-06	1.57E-04	5.06E-05	5.26E-05	1.89E-04	5.00E-03	2.30E-02	7.00E-03
BATCH-315	12/5/22	99	10.3	0.24	3.94E-07	2.96E+02	2.53E+02	2.10E-02	1.59E+00	1.04E-01	3.40E-02	9.49E-06	1.86E-04	6.75E-05	1.98E-04	2.66E-04	9.00E-03	4.60E-02	2.00E-02
BATCH-316	12/12/22	113	11.7	0.24	4.50E-07	3.38E+02	2.88E+02	2.40E-02	1.81E+00	1.18E-01	3.90E-02	1.08E-05	2.12E-04	7.71E-05	2.26E-04	3.04E-04	1.10E-02	5.30E-02	2.30E-02
BATCH-317	12/20/22	98	10.2	0.24	3.90E-07	2.93E+02	2.50E+02	2.10E-02	1.57E+00	1.03E-01	3.40E-02	9.39E-06	1.84E-04	6.68E-05	1.96E-04	2.63E-04	9.00E-03	4.60E-02	2.00E-02
BATCH-318	12/24/22	98	10.2	0.24	3.92E-07	2.94E+02	2.51E+02	2.10E-02	1.58E+00	1.03E-01	3.40E-02	9.43E-06	1.85E-04	6.71E-05	1.96E-04	2.64E-04	9.00E-03	4.60E-02	2.00E-02
BATCH-319	12/30/22	19	2.0	0.24	1.27E-07	5.68E+01	2.48E+01	3.00E-03	1.37E-01	1.50E-02	4.00E-03	9.51E-07	3.93E-05	1.27E-05	1.32E-05	4.75E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-320	1/1/23	100	10.4	0.24	2.85E-07	2.99E+02	2.53E+02	2.00E-02	1.48E+00	9.10E-02	3.40E-02	9.29E-06	1.69E-04	6.82E-05	2.00E-04	2.69E-04	9.00E-03	4.70E-02	2.00E-02
BATCH-321	1/3/23	81	8.4	0.24	3.57E-07	2.43E+02	3.05E+02	2.70E-02	1.87E+00	1.22E-01	2.80E-02	1.10E-05	2.84E-04	1.32E-04	1.95E-04	5.51E-04	1.50E-02	7.70E-02	2.40E-02
BATCH-322	1/12/23	85	8.9	0.24	4.91E-07	2.55E+02	4.12E+02	3.80E-02	2.57E+00	1.73E-01	3.00E-02	1.47E-05	4.33E-04	2.10E-04	2.34E-04	8.83E-04	2.30E-02	1.17E-01	3.20E-02
BATCH-323	1/12/23	74	7.7	0.24	4.26E-07	2.21E+02	3.58E+02	3.30E-02	2.23E+00	1.50E-01	2.60E-02	1.28E-05	3.76E-04	1.82E-04	2.04E-04	7.67E-04	2.00E-02	1.01E-01	2.80E-02
BATCH-324	1/20/23	119	12.4	0.24	6.88E-07	3.57E+02	5.78E+02	5.40E-02	3.61E+00	2.42E-01	4.20E-02	2.07E-05	6.08E-04	2.94E-04	3.29E-04	1.00E-03	3.20E-02	1.64E-01	4.50E-02
BATCH-325	1/21/23	74	7.7	0.24	4.27E-07	2.22E+02	3.59E+02	3.30E-02	2.24E+00	1.50E-01	2.60E-02	1.28E-05	3.78E-04	1.83E-04	2.04E-04	7.69E-04	2.00E-02	1.02E-01	2.80E-02
BATCH-326	1/29/23	81	8.5	0.24	3.78E-07	2.44E+02	1.23E+02	1.10E-02	6.63E-01	6.10E-02	1.70E-02	4.58E-06	1.69E-04	5.85E-05	7.36E-05	2.19E-04	6.00E-03	2.90E-02	9.00E-03
BATCH-327	2/2/23	75	7.9	0.24	4.35E-07	2.26E+02	3.66E+02	3.40E-02	2.28E+00	1.53E-01	2.70E-02	1.31E-05	3.84E-04	1.86E-04	2.08E-04	7.84E-04	2.00E-02	1.04E-01	2.90E-02
BATCH-328	2/7/23	80	8.3	0.24	3.77E-07	2.39E+02	1.22E+02	1.10E-02	6.61E-01	6.10E-02	1.70E-02	4.55E-06	1.69E-04	5.88E-05	7.24E-05	2.21E-04	6.00E-03	2.90E-02	9.00E-03
BATCH-329	2/10/23	82	8.5	0.24	4.72E-07	2.45E+02	3.96E+02	3.70E-02	2.48E+00	1.66E-01	2.90E-02	1.42E-05	4.17E-04	2.02E-04	2.26E-04	8.50E-04	2.20E-02	1.12E-01	3.10E-02
BATCH-330	2/15/23	79	8.2	0.24	3.72E-07	2.36E+02	1.20E+02	1.10E-02	6.49E-01	6.00E-02	1.70E-02	4.48E-06	1.66E-04	5.77E-05	7.11E-05	2.16E-04	6.00E-03	2.90E-02	9.00E-03
BATCH-331	2/19/23	115	11.9	0.24	6.61E-07	3.43E+02	5.55E+02	5.10E-02	3.47E+00	2.33E-01	4.00E-02	1.98E-05	5.84E-04	2.83E-04	3.16E-04	1.00E-03	3.10E-02	1.57E-01	4.40E-02
BATCH-332	2/24/23	56	5.9	0.24	2.38E-07	1.68E+02	7.75E+01	7.00E-03	4.18E-01	3.90E-02	1.00E-02	2.89E-06	1.06E-04	3.68E-05	4.64E-05	1.38E-04	4.00E-03	1.80E-02	6.00E-03
BATCH-333	3/2/23	59	6.1	0.24	2.50E-07	1.76E+02	1.58E+02	1.60E-02	1.04E+00	7.10E-02	4.00E-03	5.51E-06	2.25E-04	1.02E-04	1.00E-04	4.50E-04	1.00E-02	5.20E-02	1.20E-02
BATCH-334	3/3/23	56	5.8	0.24	2.40E-07	1.67E+02	7.79E+01	7.00E-03	4.21E-01	3.90E-02	1.10E-02	2.90E-06	1.08E-04	3.75E-05	4.61E-05	1.41E-04	4.00E-03	1.90E-02	6.00E-03
BATCH-335	3/8/23	64	6.6	0.24	2.69E-07	1.91E+02	1.69E+02	1.70E-02	1.11E+00	7.60E-02	4.00E-03	5.89E-06	2.42E-04	1.09E-04	1.08E-04	4.85E-04	1.10E-02	5.50E-02	1.30E-02
BATCH-336	3/9/23	56	5.8	0.24	2.41E-07	1.68E+02	7.79E+01	7.00E-03	4.20E-01	3.90E-02	1.10E-02	2.90E-06	1.08E-04	3.74E-05	4.61E-05	1.40E-04	4.00E-03	1.90E-02	6.00E-03
BATCH-337	3/15/23	20	2.1	0.24	6.51E-08	5.99E+01	2.12E+01	2.00E-03	1.14E-01	1.10E-02	3.00E-03	7.90E-07	2.91E-05	1.01E-05	1.27E-05	3.77E-05	9.88E-04	5.00E-03	2.00E-03
BATCH-338	3/15/23	89	9.3	0.24	3.77E-07	2.68E+02	2.38E+02	2.30E-02	1.56E+00	1.06E-01	6.00E-03	8.26E-06	3.40E-04	1.53E-04	1.51E-04	6.80E-04	1.50E-02	7.80E-02	1.80E-02
BATCH-339	3/17/23	101	10.5	0.24	2.69E-07	3.03E+02	1.14E+02	1.10E-02	6.71E-01	5.20E-02	8.00E-03	4.16E-06	1.71E-04	5.70E-05	7.25E-05	2.18E-04	6.00E-03	3.00E-02	9.00E-03
BATCH-340	3/24/23	20	2.1	0.24	6.49E-08	5.92E+01	2.11E+01	2.00E-03	1.14E-01	1.10E-02	3.00E-03	7.84E-07	2.91E-05	1.01E-05	1.25E-05	3.80E-05	9.91E-04	5.00E-03	2.00E-03
BATCH-341	3/26/23	85	8.8	0.24	1.42E-07	2.53E+02	8.54E+01	8.00E-03	5.30E-01	3.60E-02	2.00E-03	3.09E-06	1.22E-04	4.26E-05	5.69E-05	1.68E-04	5.00E-03	2.40E-02	7.00E-03
BATCH-342	3/28/23	20	2.1	0.24	6.54E-08	5.94E+01	2.11E+01	2.00E-03	1.14E-01	1.10E-02	3.00E-03	7.86E-07	2.92E-05	1.01E-05	1.25E-05	3.80E-05	9.91E-04	5.00E-03	2.00E-03

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	239-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-294	8/20/22	159	16.6	0.24	9.23E-04	6.94E-04	3.80E-02	3.40E-02	2.60E-02	1.55E+00	2.69E-01	1.58E+00	7.32E-01	1.37E-21	1.55E-05	5.60E-05	4.84E-04	4.00E-03	2.35E-07
BATCH-295	8/31/22	111	11.6	0.24	1.00E-03	9.82E-04	4.60E-02	4.80E-02	3.90E-02	2.05E+00	3.52E-01	2.28E+00	1.05E+00	1.55E-21	2.22E-05	8.56E-05	7.01E-04	4.00E-03	6.52E-07
BATCH-296	9/6/22	68	7.1	0.24	1.00E-03	9.37E-04	4.20E-02	4.50E-02	3.70E-02	1.91E+00	3.27E-01	2.19E+00	1.01E+00	1.35E-21	2.13E-05	8.38E-05	6.74E-04	4.00E-03	8.03E-07
BATCH-297	9/11/22	78	8.1	0.24	1.00E-03	1.00E-03	4.80E-02	5.20E-02	4.30E-02	2.18E+00	3.73E-01	2.50E+00	1.15E+00	1.55E-21	2.44E-05	9.56E-05	7.69E-04	4.00E-03	9.16E-07
BATCH-298	9/13/22	89	9.3	0.24	2.00E-03	1.00E-03	5.50E-02	5.90E-02	4.90E-02	2.49E+00	4.25E-01	2.86E+00	1.31E+00	1.76E-21	2.78E-05	1.09E-04	8.78E-04	5.00E-03	1.05E-06
BATCH-299	9/20/22	78	8.1	0.24	1.00E-03	1.00E-03	4.80E-02	5.20E-02	4.30E-02	2.18E+00	3.72E-01	2.50E+00	1.15E+00	1.54E-21	2.43E-05	9.55E-05	7.69E-04	4.00E-03	9.15E-07
BATCH-300	9/22/22	78	8.1	0.24	1.00E-03	1.00E-03	4.80E-02	5.20E-02	4.30E-02	2.18E+00	3.72E-01	2.50E+00	1.15E+00	1.54E-21	2.43E-05	9.54E-05	7.68E-04	4.00E-03	9.14E-07
BATCH-301	9/28/22	79	8.2	0.24	1.00E-03	1.00E-03	4.90E-02	5.30E-02	4.30E-02	2.22E+00	3.79E-01	2.54E+00	1.17E+00	1.57E-21	2.47E-05	9.71E-05	7.81E-04	4.00E-03	9.30E-07
BATCH-302	10/1/22	71	7.4	0.24	1.00E-03	7.98E-04	3.50E-02	3.80E-02	3.10E-02	1.62E+00	2.76E-01	1.89E+00	8.41E-01	1.24E-21	1.83E-05	7.00E-05	5.60E-04	3.00E-03	4.69E-06
BATCH-303	10/7/22	104	10.8	0.24	9.29E-04	6.88E-04	2.80E-02	3.30E-02	2.60E-02	1.37E+00	2.32E-01	1.69E+00	6.67E-01	1.35E-21	1.61E-05	5.61E-05	4.36E-04	3.00E-03	1.72E-05
BATCH-304	10/8/22	119	12.4	0.24	1.00E-03	7.85E-04	3.20E-02	3.70E-02	2.90E-02	1.56E+00	2.64E-01	1.92E+00	7.61E-01	1.54E-21	1.83E-05	6.40E-05	4.97E-04	4.00E-03	1.96E-05
BATCH-305	10/18/22	104	10.8	0.24	9.28E-04	6.87E-04	2.80E-02	3.20E-02	2.60E-02	1.36E+00	2.31E-01	1.69E+00	6.67E-01	1.35E-21	1.60E-05	5.61E-05	4.36E-04	3.00E-03	1.72E-05
BATCH-306	10/21/22	104	10.8	0.24	9.28E-04	6.87E-04	2.80E-02	3.20E-02	2.60E-02	1.36E+00	2.31E-01	1.69E+00	6.67E-01	1.35E-21	1.60E-05	5.61E-05	4.36E-04	3.00E-03	1.72E-05
BATCH-307	10/29/22	106	11.0	0.24	9.45E-04	7.00E-04	2.90E-02	3.30E-02	2.60E-02	1.39E+00	2.36E-01	1.72E+00	6.79E-01	1.37E-21	1.63E-05	5.71E-05	4.44E-04	4.00E-03	1.75E-05
BATCH-308	11/1/22	89	9.2	0.24	4.71E-04	3.98E-04	2.30E-02	1.90E-02	1.30E-02	7.21E-01	1.27E-01	1.47E+00	4.33E-01	4.08E-22	8.83E-06	3.15E-05	2.69E-04	4.00E-03	6.07E-05
BATCH-309	11/9/22	98	10.3	0.24	8.78E-04	6.50E-04	2.70E-02	3.10E-02	2.40E-02	1.29E+00	2.19E-01	1.59E+00	6.31E-01	1.27E-21	1.52E-05	5.30E-05	4.12E-04	3.00E-03	1.63E-05
BATCH-310	11/10/22	112	11.7	0.24	1.00E-03	7.40E-04	3.00E-02	3.50E-02	2.80E-02	1.47E+00	2.49E-01	1.82E+00	7.18E-01	1.45E-21	1.73E-05	6.04E-05	4.69E-04	4.00E-03	1.85E-05
BATCH-311	11/20/22	102	10.7	0.24	8.56E-04	6.38E-04	2.60E-02	2.80E-02	2.30E-02	1.22E+00	2.06E-01	1.52E+00	6.01E-01	1.26E-21	1.37E-05	4.94E-05	4.75E-04	4.00E-03	9.57E-06
BATCH-312	11/22/22	104	10.9	0.24	8.58E-04	6.41E-04	2.60E-02	2.80E-02	2.30E-02	1.21E+00	2.04E-01	1.51E+00	5.99E-01	1.27E-21	1.35E-05	4.90E-05	4.97E-04	4.00E-03	7.83E-06
BATCH-313	12/1/22	106	11.1	0.24	8.74E-04	6.53E-04	2.60E-02	2.80E-02	2.30E-02	1.23E+00	2.08E-01	1.54E+00	6.10E-01	1.29E-21	1.37E-05	4.99E-05	5.06E-04	4.00E-03	7.97E-06
BATCH-314	12/3/22	56	5.8	0.24	2.69E-04	2.27E-04	1.30E-02	1.10E-02	8.00E-03	4.11E-01	7.30E-02	8.38E-01	2.47E-01	2.33E-22	5.04E-06	1.80E-05	1.54E-04	2.00E-03	3.47E-05
BATCH-315	12/9/22	99	10.3	0.24	8.13E-04	6.07E-04	2.50E-02	2.60E-02	2.20E-02	1.15E+00	1.93E-01	1.43E+00	5.68E-01	1.20E-21	1.28E-05	4.64E-05	4.71E-04	4.00E-03	7.41E-06
BATCH-316	12/12/22	113	11.7	0.24	9.27E-04	6.93E-04	2.80E-02	3.00E-02	2.50E-02	1.31E+00	2.20E-01	1.63E+00	6.47E-01	1.37E-21	1.46E-05	5.29E-05	5.37E-04	4.00E-03	8.46E-06
BATCH-317	12/20/22	98	10.2	0.24	8.04E-04	6.01E-04	2.40E-02	2.60E-02	2.10E-02	1.14E+00	1.91E-01	1.42E+00	5.62E-01	1.19E-21	1.26E-05	4.59E-05	4.66E-04	4.00E-03	7.33E-06
BATCH-318	12/24/22	98	10.2	0.24	8.07E-04	6.03E-04	2.40E-02	2.60E-02	2.10E-02	1.14E+00	1.92E-01	1.42E+00	5.64E-01	1.19E-21	1.27E-05	4.60E-05	4.68E-04	4.00E-03	7.36E-06
BATCH-319	12/30/22	19	2.0	0.24	6.74E-05	5.70E-05	3.00E-03	3.00E-03	2.00E-03	1.03E-01	1.80E-02	2.10E-01	6.20E-02	5.83E-23	1.26E-06	4.50E-06	3.86E-05	5.07E-04	8.69E-06
BATCH-320	1/1/23	100	10.4	0.24	8.21E-04	6.13E-04	2.50E-02	2.70E-02	2.20E-02	1.16E+00	1.95E-01	1.45E+00	5.46E-01	2.58E-22	1.29E-05	4.68E-05	4.64E-04	4.00E-03	7.48E-06
BATCH-321	1/3/23	81	8.4	0.24	9.78E-04	7.39E-04	3.30E-02	3.30E-02	2.80E-02	1.42E+00	2.39E-01	1.82E+00	6.84E-01	2.33E-22	1.57E-05	6.73E-05	4.14E-04	3.00E-03	6.69E-06
BATCH-322	1/12/23	85	8.9	0.24	1.00E-03	9.97E-04	4.60E-02	4.50E-02	3.80E-02	1.92E+00	3.25E-01	2.50E+00	9.39E-01	2.66E-22	2.12E-05	9.75E-05	4.70E-04	4.00E-03	7.60E-06
BATCH-323	1/12/23	74	7.7	0.24	1.00E-03	8.65E-04	4.00E-02	3.90E-02	3.30E-02	1.67E+00	2.82E-01	2.17E+00	8.15E-01	2.31E-22	1.84E-05	8.46E-05	4.08E-04	3.00E-03	6.59E-06
BATCH-324	1/20/23	119	12.4	0.24	2.00E-03	1.00E-03	6.50E-02	6.30E-02	5.40E-02	2.70E+00	4.55E-01	3.51E+00	1.32E+00	3.72E-22	2.97E-05	1.37E-04	6.58E-04	5.00E-03	1.07E-05
BATCH-325	1/21/23	74	7.7	0.24	1.00E-03	8.69E-04	4.00E-02	3.90E-02	3.30E-02	1.68E+00	2.83E-01	2.18E+00	8.18E-01	2.31E-22	1.85E-05	8.50E-05	4.09E-04	3.00E-03	6.62E-06
BATCH-326	1/29/23	81	8.5	0.24	3.57E-04	2.90E-04	1.50E-02	1.40E-02	1.00E-02	5.43E-01	9.50E-02	9.49E-01	2.91E-01	8.05E-23	6.43E-06	2.30E-05	1.92E-04	2.00E-03	3.17E-05
BATCH-327	2/2/23	75	7.9	0.24	1.00E-03	8.84E-04	4.10E-02	4.00E-02	3.40E-02	1.71E+00	2.88E-01	2.22E+00	8.33E-01	2.36E-22	1.88E-05	8.65E-05	4.17E-04	3.00E-03	6.74E-06
BATCH-328	2/7/23	80	8.3	0.24	3.55E-04	2.89E-04	1.50E-02	1.40E-02	1.00E-02	5.40E-01	9.40E-02	9.45E-01	2.90E-01	7.87E-23	6.39E-06	2.31E-05	1.90E-04	2.00E-03	3.14E-05
BATCH-329	2/10/23	82	8.5	0.24	1.00E-03	9.59E-04	4.40E-02	4.30E-02	3.70E-02	1.85E+00	3.12E-01	2.41E+00	9.03E-01	2.56E-22	2.04E-05	9.38E-05	4.52E-04	4.00E-03	7.30E-06
BATCH-330	2/15/23	79	8.2	0.24	3.49E-04	2.84E-04	1.50E-02	1.30E-02	1.00E-02	5.31E-01	9.30E-02	9.30E-01	2.85E-01	7.73E-23	6.26E-06	2.27E-05	1.88E-04	2.00E-03	3.09E-05
BATCH-331	2/19/23	115	11.9	0.24	2.00E-03	1.00E-03	6.20E-02	6.10E-02	5.20E-02	2.59E+00	4.38E-01	3.37E+00	1.27E+00	3.58E-22	2.86E-05	1.31E-04	6.33E-04	5.00E-03	1.02E-05
BATCH-332	2/24/23	56	5.9	0.24	2.25E-04	1.83E-04	1.00E-02	9.00E-03	6.00E-03	3.42E-01	6.00E-02	5.98E-01	1.83E-01	5.07E-23	4.05E-06	1.45E-05	1.21E-04	1.00E-03	2.00E-05
BATCH-333	3/2/23	59	6.1	0.24	4.86E-04	3.74E-04	1.80E-02	1.80E-02	1.50E-02	7.80E-01	1.32E-01	9.85E-01	3.86E-01	3.85E-22	8.53E-06	3.65E-05	5.43E-04	7.00E-03	3.86E-07
BATCH-334	3/3/23	56	5.8	0.24	2.26E-04	1.84E-04	1.00E-02	9.00E-03	6.00E-03	3.44E-01	6.00E-02	6.02E-01	1.85E-01	5.01E-23	4.06E-06	1.47E-05	1.21E-04	1.00E-03	2.00E-05
BATCH-335	3/8/23	64	6.6	0.24	5.20E-04	4.00E-04	1.90E-02	1.90E-02	1.60E-02	8.36E-01	1.42E-01	1.05E+00	4.14E-01	4.20E-22	9.14E-06	3.91E-05	8.00E-04	1.00E-03	3.42E-07
BATCH-336	3/9/23	56	5.8	0.24	2.26E-04	1.84E-04	1.00E-02	9.00E-03	6.00E-03	3.44E-01	6.00E-02	6.03E-01	1.85E-01	5.01E-23	4.06E-06	1.47E-05	1.22E-04	1.00E-03	2.00E-05
BATCH-337	3/15/23	20	2.1	0.24	6.16E-05	5.00E-05	3.00E-03	2.00E-03	2.00E-03	9.40E-02	1.60E-02	1.64E-01	5.00E-02	1.39E-23	1.11E-06	3.97E-06	3.31E-05	3.76E-04	5.46E-06
BATCH-338	3/15/23	89	9.3	0.24	7.29E-04	5.61E-04	2.70E-02	2.70E-02	2.20E-02	1.17E+00	1.99E-01	1.48E+00	5.81E-01	5.90E-22	1.28E-05	5.48E-05	8.30E-04	1.10E-02	4.78E-07
BATCH-339	3/17/23	101	10.5	0.24	3.49E-04	2.72E-04	1.40E-02	1.30E-02	1.00E-02	5.44E-01	9.40E-02	7.41E-01	2.70E-01	1.11E-22	6.03E-06	2.27E-05	2.04E-04	2.00E-03	1.22E-05
BATCH-340	3/24/23	20	2.1	0.24	6.12E-05	4.97E-05	3.00E-03	2.00E-03	2.00E-03	9.30E-02	1.60E-02	1.63E-01	5.00E-02	1.36E-23	1.10E-06	3.98E-06	3.27E-05	3.72E-04	5.41E-06
BATCH-341	3/26/23	85	8.8	0.24	2.71E-04	2.05E-04	1.00E-02	1.00E-02	8.00E-03	4.21E-01	7.20E-02	4.93E-01	2.00E-01	9.60E-23	4.58E-06	1.78E-05	1.55E-04	1.00E-03	1.55E-06
BATCH-342	3/28/23	20	2.1	0.24	6.13E-05	4.99E-05	3.00E-03	2.00E-03	2.00E-03	9.30E-02	1.60E-02	1.63E-01	5.00E-02	1.36E-23	1.10E-06	3.98E-06	3.30E-05	3.75E-04	5.43E-06

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses			16.6	0.24	4.02E-06	1.64E+02	2.40E-08	3.14E-05	2.66E-08	3.01E-35	7.00E-03	4.26E-01	7.22E-06	8.10E-02	4.20E+01	0.00E+00	2.88E-07	4.76E+00	5.39E-05
BATCH-294	8/20/22	159																	
BATCH-295	8/31/22	111	11.6	0.24	1.62E-06	1.23E+02	1.03E-05	3.05E-05	1.79E-05	1.40E-04	1.70E-02	2.52E-01	1.16E-04	3.10E-02	2.70E+01	0.00E+00	9.21E-08	5.45E+00	8.09E-05
BATCH-296	9/6/22	68	7.1	0.24	1.34E-12	8.10E+01	1.32E-05	3.46E-05	2.30E-05	1.80E-04	1.80E-02	1.24E-01	1.46E-04	1.00E-03	1.50E+01	0.00E+00	1.18E-13	4.77E+00	8.09E-05
BATCH-297	9/11/22	78	8.1	0.24	2.69E-09	9.25E+01	1.50E-05	3.95E-05	2.62E-05	2.06E-04	2.10E-02	1.41E-01	1.66E-04	2.00E-03	1.72E+01	0.00E+00	1.75E-10	5.44E+00	1.08E-04
BATCH-298	9/13/22	89	9.3	0.24	4.65E-06	1.05E+02	1.72E-05	4.50E-05	2.99E-05	2.35E-04	2.40E-02	1.61E-01	1.89E-04	2.00E-03	1.96E+01	0.00E+00	3.77E-07	6.21E+00	1.35E-04
BATCH-299	9/20/22	78	8.1	0.24	2.54E-09	9.24E+01	1.50E-05	3.94E-05	2.62E-05	2.05E-04	2.10E-02	1.41E-01	1.66E-04	2.00E-03	1.71E+01	0.00E+00	1.79E-10	5.44E+00	1.08E-04
BATCH-300	9/22/22	78	8.1	0.24	2.53E-09	9.23E+01	1.50E-05	3.94E-05	2.62E-05	2.05E-04	2.10E-02	1.41E-01	1.66E-04	2.00E-03	1.71E+01	0.00E+00	1.81E-10	5.43E+00	1.08E-04
BATCH-301	9/28/22	79	8.2	0.24	9.97E-10	9.39E+01	1.53E-05	4.01E-05	2.67E-05	2.09E-04	2.10E-02	1.43E-01	1.69E-04	2.00E-03	1.74E+01	0.00E+00	5.69E-11	5.53E+00	1.08E-04
BATCH-302	10/1/22	71	7.4	0.24	9.69E-16	8.46E+01	8.90E-06	2.01E-04	1.55E-05	1.22E-04	2.50E-02	1.17E-01	9.87E-05	2.00E-03	1.47E+01	0.00E+00	8.55E-17	5.88E+00	2.16E-04
BATCH-303	10/7/22	104	10.8	0.24	1.76E-12	1.24E+02	4.78E-08	7.37E-04	1.20E-07	1.34E-07	5.30E-02	1.39E-01	2.14E-06	4.00E-03	1.89E+01	0.00E+00	1.14E-13	1.10E+01	2.43E-04
BATCH-304	10/8/22	119	12.4	0.24	2.66E-09	1.42E+02	5.32E-08	8.41E-04	1.34E-07	1.34E-07	6.10E-02	1.58E-01	2.43E-06	4.00E-03	2.16E+01	0.00E+00	2.15E-10	1.26E+01	2.16E-04
BATCH-305	10/18/22	104	10.8	0.24	1.66E-12	1.24E+02	4.78E-08	7.36E-04	1.20E-07	1.34E-07	5.30E-02	1.39E-01	2.14E-06	4.00E-03	1.89E+01	0.00E+00	1.17E-13	1.10E+01	2.16E-04
BATCH-306	10/21/22	104	10.8	0.24	1.64E-12	1.24E+02	4.78E-08	7.36E-04	1.19E-07	1.33E-07	5.30E-02	1.39E-01	2.14E-06	4.00E-03	1.89E+01	0.00E+00	1.18E-13	1.10E+01	2.16E-04
BATCH-307	10/29/22	106	11.0	0.24	6.37E-13	1.26E+02	4.85E-08	7.49E-04	1.21E-07	1.33E-07	5.40E-02	1.41E-01	2.18E-06	4.00E-03	1.93E+01	0.00E+00	3.63E-14	1.12E+01	2.16E-04
BATCH-308	11/1/22	89	9.2	0.24	2.12E+02	0.00E+00	6.75E-06	8.00E-03	7.65E-06	8.95E-06	5.00E-03	5.14E-01	8.13E-05	8.00E-03	7.99E+00	0.00E+00	2.96E+01	0.00E+00	9.17E-04
BATCH-309	11/9/22	98	10.3	0.24	1.21E-15	1.18E+02	3.60E-08	6.97E-04	9.69E-08	9.20E-11	5.00E-02	1.31E-01	1.92E-06	3.00E-03	1.79E+01	0.00E+00	7.82E-17	1.04E+01	2.16E-04
BATCH-310	11/10/22	112	11.7	0.24	1.60E-12	1.34E+02	4.10E-08	7.94E-04	1.10E-07	8.06E-11	5.70E-02	1.49E-01	2.19E-06	4.00E-03	2.04E+01	0.00E+00	1.30E-13	1.19E+01	2.43E-04
BATCH-311	11/20/22	102	10.7	0.24	1.07E-15	1.21E+02	9.36E-06	1.00E-03	5.44E-06	8.63E-11	2.80E-02	1.25E-01	8.46E-06	3.00E-03	1.84E+01	0.00E+00	7.52E-17	1.11E+01	3.05E-03
BATCH-312	11/22/22	104	10.9	0.24	1.12E-15	1.23E+02	1.20E-05	1.00E-03	6.96E-06	9.13E-11	2.20E-02	1.25E-01	1.03E-05	3.00E-03	1.87E+01	0.00E+00	8.06E-17	1.14E+01	3.10E-03
BATCH-313	12/1/22	106	11.1	0.24	4.27E-16	1.25E+02	1.22E-05	1.00E-03	7.09E-06	8.94E-11	2.20E-02	1.27E-01	1.05E-05	3.00E-03	1.90E+01	0.00E+00	1.16E-17	1.16E+01	5.12E-04
BATCH-314	12/3/22	56	5.8	0.24	1.21E+02	0.00E+00	3.85E-06	5.00E-03	4.36E-06	5.11E-06	3.00E-03	2.93E-01	4.64E-05	5.00E-03	4.56E+00	0.00E+00	1.69E+01	0.00E+00	1.69E-03
BATCH-315	12/9/22	99	10.3	0.24	8.68E-19	1.16E+02	1.14E-05	1.00E-03	6.59E-06	6.63E-14	2.00E-02	1.18E-01	9.79E-06	3.00E-03	1.77E+01	0.00E+00	5.63E-20	1.08E+01	2.89E-03
BATCH-316	12/12/22	113	11.7	0.24	1.01E-15	1.33E+02	1.30E-05	1.00E-03	7.52E-06	5.08E-14	2.30E-02	1.35E-01	1.12E-05	3.00E-03	2.02E+01	0.00E+00	8.17E-17	1.23E+01	3.29E-03
BATCH-317	12/20/22	98	10.2	0.24	7.76E-19	1.15E+02	1.13E-05	1.00E-03	6.53E-06	6.27E-14	2.00E-02	1.17E-01	9.70E-06	3.00E-03	1.75E+01	0.00E+00	5.46E-20	1.07E+01	2.86E-03
BATCH-318	12/24/22	98	10.2	0.24	8.12E-19	1.15E+02	1.13E-05	1.00E-03	6.55E-06	6.60E-14	2.00E-02	1.18E-01	9.73E-06	3.00E-03	1.76E+01	0.00E+00	5.83E-20	1.07E+01	2.89E-03
BATCH-319	12/30/22	19	2.0	0.24	3.03E+01	0.00E+00	9.66E-07	1.00E-03	1.10E-06	1.28E-06	6.76E-04	7.40E-02	1.16E-05	1.00E-03	1.14E+00	0.00E+00	4.23E+00	0.00E+00	1.35E-04
BATCH-320	1/1/23	100	10.4	0.24	3.03E-19	1.17E+02	1.15E-05	1.00E-03	6.67E-06	6.35E-14	2.10E-02	1.20E-01	9.90E-06	3.00E-03	1.79E+01	0.00E+00	1.73E-20	1.09E+01	2.91E-03
BATCH-321	1/3/23	81	8.4	0.24	6.33E-22	9.81E+01	7.11E-06	7.36E-04	4.68E-06	4.84E-17	1.60E-02	8.60E-02	1.74E-05	2.00E-03	1.49E+01	0.00E+00	4.11E-23	8.08E+00	1.94E-03
BATCH-322	1/12/23	85	8.9	0.24	6.87E-19	1.06E+02	5.43E-06	5.93E-04	4.24E-06	3.46E-17	1.70E-02	8.10E-02	2.68E-05	2.00E-03	1.59E+01	0.00E+00	5.57E-20	7.78E+00	1.65E-03
BATCH-323	1/12/23	74	7.7	0.24	6.09E-22	9.17E+01	4.72E-06	5.15E-04	3.68E-06	4.91E-17	1.50E-02	7.00E-02	2.33E-05	1.00E-03	1.38E+01	0.00E+00	4.28E-23	6.75E+00	1.43E-03
BATCH-324	1/20/23	119	12.4	0.24	5.00E-03	1.48E+02	7.61E-06	8.31E-04	5.94E-06	2.22E-10	2.40E-02	1.14E-01	3.76E-05	2.00E-03	2.23E+01	0.00E+00	7.32E-04	1.09E+01	2.29E-03
BATCH-325	1/21/23	74	7.7	0.24	6.33E-22	9.21E+01	4.73E-06	5.17E-04	3.69E-06	5.15E-17	1.50E-02	7.10E-02	2.33E-05	1.00E-03	1.39E+01	0.00E+00	4.55E-23	6.78E+00	1.43E-03
BATCH-326	1/29/23	81	8.5	0.24	1.78E+02	0.00E+00	3.94E-06	4.00E-03	4.14E-06	4.20E-06	7.00E-03	3.87E-01	4.15E-05	7.00E-03	7.32E+00	0.00E+00	1.32E-23	6.90E+00	1.46E-03
BATCH-327	2/2/23	75	7.9	0.24	2.32E-22	9.38E+01	4.82E-06	5.26E-04	3.76E-06	4.86E-17	1.50E-02	7.20E-02	2.38E-05	1.00E-03	7.17E+00	0.00E+00	3.43E-01	0.00E+00	6.20E-04
BATCH-328	2/7/23	80	8.3	0.24	1.77E+02	0.00E+00	3.93E-06	4.00E-03	4.14E-06	4.18E-06	7.00E-03	3.84E-01	4.15E-05	7.00E-03	1.53E+01	0.00E+00	3.92E-23	7.48E+00	1.56E-03
BATCH-329	2/10/23	82	8.5	0.24	4.84E-22	1.02E+02	5.22E-06	5.70E-04	4.08E-06	2.44E-20	1.60E-02	7.80E-02	2.58E-05	2.00E-03	7.06E+00	0.00E+00	3.41E+01	0.00E+00	6.47E-04
BATCH-330	2/15/23	79	8.2	0.24	1.75E+02	0.00E+00	4.02E-06	4.00E-03	4.16E-06	4.14E-06	6.00E-03	3.80E-01	4.11E-05	7.00E-03	2.14E+01	0.00E+00	3.68E-07	1.05E+01	2.21E-03
BATCH-331	2/19/23	115	11.9	0.24	2.63E-06	1.42E+02	7.31E-06	7.98E-04	5.71E-06	1.11E-13	2.30E-02	1.09E-01	3.61E-05	2.00E-03	4.61E+00	0.00E+00	2.19E+01	0.00E+00	3.78E-04
BATCH-332	2/24/23	56	5.9	0.24	1.12E+02	0.00E+00	2.48E-06	3.00E-03	2.61E-06	2.65E-06	5.00E-03	2.44E-01	2.62E-05	5.00E-03	4.61E+00	0.00E+00	9.18E-27	5.05E+00	1.35E-04
BATCH-333	3/2/23	59	6.1	0.24	1.61E-25	5.12E+01	1.03E-06	1.63E-04	8.47E-07	3.37E-20	5.00E-03	4.30E-02	6.95E-06	1.00E-03	1.30E+01	0.00E+00	2.18E+01	0.00E+00	4.05E-04
BATCH-334	3/3/23	56	5.8	0.24	1.12E+02	0.00E+00	2.50E-06	3.00E-03	2.64E-06	2.66E-06	4.00E-03	2.44E-01	2.64E-05	5.00E-03	4.56E+00	0.00E+00	2.62E-26	5.46E+00	1.35E-04
BATCH-335	3/8/23	64	6.6	0.24	3.23E-25	5.51E+01	1.08E-06	1.72E-04	8.84E-07	1.63E-23	5.00E-03	4.60E-02	7.34E-06	1.00E-03	1.40E+01	0.00E+00	2.21E+01	0.00E+00	4.05E-04
BATCH-336	3/9/23	56	5.8	0.24	1.13E+02	0.00E+00	2.60E-06	3.00E-03	2.70E-06	2.68E-06	4.00E-03	2.46E-01	2.66E-05	5.00E-03	4.57E+00	0.00E+00	6.00E+00	0.00E+00	1.08E-04
BATCH-337	3/15/23	20	2.1	0.24	3.07E+01	0.00E+00	6.78E-07	7.15E-04	7.14E-07	7.24E-07	1.00E-03	6.70E-02	7.16E-06	1.00E-03	1.26E+00	0.00E+00	1.75E-10	7.67E+00	1.89E-04
BATCH-338	3/15/23	89	9.3	0.24	1.25E-09	7.73E+01	1.51E-06	2.41E-04	1.24E-06	5.29E-17	7.00E-03	6.50E-02	1.03E-05	2.00E-03	1.97E+01	0.00E+00	4.00E+01	0.00E+00	4.05E-04
BATCH-339	3/17/23	101	10.5	0.24	2.59E-02	0.00E+00	2.49E-06	2.00E-03	2.59E-06	6.65E-06	7.00E-03	3.50E-01	2.13E-05	1.00E-02	9.06E+00	0.00E+00	5.91E+00	0.00E+00	1.08E-04
BATCH-340	3/24/23	20	2.1	0.24	3.04E+01	0.00E+00	6.77E-07	7.10E-04	7.13E-07	7.20E-07	1.00E-03	6.60E-02	7.15E-06	1.00E-03	1.24E+00	0.00E+00	3.85E+01	0.00E+00	1.89E-04
BATCH-341	3/26/23	85	8.8	0.24	2.24E+02	0.00E+00	1.01E-06	1.14E-04	1.07E-06	5.03E-06	8.00E-03	2.92E-01	6.51E-06	7.00E-03	7.05E+00	0.00E+00	5.98E+00	0.00E+00	1.08E-04
BATCH-342	3/28/23	20	2.1	0.24	3.07E+01	0.00E+00	7.06E-07	7.16E-04	7.32E-07	7.27E-07	1.00E-03	6.70E-02	7.22E-06	1.00E-03	1.24E+00	0.00E+00			

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-294	8/20/22	159	16.6	0.24	6.80E-09	4.95E+01	2.52E-01	0.00E+00	0.00E+00	1.92E-04	1.28E+01	1.77E-06	9.48E-07	3.39E-05	6.00E-02	5.08E-06	2.71E+03	0.00E+00	8.70E-02
BATCH-295	8/31/22	111	11.6	0.24	3.31E-09	3.82E+01	9.80E-02	0.00E+00	0.00E+00	9.83E-05	1.07E+01	1.12E-04	1.66E-07	8.86E-06	6.20E-02	4.40E-06	1.90E+03	0.00E+00	4.00E-02
BATCH-296	9/6/22	68	7.1	0.24	2.87E-09	2.59E+01	8.00E-03	0.00E+00	0.00E+00	3.61E-05	7.81E+00	1.44E-04	5.98E-08	5.79E-08	5.20E-02	4.92E-06	1.17E+03	0.00E+00	1.10E-02
BATCH-297	9/11/22	78	8.1	0.24	3.27E-09	2.96E+01	9.00E-03	0.00E+00	0.00E+00	4.11E-05	8.91E+00	1.64E-04	6.80E-08	6.16E-08	5.90E-02	5.61E-06	1.33E+03	0.00E+00	1.20E-02
BATCH-298	9/13/22	89	9.3	0.24	3.72E-09	3.36E+01	1.00E-02	0.00E+00	0.00E+00	4.69E-05	1.02E+01	1.87E-04	7.69E-08	5.86E-08	6.70E-02	6.39E-06	1.52E+03	0.00E+00	1.40E-02
BATCH-299	9/20/22	78	8.1	0.24	3.26E-09	2.96E+01	9.00E-03	0.00E+00	0.00E+00	4.11E-05	8.90E+00	1.64E-04	6.79E-08	6.15E-08	5.90E-02	5.60E-06	1.33E+03	0.00E+00	1.20E-02
BATCH-300	9/22/22	78	8.1	0.24	3.26E-09	2.95E+01	9.00E-03	0.00E+00	0.00E+00	4.11E-05	8.90E+00	1.64E-04	6.79E-08	6.14E-08	5.90E-02	5.60E-06	1.33E+03	0.00E+00	1.20E-02
BATCH-301	9/28/22	79	8.2	0.24	3.32E-09	3.01E+01	9.00E-03	0.00E+00	0.00E+00	4.17E-05	9.05E+00	1.67E-04	6.86E-08	6.14E-08	6.00E-02	5.70E-06	1.35E+03	0.00E+00	1.20E-02
BATCH-302	10/1/22	71	7.4	0.24	2.27E-09	2.91E+01	1.00E-02	0.00E+00	0.00E+00	2.00E-04	6.69E+00	1.02E-04	2.43E-07	7.72E-08	1.30E-01	2.87E-05	1.22E+03	0.00E+00	1.20E-02
BATCH-303	10/7/22	104	10.8	0.24	1.39E-09	4.83E+01	2.10E-02	0.00E+00	0.00E+00	8.00E-04	6.71E+00	1.88E-05	8.41E-07	2.21E-07	3.94E-01	1.05E-04	1.78E+03	0.00E+00	2.10E-02
BATCH-304	10/8/22	119	12.4	0.24	1.59E-09	5.51E+01	2.40E-02	0.00E+00	0.00E+00	8.00E-04	7.66E+00	2.15E-05	9.59E-07	2.52E-07	4.50E-01	1.20E-04	2.03E+03	0.00E+00	2.40E-02
BATCH-305	10/18/22	104	10.8	0.24	1.39E-09	4.83E+01	2.10E-02	0.00E+00	0.00E+00	8.00E-04	6.71E+00	1.88E-05	8.40E-07	2.21E-07	3.94E-01	1.05E-04	1.78E+03	0.00E+00	2.10E-02
BATCH-306	10/21/22	104	10.8	0.24	1.39E-09	4.83E+01	2.10E-02	0.00E+00	0.00E+00	8.00E-04	6.71E+00	1.88E-05	8.40E-07	2.21E-07	3.94E-01	1.05E-04	1.78E+03	0.00E+00	2.10E-02
BATCH-307	10/29/22	106	11.0	0.24	1.41E-09	4.91E+01	2.10E-02	0.00E+00	0.00E+00	8.00E-04	6.83E+00	1.92E-05	8.55E-07	2.25E-07	4.01E-01	1.07E-04	1.81E+03	0.00E+00	2.10E-02
BATCH-308	11/1/22	89	9.2	0.24	1.45E-06	1.04E+01	1.80E-01	0.00E+00	0.00E+00	5.04E-05	6.07E+00	4.20E-04	2.34E-04	4.00E-03	3.90E-02	1.00E-03	1.51E+03	0.00E+00	5.20E-02
BATCH-309	11/9/22	98	10.3	0.24	1.31E-09	4.57E+01	2.00E-02	0.00E+00	0.00E+00	8.00E-04	6.34E+00	1.77E-05	7.95E-07	2.09E-07	3.73E-01	9.93E-05	1.68E+03	0.00E+00	2.00E-02
BATCH-310	11/10/22	112	11.7	0.24	1.49E-09	5.20E+01	2.30E-02	0.00E+00	0.00E+00	8.00E-04	7.22E+00	2.02E-05	9.06E-07	2.38E-07	4.25E-01	1.13E-04	1.91E+03	0.00E+00	2.30E-02
BATCH-311	11/20/22	102	10.7	0.24	6.44E-08	4.95E+01	1.50E-02	0.00E+00	0.00E+00	8.00E-04	6.30E+00	1.16E-05	3.17E-06	2.30E-04	4.08E-01	3.40E-05	1.75E+03	0.00E+00	1.00E-02
BATCH-312	11/22/22	104	10.9	0.24	8.23E-08	5.10E+01	1.40E-02	0.00E+00	0.00E+00	8.00E-04	6.35E+00	1.01E-05	3.85E-06	2.95E-04	4.21E-01	1.64E-05	1.78E+03	0.00E+00	7.00E-03
BATCH-313	12/1/22	106	11.1	0.24	8.39E-08	5.20E+01	1.40E-02	0.00E+00	0.00E+00	8.00E-04	6.46E+00	1.03E-05	3.92E-06	3.01E-04	4.29E-01	1.67E-05	1.81E+03	0.00E+00	8.00E-03
BATCH-314	12/3/22	56	5.8	0.24	8.25E-07	5.95E+00	1.03E-01	0.00E+00	0.00E+00	2.87E-05	3.46E+00	2.39E-04	1.34E-04	2.00E-03	2.20E-02	7.51E-04	9.52E+02	0.00E+00	3.00E-02
BATCH-315	12/9/22	99	10.3	0.24	7.80E-08	4.83E+01	1.30E-02	0.00E+00	0.00E+00	8.00E-04	6.01E+00	9.55E-06	3.64E-06	2.80E-04	3.99E-01	1.56E-05	1.69E+03	0.00E+00	7.00E-03
BATCH-316	12/12/22	113	11.7	0.24	8.90E-08	5.51E+01	1.50E-02	0.00E+00	0.00E+00	8.00E-04	6.86E+00	1.09E-05	4.16E-06	3.19E-04	4.55E-01	1.77E-05	1.92E+03	0.00E+00	8.00E-03
BATCH-317	12/20/22	98	10.2	0.24	7.72E-08	4.78E+01	1.30E-02	0.00E+00	0.00E+00	8.00E-04	5.95E+00	9.44E-06	3.61E-06	2.77E-04	3.95E-01	1.53E-05	1.67E+03	0.00E+00	7.00E-03
BATCH-318	12/24/22	98	10.2	0.24	7.75E-08	4.80E+01	1.30E-02	0.00E+00	0.00E+00	8.00E-04	5.97E+00	9.47E-06	3.62E-06	2.78E-04	3.96E-01	1.54E-05	1.68E+03	0.00E+00	7.00E-03
BATCH-319	12/30/22	19	2.0	0.24	2.07E-07	1.49E+00	2.60E-02	0.00E+00	0.00E+00	7.21E-06	8.69E-01	6.01E-05	3.35E-05	5.24E-04	6.00E-03	1.88E-04	3.23E+02	0.00E+00	7.00E-03
BATCH-320	1/1/23	100	10.4	0.24	7.88E-08	4.88E+01	1.30E-02	0.00E+00	0.00E+00	8.00E-04	6.07E+00	9.64E-06	3.68E-06	2.83E-04	4.03E-01	1.56E-05	1.70E+03	0.00E+00	7.00E-03
BATCH-321	1/3/23	81	8.4	0.24	2.40E-07	3.34E+01	8.00E-03	0.00E+00	0.00E+00	6.00E-04	6.19E+00	2.67E-05	2.88E-05	1.78E-04	3.18E-01	1.89E-05	1.38E+03	0.00E+00	9.00E-03
BATCH-322	1/12/23	85	8.9	0.24	4.13E-07	2.94E+01	6.00E-03	0.00E+00	0.00E+00	6.00E-04	7.67E+00	4.52E-05	5.40E-05	1.39E-04	3.28E-01	2.55E-05	1.45E+03	0.00E+00	1.30E-02
BATCH-323	1/12/23	74	7.7	0.24	3.58E-07	2.55E+01	6.00E-03	0.00E+00	0.00E+00	6.00E-04	6.66E+00	3.93E-05	4.69E-05	1.21E-04	2.83E-01	2.21E-05	1.26E+03	0.00E+00	1.10E-02
BATCH-324	1/20/23	119	12.4	0.24	5.79E-07	4.12E+01	9.00E-03	0.00E+00	0.00E+00	1.00E-03	1.08E+01	6.35E-05	7.57E-05	1.95E-04	4.57E-01	3.57E-05	2.04E+03	0.00E+00	1.80E-02
BATCH-325	1/21/23	74	7.7	0.24	3.60E-07	2.56E+01	6.00E-03	0.00E+00	0.00E+00	6.00E-04	6.68E+00	3.94E-05	4.70E-05	1.21E-04	2.84E-01	2.22E-05	1.27E+03	0.00E+00	1.10E-02
BATCH-326	1/29/23	81	8.5	0.24	7.32E-07	1.17E+01	2.22E-01	0.00E+00	0.00E+00	1.07E-04	4.14E+00	2.12E-04	1.18E-04	2.00E-03	6.10E-02	6.66E-04	1.39E+03	0.00E+00	3.10E-02
BATCH-327	2/2/23	75	7.9	0.24	3.66E-07	2.61E+01	6.00E-03	0.00E+00	0.00E+00	6.00E-04	6.81E+00	4.01E-05	4.79E-05	1.24E-04	2.90E-01	2.26E-05	1.29E+03	0.00E+00	1.10E-02
BATCH-328	2/7/23	80	8.3	0.24	7.32E-07	1.13E+01	2.18E-01	0.00E+00	0.00E+00	1.02E-04	4.10E+00	2.11E-04	1.18E-04	2.00E-03	5.80E-02	6.62E-04	1.36E+03	0.00E+00	3.00E-02
BATCH-329	2/10/23	82	8.5	0.24	3.97E-07	2.83E+01	6.00E-03	0.00E+00	0.00E+00	6.00E-04	7.38E+00	4.35E-05	5.20E-05	1.34E-04	3.14E-01	2.45E-05	1.40E+03	0.00E+00	1.20E-02
BATCH-330	2/15/23	79	8.2	0.24	7.24E-07	2.16E+01	0.00E+00	0.00E+00	0.00E+00	9.97E-05	4.04E+00	2.08E-04	1.17E-04	2.00E-03	5.70E-02	6.53E-04	1.34E+03	0.00E+00	3.00E-02
BATCH-331	2/19/23	115	11.9	0.24	5.57E-07	3.96E+01	9.00E-03	0.00E+00	0.00E+00	8.00E-04	1.03E+01	6.10E-05	7.28E-05	1.88E-04	4.40E-01	3.43E-05	1.96E+03	0.00E+00	1.70E-02
BATCH-332	2/24/23	56	5.9	0.24	4.61E-07	7.38E+00	1.40E-01	0.00E+00	0.00E+00	6.73E-05	2.61E+00	1.34E-04	7.43E-05	1.00E-03	3.80E-02	4.20E-04	9.59E+02	0.00E+00	1.90E-02
BATCH-333	3/2/23	59	6.1	0.24	9.44E-08	1.50E+01	1.40E-02	0.00E+00	0.00E+00	1.90E-04	4.01E+00	6.06E-07	7.61E-06	3.01E-05	1.22E-01	2.76E-07	1.00E+03	0.00E+00	4.30E-02
BATCH-334	3/3/23	56	5.8	0.24	4.66E-07	7.16E+00	1.39E-01	0.00E+00	0.00E+00	6.48E-05	2.61E+00	1.34E-04	7.51E-05	1.00E-03	3.70E-02	4.22E-04	9.53E+02	0.00E+00	1.90E-02
BATCH-335	3/8/23	64	6.6	0.24	9.91E-08	1.61E+01	1.60E-02	0.00E+00	0.00E+00	2.00E-04	4.32E+00	1.75E-07	7.77E-06	3.16E-05	1.30E+01	2.76E-08	1.09E+03	0.00E+00	4.70E-02
BATCH-336	3/9/23	56	5.8	0.24	4.69E-07	7.19E+00	1.40E-01	0.00E+00	0.00E+00	6.46E-05	2.62E+00	1.35E-04	7.55E-05	1.00E-03	3.70E-02	4.23E-04	9.56E+02	0.00E+00	1.90E-02
BATCH-337	3/15/23	20	2.1	0.24	1.26E-07	2.02E+00	3.80E-02	0.00E+00	0.00E+00	1.84E-05	7.13E-01	3.65E-05	2.04E-05	3.20E-04	1.00E-02	1.15E-04	3.41E+02	0.00E+00	5.00E-03
BATCH-338	3/15/23	89	9.3	0.24	1.39E-07	2.26E+01	2.20E-02	0.00E+00	0.00E+00	2.00E-04	6.06E+00	2.34E-07	1.09E-05	4.43E-05	1.83E-01	3.21E-08	1.52E+03	0.00E+00	6.60E-02
BATCH-339	3/17/23	101	10.5	0.24	2.83E-07	1.37E+01	2.80E-01	0.00E+00	0.00E+00	1.23E-04	3.63E+00	8.26E-05	4.45E-05	6.94E-04	6.50E-02	2.45E-04	1.73E+03	0.00E+00	2.30E-02
BATCH-340	3/24/23	20	2.1	0.24	1.26E-07	1.94E+00	3.80E-02	0.00E+00	0.00E+00	1.75E-05	7.06E-01	3.64E-05	2.03E-05	3.18E-04	1.00E-02	1.14E-04	3.39E+02	0.00E+00	5.00E-03
BATCH-341	3/26/23	85	8.8	0.24	2.40E-08	1.13E+01	2.72E-01	0.00E+00	0.00E+00	1.22E-04	2.41E+00	6.99E-06	2.57E-06	1.78E-05	6.30E-02	7.62E-06	1.44E+03	0.00E+00	1.30E-02
BATCH-342	3/28/23	20	2.1	0.24	1.27E-07	1.95E+00	3.80E-02	0.00E+00	0.00E+00	1.75E-05	7.09E-01	3.66E-05	2.05E-05	3.21E-04	1.00E-02	1.15E-04	3.39E+02	0.00E+00	5.00E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-294	8/20/22	159	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.90E+01	4.93E-09	5.42E+00	4.62E+01	1.60E-02	6.23E-07	0.00E+00	2.20E-02	6.01E-05	1.50E-02
BATCH-295	8/31/22	111	11.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.97E+01	3.69E-08	8.13E+00	3.94E+01	2.20E-02	7.33E-08	0.00E+00	9.00E-03	2.93E-05	2.30E-02
BATCH-296	9/6/22	68	7.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	2.80E+01	4.68E-08	7.91E+00	2.90E+01	2.00E-02	2.87E-09	0.00E+00	9.61E-04	2.03E-05	2.30E-02
BATCH-297	9/11/22	78	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.20E+01	5.34E-08	9.03E+00	3.31E+01	2.30E-02	3.16E-09	0.00E+00	1.00E-03	2.31E-05	2.60E-02
BATCH-298	9/13/22	89	9.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.65E+01	6.09E-08	1.03E+01	3.77E+01	2.70E-02	3.15E-09	0.00E+00	1.00E-03	2.64E-05	3.00E-02
BATCH-299	9/20/22	78	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.19E+01	5.33E-08	9.02E+00	3.30E+01	2.30E-02	3.15E-09	0.00E+00	1.00E-03	2.31E-05	2.60E-02
BATCH-300	9/22/22	78	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.19E+01	5.33E-08	9.01E+00	3.30E+01	2.30E-02	3.15E-09	0.00E+00	1.00E-03	2.31E-05	2.60E-02
BATCH-301	9/28/22	79	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.25E+01	5.42E-08	9.17E+00	3.36E+01	2.40E-02	2.85E-09	0.00E+00	1.00E-03	2.35E-05	2.60E-02
BATCH-302	10/1/22	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.47E+01	3.16E-08	7.80E+00	2.76E+01	1.70E-02	1.87E-09	0.00E+00	3.00E-03	1.49E-04	2.10E-02
BATCH-303	10/7/22	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.57E+01	7.28E-11	1.02E+01	3.34E+01	1.40E-02	9.80E-10	0.00E+00	1.00E-02	5.62E-04	2.30E-02
BATCH-304	10/8/22	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	7.49E+01	7.82E-11	1.17E+01	3.81E+01	1.60E-02	1.12E-09	0.00E+00	1.10E-02	6.41E-04	2.60E-02
BATCH-305	10/18/22	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.56E+01	7.28E-11	1.02E+01	3.34E+01	1.40E-02	9.80E-10	0.00E+00	1.00E-02	5.61E-04	2.30E-02
BATCH-306	10/21/22	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.56E+01	7.27E-11	1.02E+01	3.34E+01	1.40E-02	9.80E-10	0.00E+00	1.00E-02	5.61E-04	2.30E-02
BATCH-307	10/29/22	106	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.68E+01	7.34E-11	1.04E+01	3.40E+01	1.50E-02	9.97E-10	0.00E+00	1.00E-02	5.71E-04	2.30E-02
BATCH-308	11/1/22	89	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.83E+01	1.28E-06	4.20E+00	1.18E+01	5.00E-03	1.61E-04	0.00E+00	1.50E-02	9.00E-03	8.00E-03
BATCH-309	11/9/22	98	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.21E+01	3.60E-11	9.67E+00	3.16E+01	1.40E-02	9.25E-10	0.00E+00	9.00E-03	5.31E-04	2.20E-02
BATCH-310	11/10/22	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	7.07E+01	4.10E-11	1.10E+01	3.60E+01	1.50E-02	1.05E-09	0.00E+00	1.10E-02	6.05E-04	2.50E-02
BATCH-311	11/20/22	102	10.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	6.57E+01	5.25E-07	9.80E+00	3.18E+01	1.10E-02	2.16E-10	0.00E+00	1.10E-02	6.16E-04	3.60E-02
BATCH-312	11/22/22	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.73E-04	6.73E+01	6.75E-07	9.93E+00	3.22E+01	1.10E-02	2.35E-11	0.00E+00	1.10E-02	6.46E-04	4.10E-02
BATCH-313	12/1/22	106	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.89E-04	6.86E+01	6.88E-07	1.01E+01	3.28E+01	1.10E-02	2.39E-11	0.00E+00	1.10E-02	6.58E-04	4.20E-02
BATCH-314	12/3/22	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.04E+01	7.29E-07	2.39E+00	6.71E+00	3.00E-03	9.21E-05	0.00E+00	9.00E-03	5.00E-03	5.00E-03
BATCH-315	12/9/22	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.27E-04	6.38E+01	6.39E-07	9.40E+00	3.05E+01	1.00E-02	2.23E-11	0.00E+00	1.10E-02	6.12E-04	3.90E-02
BATCH-316	12/12/22	113	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.43E-04	7.27E+01	7.29E-07	1.07E+01	3.48E+01	1.20E-02	2.53E-11	0.00E+00	1.20E-02	6.98E-04	4.40E-02
BATCH-317	12/20/22	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E-04	6.31E+01	6.33E-07	9.30E+00	3.02E+01	1.00E-02	2.15E-11	0.00E+00	1.10E-02	6.06E-04	3.80E-02
BATCH-318	12/24/22	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-04	6.33E+01	6.35E-07	9.34E+00	3.03E+01	1.00E-02	2.15E-11	0.00E+00	1.10E-02	6.08E-04	3.80E-02
BATCH-319	12/30/22	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.48E-04	2.62E+00	1.83E-07	6.01E-01	1.68E+00	6.89E-04	2.31E-05	0.00E+00	2.00E-03	1.00E-03	1.00E-03
BATCH-320	1/1/23	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.34E-04	6.44E+01	6.46E-07	9.50E+00	3.08E+01	1.00E-02	2.18E-11	0.00E+00	1.10E-02	6.18E-04	3.90E-02
BATCH-321	1/3/23	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.59E+01	3.92E-07	6.02E+00	2.70E+01	1.00E-02	1.72E-07	0.00E+00	8.00E-03	4.06E-04	2.60E-02
BATCH-322	1/12/23	85	8.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.25E+01	2.91E-07	4.78E+00	3.02E+01	1.20E-02	3.37E-07	0.00E+00	8.00E-03	3.39E-04	2.20E-02
BATCH-323	1/12/23	74	7.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.69E+01	2.53E-07	4.15E+00	2.62E+01	1.00E-02	2.93E-07	0.00E+00	7.00E-03	2.94E-04	1.90E-02
BATCH-324	1/20/23	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.95E+01	4.08E-07	6.69E+00	4.23E+01	1.70E-02	4.77E-07	0.00E+00	1.10E-02	4.75E-04	3.10E-02
BATCH-325	1/21/23	74	7.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.70E+01	2.54E-07	4.16E+00	2.63E+01	1.00E-02	2.94E-07	0.00E+00	7.00E-03	2.95E-04	1.90E-02
BATCH-326	1/29/23	81	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.27E+01	6.73E-07	4.52E+00	1.12E+01	4.00E-03	8.10E-05	0.00E+00	1.10E-02	4.00E-03	8.00E-03
BATCH-327	2/2/23	75	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.77E+01	2.58E-07	4.24E+00	2.68E+01	1.10E-02	2.99E-07	0.00E+00	7.00E-03	3.01E-04	2.00E-02
BATCH-328	2/7/23	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.22E+01	6.70E-07	4.57E+00	1.10E+01	4.00E-03	8.06E-05	0.00E+00	1.10E-02	4.00E-03	7.00E-03
BATCH-329	2/10/23	82	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.08E+01	2.80E-07	4.59E+00	2.91E+01	1.20E-02	3.25E-07	0.00E+00	8.00E-03	3.26E-04	2.10E-02
BATCH-330	2/15/23	79	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.19E+01	6.70E-07	4.52E+00	1.08E+01	4.00E-03	7.96E-05	0.00E+00	1.00E-02	4.00E-03	7.00E-03
BATCH-331	2/19/23	115	11.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.72E+01	3.92E-07	6.43E+00	4.07E+01	1.60E-02	4.55E-07	0.00E+00	1.10E-02	4.56E-04	3.00E-02
BATCH-332	2/24/23	56	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.43E+01	4.24E-07	2.84E+00	7.07E+00	3.00E-03	5.10E-05	0.00E+00	7.00E-03	3.00E-03	5.00E-03
BATCH-333	3/2/23	59	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.87E+01	1.12E-07	3.06E+00	2.06E+01	1.40E-02	3.53E-09	0.00E+00	3.00E-03	1.00E-03	4.00E-03
BATCH-334	3/3/23	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.41E+01	4.27E-07	2.91E+00	7.01E+00	3.00E-03	5.13E-05	0.00E+00	7.00E-03	3.00E-03	5.00E-03
BATCH-335	3/8/23	64	6.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.01E+01	1.19E-07	3.31E+00	2.23E+01	1.50E-02	2.20E-10	0.00E+00	3.00E-03	1.00E-03	5.00E-03
BATCH-336	3/9/23	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.42E+01	4.34E-07	2.93E+00	7.02E+00	3.00E-03	5.16E-05	0.00E+00	7.00E-03	3.00E-03	5.00E-03
BATCH-337	3/15/23	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.44E-04	3.91E+00	1.16E-07	7.78E-01	1.94E+00	7.23E-04	1.40E-05	0.00E+00	2.00E-03	7.66E-04	1.00E-03
BATCH-338	3/15/23	89	9.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.81E+01	1.68E-07	4.64E+00	3.12E+01	2.10E-02	2.21E-10	0.00E+00	5.00E-03	2.00E-03	6.00E-03
BATCH-339	3/17/23	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.71E+01	2.88E-07	5.69E+00	1.35E+01	5.00E-03	2.95E-05	0.00E+00	9.00E-03	2.00E-03	7.00E-03
BATCH-340	3/24/23	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.39E-04	3.82E+00	1.15E-07	7.87E-01	1.90E+00	7.06E-04	1.39E-05	0.00E+00	2.00E-03	7.60E-04	1.00E-03
BATCH-341	3/26/23	85	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.95E-04	2.48E+01	4.07E-08	5.79E+00	1.12E+01	5.00E-03	1.19E-08	0.00E+00	6.00E-03	1.69E-04	6.00E-03
BATCH-342	3/28/23	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E-04	3.85E+00	1.18E-07	7.93E-01	1.90E+00	7.01E-04	1.40E-05	0.00E+00	2.00E-03	7.66E-04	1.00E-03

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-343	3/30/23	96	10.0	0.24	0.00E+00	0.00E+00	5.70E-02	2.70E-02	4.47E+00	3.09E-01	1.91E+03	6.67E-01	1.10E-01	9.51E+00	1.02E-11	6.95E-01	5.00E-03	1.44E-01	7.25E-03
BATCH-344	4/4/23	78	8.1	0.24	0.00E+00	0.00E+00	4.60E-02	2.20E-02	3.64E+00	2.51E-01	1.55E+03	5.43E-01	9.00E-02	7.74E+00	8.30E-12	5.65E-01	4.00E-03	1.17E-01	5.75E-03
BATCH-345	4/9/23	55	5.7	0.24	0.00E+00	0.00E+00	1.50E-02	7.00E-03	1.19E+00	5.76E-02	8.79E+02	1.47E-01	2.60E-02	3.19E+00	6.73E-12	2.05E-01	1.00E-03	3.20E-02	2.00E-03
BATCH-346	4/13/23	95	9.9	0.24	0.00E+00	0.00E+00	5.70E-02	2.70E-02	4.46E+00	3.08E-01	1.91E+03	6.66E-01	1.10E-01	9.49E+00	1.02E-11	6.93E-01	5.00E-03	1.44E-01	7.00E-03
BATCH-347	4/15/23	74	7.8	0.24	0.00E+00	0.00E+00	3.40E-02	2.20E-02	2.70E+00	2.01E-01	1.49E+03	3.48E-01	5.70E-02	7.41E+00	9.01E-12	4.08E-01	2.00E-03	7.60E-02	5.00E-03
BATCH-348	4/23/23	53	5.5	0.24	0.00E+00	0.00E+00	1.30E-02	5.00E-03	9.99E-01	5.31E-02	8.46E+02	1.33E-01	2.30E-02	3.15E+00	2.46E-12	1.71E-01	9.06E-04	2.70E-02	1.75E-03
BATCH-349	4/23/23	50	5.2	0.24	0.00E+00	0.00E+00	1.30E-02	1.50E-02	9.90E-01	9.36E-02	4.24E+02	5.20E-02	8.00E-03	5.00E+00	7.20E-12	1.34E-01	3.53E-04	1.40E-02	2.75E-03
BATCH-350	4/28/23	41	4.3	0.24	0.00E+00	0.00E+00	1.00E-02	1.30E-02	8.06E-01	7.65E-02	3.46E+02	4.20E-02	7.00E-03	4.07E+00	5.86E-12	1.09E-01	2.88E-04	1.10E-02	2.25E-03
BATCH-351	4/28/23	20	2.1	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.31E-01	1.62E-02	2.44E+02	4.10E-02	7.00E-03	8.87E-01	1.87E-12	5.70E-02	2.89E-04	9.00E-03	5.00E-04
BATCH-352	5/1/23	44	4.6	0.24	0.00E+00	0.00E+00	1.10E-02	1.40E-02	8.72E-01	8.28E-02	3.72E+02	4.50E-02	7.00E-03	4.40E+00	6.34E-12	1.18E-01	3.10E-04	1.20E-02	2.25E-03
BATCH-353	5/3/23	50	5.2	0.24	0.00E+00	0.00E+00	1.30E-02	1.50E-02	9.89E-01	9.36E-02	4.23E+02	5.20E-02	8.00E-03	4.99E+00	7.19E-12	1.34E-01	3.52E-04	1.40E-02	2.75E-03
BATCH-354	5/5/23	19	2.0	0.24	0.00E+00	0.00E+00	3.00E-03	1.00E-03	2.70E-01	1.44E-02	2.28E+02	3.60E-02	6.00E-03	8.51E-01	6.64E-13	4.60E-02	2.45E-04	7.00E-03	5.00E-04
BATCH-355	5/8/23	35	3.6	0.24	0.00E+00	0.00E+00	9.00E-03	1.10E-02	6.89E-01	6.57E-02	2.93E+02	3.60E-02	6.00E-03	3.48E+00	5.02E-12	9.30E-02	2.45E-04	1.00E-02	1.75E-03
BATCH-356	5/8/23	131	13.6	0.24	0.00E+00	0.00E+00	1.70E-02	1.00E-02	1.35E+00	9.00E-02	1.92E+03	1.71E-01	2.80E-02	8.30E+00	5.93E-12	1.99E-01	1.00E-03	4.00E-02	2.25E-03
BATCH-357	5/11/23	57	6.0	0.24	0.00E+00	0.00E+00	1.40E-02	1.80E-02	1.13E+00	1.07E-01	4.79E+02	5.90E-02	9.00E-03	5.71E+00	8.22E-12	1.53E-01	4.01E-04	1.60E-02	3.00E-03
BATCH-358	5/18/23	132	13.7	0.24	0.00E+00	0.00E+00	1.20E-02	9.00E-03	9.38E-01	7.29E-02	1.57E+03	1.09E-01	1.80E-02	7.40E+00	3.73E-12	1.39E-01	7.57E-04	2.40E-02	1.75E-03
BATCH-359	5/22/23	29	3.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.90E-02	9.25E-01	1.42E-01	5.73E+02	7.80E-02	1.20E-02	2.86E+00	2.07E-12	1.26E-01	5.32E-04	1.70E-02	1.50E-03
BATCH-360	5/25/23	50	5.2	0.24	0.00E+00	0.00E+00	2.80E-02	5.10E-02	2.21E+00	3.96E-01	9.93E+02	2.16E-01	3.10E-02	4.95E+00	1.67E-13	3.02E-01	1.00E-03	4.40E-02	2.25E-03
BATCH-361	5/30/23	163	16.9	0.24	0.00E+00	0.00E+00	1.20E-02	1.00E-02	9.15E-01	7.56E-02	1.20E+03	9.00E-02	1.50E-02	7.60E+00	4.50E-12	1.32E-01	6.21E-04	2.10E-02	2.00E-03
BATCH-362	6/1/23	35	3.6	0.24	0.00E+00	0.00E+00	2.00E-02	3.60E-02	1.55E+00	2.77E-01	6.95E+02	1.51E-01	2.20E-02	3.46E+00	2.11E-13	2.11E-01	1.00E-03	3.10E-02	1.75E-03
BATCH-363	6/5/23	46	4.8	0.24	0.00E+00	0.00E+00	5.00E-03	3.00E-03	4.20E-01	2.79E-02	6.00E+02	5.40E-02	9.00E-03	2.59E+00	1.85E-12	6.20E-02	3.69E-04	1.20E-02	7.50E-04
BATCH-364	6/10/23	169	17.6	0.24	0.00E+00	0.00E+00	1.30E-02	1.20E-02	1.01E+00	9.09E-02	1.39E+03	9.80E-02	1.60E-02	8.75E+00	4.59E-12	1.45E-01	6.79E-04	2.20E-02	2.00E-03
BATCH-365	6/17/23	37	3.8	0.24	0.00E+00	0.00E+00	2.10E-02	3.80E-02	1.63E+00	2.92E-01	7.32E+02	1.59E-01	2.30E-02	3.65E+00	1.23E-13	2.23E-01	1.00E-03	3.30E-02	1.75E-03
BATCH-366	6/20/23	34	3.5	0.24	0.00E+00	0.00E+00	3.00E-03	2.00E-03	2.11E-01	1.62E-02	3.51E+02	2.40E-02	4.00E-03	1.66E+00	8.38E-13	3.10E-02	1.70E-04	5.00E-03	5.00E-04
BATCH-367	6/24/23	130	13.5	0.24	0.00E+00	0.00E+00	9.00E-03	1.30E-02	6.80E-01	9.54E-02	9.76E+02	5.20E-02	8.00E-03	7.86E+00	2.34E-12	9.30E-02	3.55E-04	1.20E-02	1.25E-03
BATCH-368	6/27/23	16	1.7	0.24	0.00E+00	0.00E+00	1.00E-03	7.24E-04	9.80E-02	6.30E-03	1.40E+02	1.30E-02	2.00E-03	6.07E-01	4.34E-13	1.50E-02	8.63E-05	3.00E-03	1.70E-04
BATCH-369	6/29/23	46	4.8	0.24	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.27E-01	1.89E-02	2.98E+02	2.20E-02	4.00E-03	1.88E+00	1.12E-12	3.30E-02	1.54E-04	5.00E-03	5.00E-04
BATCH-370	7/4/23	109	11.3	0.24	0.00E+00	0.00E+00	1.10E-02	2.00E-02	8.51E-01	1.53E-01	1.98E+03	8.30E-02	1.20E-02	1.08E+01	6.43E-14	1.16E-01	5.70E-04	1.70E-02	1.00E-03
BATCH-371	7/8/23	12	1.3	0.24	0.00E+00	0.00E+00	6.35E-04	4.62E-04	5.00E-02	3.60E-03	8.34E+01	6.00E-03	9.54E-04	3.94E-01	1.99E-13	7.00E-03	4.03E-05	1.00E-03	9.87E-05
BATCH-372	7/9/23	45	4.7	0.24	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.37E-01	2.16E-02	3.28E+02	2.30E-02	4.00E-03	2.06E+00	1.08E-12	3.40E-02	1.60E-04	5.00E-03	5.00E-04
BATCH-373	7/14/23	50	5.2	0.24	0.00E+00	0.00E+00	2.80E-02	5.10E-02	2.21E+00	3.95E-01	9.92E+02	2.16E-01	3.10E-02	4.94E+00	1.67E-13	3.02E-01	1.00E-03	4.40E-02	2.25E-03
BATCH-374	7/16/23	16	1.7	0.24	0.00E+00	0.00E+00	6.79E-04	5.88E-04	5.30E-02	4.50E-03	7.01E+01	5.00E-03	8.53E-04	4.43E-01	2.62E-13	8.00E-03	1.62E-05	1.00E-03	1.18E-04
BATCH-375	7/18/23	39	4.0	0.24	0.00E+00	0.00E+00	2.00E-03	3.00E-03	1.79E-01	2.52E-02	2.56E+02	1.40E-02	2.00E-03	2.07E+00	6.16E-13	2.40E-02	9.33E-05	3.00E-03	2.50E-04
BATCH-376	7/19/23	50	5.2	0.24	0.00E+00	0.00E+00	2.80E-02	5.10E-02	2.20E+00	3.95E-01	9.91E+02	2.16E-01	3.10E-02	4.94E+00	1.66E-13	3.01E-01	1.00E-03	4.40E-02	2.25E-03
BATCH-377	7/22/23	16	1.7	0.24	0.00E+00	0.00E+00	7.07E-04	6.65E-04	5.50E-02	5.40E-03	7.69E+01	5.00E-03	8.78E-04	4.83E-01	2.53E-13	8.00E-03	3.75E-05	1.00E-03	1.17E-04
BATCH-378	7/24/23	40	4.1	0.24	0.00E+00	0.00E+00	3.00E-03	6.00E-03	2.72E-01	4.86E-02	6.31E+02	2.70E-02	4.00E-03	3.67E+00	2.05E-14	3.70E-02	1.82E-04	5.00E-03	2.50E-04
BATCH-379	7/25/23	108	11.2	0.24	0.00E+00	0.00E+00	8.60E-02	2.90E-02	6.69E+00	3.19E-01	2.15E+03	7.96E-01	1.35E-01	1.07E+01	1.95E-12	7.86E-01	5.00E-03	1.93E-01	1.18E-02
BATCH-380	7/28/23	52	5.4	0.24	0.00E+00	0.00E+00	3.30E-02	4.20E-02	2.58E+00	3.39E-01	1.04E+03	2.72E-01	4.20E-02	5.18E+00	3.96E-13	3.35E-01	2.00E-03	6.00E-02	3.50E-03
BATCH-381	8/3/23	14	1.5	0.24	0.00E+00	0.00E+00	5.40E-04	8.29E-04	4.20E-02	6.30E-03	6.08E+01	3.00E-03	4.84E-04	4.89E-01	1.46E-13	6.00E-03	2.21E-05	7.25E-04	7.79E-05
BATCH-382	8/5/23	108	11.2	0.24	0.00E+00	0.00E+00	8.60E-02	2.90E-02	6.69E+00	3.19E-01	2.15E+03	7.96E-01	1.35E-01	1.07E+01	1.95E-12	7.86E-01	5.00E-03	1.93E-01	1.18E-02
BATCH-383	8/5/23	146	15.2	0.24	0.00E+00	0.00E+00	1.16E-01	4.00E-02	9.06E+00	4.32E-01	2.92E+03	1.08E+00	1.83E-01	1.45E+01	2.64E-12	1.06E+00	7.00E-03	2.62E-01	1.58E-02
BATCH-384	8/16/23	15	1.5	0.24	0.00E+00	0.00E+00	8.20E-04	1.00E-03	6.40E-02	1.17E-02	1.50E+02	6.00E-03	9.18E-04	8.69E-01	4.87E-15	9.00E-03	4.31E-05	1.00E-03	6.91E-05
BATCH-385	8/18/23	94	9.8	0.24	0.00E+00	0.00E+00	7.40E-02	2.50E-02	5.82E+00	2.77E-01	1.87E+03	6.92E-01	1.17E-01	9.33E+00	1.70E-12	6.84E-01	4.00E-03	1.68E-01	1.03E-02
BATCH-386	8/21/23	94	9.8	0.24	0.00E+00	0.00E+00	7.50E-02	2.60E-02	5.86E+00	2.79E-01	1.89E+03	6.97E-01	1.18E-01	9.40E+00	1.71E-12	6.89E-01	4.00E-03	1.69E-01	1.03E-02
BATCH-387	8/28/23	146	15.2	0.24	0.00E+00	0.00E+00	1.16E-01	3.90E-02	9.04E+00	4.30E-01	2.91E+03	1.08E+00	1.82E-01	1.45E+01	2.63E-12	1.06E+00	7.00E-03	2.61E-01	1.58E-02
BATCH-388	8/31/23	94	9.8	0.24	0.00E+00	0.00E+00	7.50E-02	2.50E-02	5.85E+00	2.78E-01	1.88E+03	6.95E-01	1.18E-01	9.37E+00	1.70E-12	6.86E-01	4.00E-03	1.69E-01	1.03E-02
BATCH-389	9/10/23	148	15.5	0.24	0.00E+00	0.00E+00	1.43E-01	9.70E-02	1.13E+01	9.18E-01	2.97E+03	1.00E+00	2.03E-01	1.48E+01	8.64E-13	1.04E+00	9.00E-03	2.94E-01	1.15E-02
BATCH-390	9/12/23	131	13.7	0.24	0.00E+00	0.00E+00	1.28E-01	8.90E-02	1.01E+01	8.43E-01	2.62E+03	8.80E-01	1.81E-01	1.31E+01	6.41E-13	9.13E-01	8.00E-03	2.62E-01	9.75E-03
BATCH-391	9/25/23	84	8.8	0.24	0.00E+00	0.00E+00	8.20E-02	5.70E-02	6.48E+00	5.42E-01	1.68E+03	5.65E-01	1.16E-01	8.39E+00	4.12E-13	5.86E-01	5.00E-03	1.68E-01	6.25E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-343	3/30/23	96	10.0	0.24	4.03E-07	2.86E+02	2.54E+02	2.50E-02	1.67E+00	1.14E-01	7.00E-03	8.84E-06	3.63E-04	1.64E-04	1.62E-04	7.28E-04	1.60E-02	8.30E-02	1.90E-02
BATCH-344	4/4/23	78	8.1	0.24	3.28E-07	2.33E+02	2.07E+02	2.00E-02	1.36E+00	9.30E-02	5.00E-03	7.19E-06	2.96E-04	1.34E-04	1.31E-04	5.92E-04	1.30E-02	6.80E-02	1.60E-02
BATCH-345	4/9/23	55	5.7	0.24	1.33E-07	1.64E+02	5.60E+01	5.00E-03	3.31E-01	2.50E-02	4.00E-03	2.05E-06	8.44E-05	2.81E-05	3.58E-05	1.07E-04	3.00E-03	1.50E-02	4.00E-03
BATCH-346	4/13/23	95	9.9	0.24	4.03E-07	2.86E+02	2.54E+02	2.50E-02	1.67E+00	1.14E-01	7.00E-03	8.82E-06	3.63E-04	1.64E-04	1.61E-04	7.26E-04	1.60E-02	8.30E-02	1.90E-02
BATCH-347	4/15/23	74	7.8	0.24	9.32E-07	2.23E+02	1.30E+02	1.30E-02	2.32E+00	3.69E-01	6.00E-03	4.56E-06	2.03E-04	1.06E-04	8.47E-05	3.99E-04	9.00E-03	4.40E-02	1.60E-02
BATCH-348	4/23/23	53	5.5	0.24	8.05E-08	1.59E+02	4.85E+01	4.00E-03	3.01E-01	2.00E-02	1.00E-03	1.75E-06	6.95E-05	2.42E-05	3.23E-05	9.56E-05	3.00E-03	1.30E-02	4.00E-03
BATCH-349	4/23/23	50	5.2	0.24	1.28E-06	1.50E+02	1.51E+01	2.00E-03	2.64E+00	5.47E-01	5.00E-03	6.07E-07	5.20E-05	4.74E-05	1.35E-05	9.01E-05	1.00E-03	7.00E-03	1.10E-02
BATCH-350	4/28/23	41	4.3	0.24	1.05E-06	1.22E+02	1.23E+01	1.00E-03	2.15E+00	4.45E-01	4.00E-03	4.95E-07	4.23E-05	3.86E-05	1.10E-05	7.34E-05	1.00E-03	6.00E-03	9.00E-03
BATCH-351	4/28/23	20	2.1	0.24	3.68E-08	5.93E+01	1.56E+01	1.00E-03	9.20E-02	7.00E-03	1.00E-03	5.70E-07	2.35E-05	7.81E-06	9.93E-06	2.98E-05	8.13E-04	4.00E-03	1.00E-03
BATCH-352	5/1/23	44	4.6	0.24	1.13E-06	1.33E+02	1.33E+01	2.00E-03	2.33E+00	4.82E-01	4.00E-03	5.34E-07	4.57E-05	4.17E-05	1.19E-05	7.93E-05	1.00E-03	6.00E-03	1.00E-02
BATCH-353	5/3/23	50	5.2	0.24	1.28E-06	1.50E+02	1.51E+01	2.00E-03	2.64E+00	5.46E-01	5.00E-03	6.07E-07	5.19E-05	4.73E-05	1.35E-05	9.01E-05	1.00E-03	7.00E-03	1.10E-02
BATCH-354	5/5/23	19	2.0	0.24	2.17E-08	5.69E+01	1.31E+01	1.00E-03	8.10E-02	5.00E-03	3.76E-04	4.74E-07	1.88E-05	6.54E-06	8.73E-06	2.58E-05	7.13E-04	4.00E-03	1.00E-03
BATCH-355	5/8/23	35	3.6	0.24	8.95E-07	1.05E+02	1.05E+01	1.00E-03	1.84E+00	3.81E-01	3.00E-03	4.21E-07	3.61E-05	3.30E-05	9.36E-06	6.27E-05	9.42E-04	5.00E-03	8.00E-03
BATCH-356	5/8/23	131	13.6	0.24	3.77E-07	3.91E+02	6.86E+01	7.00E-03	1.00E+00	1.49E-01	4.00E-03	2.43E-06	9.53E-05	4.91E-05	4.28E-05	1.89E-04	4.00E-03	2.20E-02	8.00E-03
BATCH-357	5/11/23	57	6.0	0.24	1.47E-06	1.72E+02	1.72E+01	2.00E-03	3.02E+00	6.25E-01	5.00E-03	6.90E-07	5.92E-05	5.40E-05	1.53E-05	1.03E-04	2.00E-03	8.00E-03	1.30E-02
BATCH-358	5/18/23	132	13.7	0.24	4.70E-07	3.95E+02	4.01E+01	4.00E-03	1.08E+00	1.92E-01	2.00E-03	1.42E-06	6.71E-05	3.80E-05	2.67E-05	1.30E-04	3.00E-03	1.40E-02	6.00E-03
BATCH-359	5/22/23	29	3.0	0.24	8.70E-07	8.60E+01	2.44E+01	4.00E-03	1.82E+00	3.68E-01	1.00E-03	7.74E-07	5.77E-05	3.06E-05	1.67E-05	1.02E-04	2.00E-03	9.00E-03	1.50E-02
BATCH-360	5/25/23	50	5.2	0.24	1.74E-06	1.49E+02	6.90E+01	1.30E-02	3.69E+00	7.29E-01	1.76E-05	2.06E-06	1.47E-04	5.90E-05	4.41E-05	2.62E-04	5.00E-03	2.40E-02	4.00E-02
BATCH-361	5/30/23	163	16.9	0.24	6.65E-07	4.87E+02	3.20E+01	3.00E-03	1.45E+00	2.78E-01	3.00E-03	1.15E-06	6.05E-05	3.90E-05	2.22E-05	1.14E-04	2.00E-03	1.10E-02	7.00E-03
BATCH-362	6/1/23	35	3.6	0.24	1.22E-06	1.04E+02	4.83E+01	9.00E-03	2.58E+00	5.10E-01	1.52E-05	1.44E-06	1.03E-04	4.13E-05	3.09E-05	1.83E-04	3.00E-03	1.70E-02	2.80E-02
BATCH-363	6/5/23	46	4.8	0.24	1.18E-07	1.38E+02	2.14E+01	2.00E-03	3.13E-01	4.70E-02	1.00E-03	7.58E-07	2.98E-05	1.54E-05	1.34E-05	5.90E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-364	6/10/23	169	17.6	0.24	7.40E-07	5.05E+02	3.47E+01	4.00E-03	1.61E+00	3.09E-01	3.00E-03	1.24E-06	6.64E-05	4.16E-05	2.40E-05	1.25E-04	2.00E-03	1.20E-02	9.00E-03
BATCH-365	6/17/23	37	3.8	0.24	1.28E-06	1.10E+02	5.08E+01	1.00E-02	2.72E+00	5.37E-01	1.29E-05	1.52E-06	1.09E-04	4.35E-05	3.25E-05	1.93E-04	3.00E-03	1.80E-02	2.90E-02
BATCH-366	6/20/23	34	3.5	0.24	1.05E-07	1.01E+02	9.01E+00	9.05E-04	2.43E-01	4.30E-02	5.52E-04	3.19E-07	1.51E-05	8.53E-06	6.00E-06	2.92E-05	6.08E-04	3.00E-03	1.00E-03
BATCH-367	6/24/23	130	13.5	0.24	6.99E-07	3.90E+02	1.62E+01	3.00E-03	1.46E+00	2.96E-01	2.00E-03	5.33E-07	4.09E-05	2.49E-05	1.16E-05	7.19E-05	1.00E-03	6.00E-03	1.00E-02
BATCH-368	6/27/23	16	1.7	0.24	2.75E-08	4.82E+01	5.02E+00	4.87E-04	7.30E-02	1.10E-02	2.86E-04	1.77E-07	6.97E-06	3.59E-06	3.13E-06	1.38E-05	2.00E-03	2.00E-03	5.50E-04
BATCH-369	6/29/23	46	4.8	0.24	1.65E-07	1.37E+02	7.93E+00	8.13E-04	3.59E-01	6.90E-02	7.39E-04	2.85E-07	1.50E-05	9.66E-06	5.50E-06	2.84E-05	5.57E-04	3.00E-03	2.00E-03
BATCH-370	7/4/23	109	11.3	0.24	6.70E-07	3.26E+02	2.66E+01	5.00E-03	1.42E+00	2.81E-01	6.77E-06	7.95E-07	5.68E-05	2.28E-05	1.70E-05	1.01E-04	2.00E-03	9.00E-03	1.50E-02
BATCH-371	7/8/23	12	1.3	0.24	2.50E-08	3.62E+01	2.14E+00	2.15E-04	5.80E-02	1.00E-02	1.31E-04	7.57E-08	3.57E-06	2.02E-06	1.42E-06	6.92E-06	1.44E-04	7.33E-04	3.37E-04
BATCH-372	7/9/23	45	4.7	0.24	1.74E-07	1.35E+02	8.17E+00	8.87E-04	3.78E-01	7.30E-02	7.15E-04	2.91E-07	1.56E-05	9.80E-06	5.65E-06	2.94E-05	5.74E-04	3.00E-03	2.00E-03
BATCH-373	7/14/23	50	5.2	0.24	1.74E-06	1.49E+02	6.89E+01	1.30E-02	3.69E+00	7.28E-01	1.75E-05	2.06E-06	1.47E-04	5.89E-05	4.41E-05	1.29E-04	5.00E-03	2.40E-02	3.90E-02
BATCH-374	7/16/23	16	1.7	0.24	3.88E-08	4.81E+01	1.86E+00	1.91E-04	8.40E-02	1.60E-02	1.74E-04	6.71E-08	3.52E-06	2.27E-06	1.29E-06	6.66E-06	1.31E-04	6.65E-04	4.31E-04
BATCH-375	7/18/23	39	4.0	0.24	1.83E-07	1.16E+02	4.24E+00	7.09E-04	3.82E-01	7.80E-02	4.07E-04	1.40E-07	1.07E-05	6.54E-06	3.04E-06	1.89E-05	3.18E-04	2.00E-03	3.00E-03
BATCH-376	7/19/23	50	5.2	0.24	1.73E-06	1.49E+02	6.88E+01	1.30E-02	3.68E+00	7.28E-01	1.75E-05	2.06E-06	1.47E-04	5.89E-05	4.40E-05	2.61E-04	5.00E-03	2.40E-02	3.90E-02
BATCH-377	7/22/23	16	1.7	0.24	4.08E-08	4.76E+01	1.92E+00	2.08E-04	8.90E-02	1.70E-02	1.68E-04	6.82E-08	3.67E-06	2.30E-06	1.32E-06	6.90E-06	1.35E-04	6.83E-04	4.91E-04
BATCH-378	7/24/23	40	4.1	0.24	2.14E-07	1.19E+02	8.50E+00	2.00E-03	4.55E-01	9.00E-02	2.16E-06	2.54E-07	1.81E-05	7.27E-06	5.43E-06	3.22E-05	5.83E-04	3.00E-03	5.00E-03
BATCH-379	7/25/23	108	11.2	0.24	3.07E-07	3.23E+02	3.55E+02	2.60E-02	2.06E+00	1.38E-01	1.00E-03	1.39E-05	1.40E-04	7.09E-05	2.19E-04	2.00E-04	1.10E-02	5.50E-02	3.40E-02
BATCH-380	7/28/23	52	5.4	0.24	1.34E-06	1.56E+02	1.01E+02	1.30E-02	3.04E+00	5.63E-01	1.55E-04	3.47E-06	1.29E-04	5.38E-05	6.34E-05	2.23E-04	5.00E-03	2.60E-02	1.20E-02
BATCH-381	8/3/23	14	1.5	0.24	4.34E-08	4.21E+01	1.01E+00	1.68E-04	9.10E-02	1.80E-02	9.65E-05	3.31E-08	2.54E-06	1.55E-06	7.19E-07	4.47E-06	7.54E-05	3.82E-04	6.30E-04
BATCH-382	8/5/23	108	11.2	0.24	3.07E-07	3.23E+02	3.55E+02	2.60E-02	2.06E+00	1.38E-01	1.00E-03	1.39E-05	1.40E-04	7.08E-05	2.19E-04	2.00E-04	1.10E-02	5.50E-02	3.40E-02
BATCH-383	8/5/23	146	15.2	0.24	4.14E-07	4.38E+02	4.80E+02	3.50E-02	2.79E+00	1.87E-01	1.00E-03	1.88E-05	1.90E-04	9.59E-05	2.96E-04	2.70E-04	1.50E-02	7.50E-02	4.60E-02
BATCH-384	8/16/23	15	1.5	0.24	5.07E-08	4.36E+01	2.01E+00	3.79E-04	1.08E-01	2.10E-02	5.12E-07	6.01E-08	4.30E-06	1.72E-06	1.29E-06	7.63E-06	1.38E-04	6.99E-04	1.00E-03
BATCH-385	8/18/23	94	9.8	0.24	2.67E-07	2.81E+02	3.08E+02	2.30E-02	1.79E+00	1.20E-01	8.88E-04	1.21E-05	1.22E-04	6.16E-05	1.90E-04	1.74E-04	9.00E-03	1.75E-04	1.00E-02
BATCH-386	8/21/23	94	9.8	0.24	2.68E-07	2.83E+02	3.11E+02	2.30E-02	1.81E+00	1.21E-01	8.95E-04	1.22E-05	1.23E-04	6.20E-05	1.92E-04	1.75E-04	1.00E-02	1.80E-02	3.00E-02
BATCH-387	8/28/23	146	15.2	0.24	4.13E-07	4.36E+02	4.79E+02	3.50E-02	2.78E+00	1.86E-01	1.00E-03	1.87E-05	1.89E-04	9.56E-05	2.96E-04	2.69E-04	1.50E-02	7.50E-02	4.60E-02
BATCH-388	8/31/23	94	9.8	0.24	2.67E-07	2.82E+02	3.10E+02	2.30E-02	1.80E+00	1.20E-01	8.92E-04	1.21E-05	1.22E-04	6.18E-05	1.91E-04	1.74E-04	1.00E-02	4.80E-02	3.00E-02
BATCH-389	9/10/23	148	15.5	0.24	1.10E-06	4.45E+02	3.49E+02	3.50E-02	2.18E+00	1.71E-01	2.43E-04	1.30E-05	3.44E-04	1.27E-04	3.96E-04	4.39E-04	1.60E-02	8.10E-02	5.30E-02
BATCH-390	9/12/23	131	13.7	0.24	1.02E-06	3.93E+02	2.99E+02	3.10E-02	1.88E+00	1.50E-01	1.37E-04	1.11E-05	3.14E-04	1.14E-04	3.56E-04	3.99E-04	1.40E-02	7.20E-02	4.70E-02
BATCH-391	9/25/23	84	8.8	0.24	6.52E-07	2.53E+02	1.92E+02	2.00E-02	1.21E+00	9.60E-02	8.81E-05	7.10E-06	2.02E-04	7.35E-05	2.29E-04	2.57E-04	9.00E-03	4.60E-02	3.00E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-343	3/30/23	96	10.0	0.24	7.80E-04	6.00E-04	2.90E-02	2.90E-02	2.40E-02	1.25E+00	2.13E-01	1.58E+00	6.21E-01	6.31E-22	1.37E-05	5.86E-05	8.89E-04	1.20E-02	5.08E-07
BATCH-344	4/4/23	78	8.1	0.24	6.35E-04	4.88E-04	2.30E-02	2.40E-02	2.00E-02	1.02E+00	1.73E-01	1.29E+00	5.06E-01	5.14E-22	1.12E-05	4.77E-05	7.23E-04	1.00E-02	4.12E-07
BATCH-345	4/9/23	55	5.7	0.24	1.72E-04	1.34E-04	7.00E-03	6.00E-03	5.00E-03	2.68E-01	4.60E-02	3.65E-01	1.33E-01	5.48E-23	2.98E-06	1.12E-05	1.01E-04	9.99E-04	6.03E-06
BATCH-346	4/13/23	95	9.9	0.24	7.79E-04	5.99E-04	2.80E-02	2.90E-02	2.40E-02	1.25E+00	2.12E-01	1.58E+00	6.20E-01	6.30E-22	1.37E-05	5.85E-05	8.87E-04	1.20E-02	5.06E-07
BATCH-347	4/15/23	74	7.8	0.24	6.58E-04	3.65E-04	1.50E-02	1.90E-02	1.80E-02	8.32E-01	1.40E-01	3.09E+00	4.02E-01	3.41E-22	8.39E-06	9.21E-05	4.82E-04	6.00E-03	6.72E-07
BATCH-348	4/23/23	53	5.5	0.24	1.54E-04	1.16E-04	5.00E-03	5.00E-03	4.00E-03	2.39E-01	4.10E-02	2.80E-01	1.13E-01	5.45E-23	2.60E-06	1.01E-05	8.80E-05	8.03E-04	8.80E-07
BATCH-349	4/23/23	50	5.2	0.24	4.97E-04	1.37E-04	3.00E-03	8.00E-03	1.10E-02	4.06E-01	6.70E-02	4.05E+00	1.84E-01	7.03E-23	3.22E-06	1.11E-04	1.01E-04	6.43E-04	7.47E-07
BATCH-350	4/28/23	41	4.3	0.24	4.05E-04	1.12E-04	2.00E-03	7.00E-03	9.00E-03	3.31E-01	5.40E-02	3.29E+00	1.50E-01	5.73E-23	2.63E-06	9.06E-05	8.24E-05	5.24E-04	6.08E-07
BATCH-351	4/28/23	20	2.1	0.24	4.78E-05	3.73E-05	2.00E-03	2.00E-03	1.00E-03	7.50E-02	1.30E-02	1.02E-01	3.70E-02	1.52E-23	8.26E-07	3.10E-06	2.80E-05	2.78E-04	1.67E-06
BATCH-352	5/1/23	44	4.6	0.24	4.38E-04	1.21E-04	3.00E-03	7.00E-03	1.00E-02	3.58E-01	5.90E-02	3.57E+00	1.62E-01	6.19E-23	2.84E-06	9.81E-05	8.90E-05	5.65E-04	6.58E-07
BATCH-353	5/3/23	50	5.2	0.24	4.97E-04	1.37E-04	3.00E-03	8.00E-03	1.10E-02	4.06E-01	6.70E-02	4.04E+00	1.84E-01	7.03E-23	3.22E-06	1.11E-04	1.01E-04	6.42E-04	7.46E-07
BATCH-354	5/5/23	19	2.0	0.24	4.15E-05	3.14E-05	1.00E-03	1.00E-03	6.50E-02	1.10E-02	7.60E-02	3.10E-02	1.47E-23	7.02E-07	2.73E-06	2.38E-05	2.17E-04	2.38E-07	
BATCH-355	5/8/23	35	3.6	0.24	3.46E-04	9.55E-05	2.00E-03	6.00E-03	8.00E-03	2.83E-01	4.70E-02	2.82E+00	1.28E-01	4.89E-23	2.25E-06	7.76E-05	7.03E-05	4.45E-04	5.20E-07
BATCH-356	5/8/23	131	13.6	0.24	3.13E-04	1.86E-04	8.00E-03	9.00E-03	9.00E-03	4.05E-01	6.80E-02	1.29E+00	1.96E-01	1.32E-22	4.17E-06	3.97E-05	1.92E-04	2.00E-03	7.03E-07
BATCH-357	5/11/23	57	6.0	0.24	5.67E-04	1.56E-04	3.00E-03	9.00E-03	1.30E-02	4.64E-01	7.60E-02	4.62E+00	2.10E-01	8.00E-23	3.68E-06	1.27E-04	1.15E-04	7.29E-04	8.53E-07
BATCH-358	5/18/23	132	13.7	0.24	2.68E-04	1.27E-04	5.00E-03	7.00E-03	7.00E-03	3.05E-01	5.10E-02	1.52E+00	1.45E-01	1.10E-22	2.94E-06	4.40E-05	1.56E-04	2.00E-03	3.11E-07
BATCH-359	5/22/23	29	3.0	0.24	6.34E-04	2.42E-04	3.00E-03	6.00E-03	1.50E-02	3.25E-01	5.60E-02	1.99E+00	1.36E-01	1.08E-22	2.67E-06	4.99E-05	1.49E-04	2.00E-03	2.11E-07
BATCH-360	5/25/23	50	5.2	0.24	2.00E-03	6.95E-04	7.00E-03	1.30E-02	4.10E-02	7.21E-01	1.28E-01	2.90E+00	2.86E-01	3.02E-22	6.01E-06	6.32E-05	4.11E-04	5.00E-03	4.36E-09
BATCH-361	5/30/23	163	16.9	0.24	3.18E-04	1.25E-04	4.00E-03	7.00E-03	8.00E-03	3.19E-01	5.30E-02	2.13E+00	1.50E-01	9.53E-23	2.90E-06	6.00E-05	1.35E-04	1.00E-03	4.13E-07
BATCH-362	6/1/23	35	3.6	0.24	1.00E-03	4.86E-04	5.00E-03	9.00E-03	2.90E-02	5.05E-01	8.90E-02	2.03E+00	2.00E-01	2.11E-22	4.20E-06	4.43E-05	2.87E-04	4.00E-03	3.49E-09
BATCH-363	6/5/23	46	4.8	0.24	9.77E-05	5.80E-05	2.00E-03	3.00E-03	3.00E-03	1.26E-01	2.10E-02	4.04E-01	6.10E-02	4.12E-23	1.30E-06	1.24E-05	5.99E-05	7.18E-04	2.20E-07
BATCH-364	6/10/23	169	17.6	0.24	3.82E-04	1.51E-04	4.00E-03	7.00E-03	9.00E-03	3.50E-01	5.80E-02	2.27E+00	1.62E-01	1.07E-22	3.15E-06	6.34E-05	1.51E-04	2.00E-03	4.22E-07
BATCH-365	6/17/23	37	3.8	0.24	1.00E-03	5.12E-04	5.00E-03	1.00E-02	3.00E-02	5.31E-01	9.40E-02	2.13E+00	2.11E-01	2.23E-22	4.43E-06	4.66E-05	3.03E-04	4.00E-03	3.18E-09
BATCH-366	6/20/23	34	3.5	0.24	6.02E-05	2.86E-05	1.00E-03	1.00E-03	2.00E-03	6.80E-02	1.10E-02	3.42E-01	3.30E-02	2.47E-23	6.60E-07	9.87E-06	3.49E-05	4.23E-04	6.98E-08
BATCH-367	6/24/23	130	13.5	0.24	4.37E-04	1.58E-04	2.00E-03	5.00E-03	1.00E-02	2.49E-01	4.20E-02	1.78E+00	1.06E-01	7.21E-23	2.02E-06	4.62E-05	9.98E-05	1.00E-03	2.41E-07
BATCH-368	6/27/23	16	1.7	0.24	2.29E-05	1.36E-05	5.81E-04	6.69E-04	6.33E-04	3.00E-02	5.00E-03	9.50E-02	1.40E-02	9.63E-24	3.05E-07	2.91E-06	1.40E-05	1.68E-04	5.14E-08
BATCH-369	6/29/23	46	4.8	0.24	7.88E-05	3.10E-05	1.00E-03	2.00E-03	2.00E-03	7.90E-02	1.30E-02	5.27E-01	3.70E-02	2.36E-23	7.19E-07	1.49E-05	3.35E-05	3.68E-04	1.03E-07
BATCH-370	7/4/23	109	11.3	0.24	6.50E-04	2.68E-04	3.00E-03	5.00E-03	1.60E-02	2.78E-01	4.90E-02	1.12E+00	1.10E-01	1.17E-22	2.32E-06	2.44E-05	1.58E-04	2.00E-03	1.67E-09
BATCH-371	7/8/23	12	1.3	0.24	1.43E-05	6.78E-06	2.60E-04	3.55E-04	3.74E-04	1.60E-02	3.00E-03	8.10E-02	8.00E-03	5.87E-24	1.57E-07	2.34E-06	8.29E-06	1.00E-04	1.66E-08
BATCH-372	7/9/23	45	4.7	0.24	9.00E-05	3.55E-05	1.00E-03	2.00E-03	2.00E-03	8.20E-02	1.40E-02	5.35E-01	3.80E-02	2.52E-23	7.42E-07	1.49E-05	3.56E-05	3.95E-04	9.93E-08
BATCH-373	7/14/23	50	5.2	0.24	2.00E-03	6.94E-04	7.00E-03	1.30E-02	4.10E-02	7.20E-01	1.28E-01	2.89E+00	2.85E-01	3.02E-22	6.00E-06	6.32E-05	4.10E-04	5.00E-03	4.32E-09
BATCH-374	7/16/23	16	1.7	0.24	1.85E-05	7.28E-06	2.42E-04	3.95E-04	4.61E-04	1.90E-02	3.00E-03	1.24E-01	9.00E-03	5.56E-24	1.69E-07	3.50E-06	7.88E-06	8.65E-05	2.41E-08
BATCH-375	7/18/23	39	4.0	0.24	1.15E-04	4.15E-05	5.62E-04	1.00E-03	3.00E-03	6.50E-02	1.10E-02	4.67E-01	2.80E-02	1.90E-23	5.31E-07	1.21E-05	2.62E-05	2.73E-04	6.33E-08
BATCH-376	7/19/23	50	5.2	0.24	2.00E-03	6.94E-04	7.00E-03	1.30E-02	4.10E-02	7.20E-01	1.28E-01	2.89E+00	2.85E-01	3.02E-22	6.00E-06	6.31E-05	4.10E-04	5.00E-03	4.32E-09
BATCH-377	7/22/23	16	1.7	0.24	2.11E-05	8.33E-06	2.47E-04	4.06E-04	5.22E-04	1.90E-02	3.00E-03	1.25E-01	9.00E-03	5.91E-24	1.74E-07	3.50E-06	8.35E-06	9.25E-05	2.33E-08
BATCH-378	7/24/23	40	4.1	0.24	2.08E-04	8.56E-05	9.15E-04	2.00E-03	5.00E-03	8.90E-02	1.60E-02	3.57E-01	3.50E-02	3.72E-23	7.40E-07	7.79E-06	5.06E-05	6.27E-04	5.35E-10
BATCH-379	7/25/23	108	11.2	0.24	1.00E-03	9.46E-04	4.50E-02	3.50E-02	3.50E-02	1.65E+00	2.71E-01	2.08E+00	7.32E-01	2.42E-22	1.60E-05	6.20E-05	3.58E-04	3.00E-03	1.22E-07
BATCH-380	7/28/23	52	5.4	0.24	1.00E-03	6.50E-04	1.20E-02	1.50E-02	3.50E-02	7.67E-01	1.33E-01	2.45E+00	3.15E-01	2.59E-22	6.71E-06	5.58E-05	3.56E-04	4.00E-03	2.02E-08
BATCH-381	8/3/23	14	1.5	0.24	2.72E-05	9.84E-06	1.33E-04	2.95E-04	6.46E-04	1.50E-02	3.00E-03	1.11E-01	7.00E-03	4.49E-24	1.26E-07	2.88E-06	6.21E-06	6.48E-05	1.50E-08
BATCH-382	8/5/23	108	11.2	0.24	1.00E-03	9.45E-04	4.50E-02	3.50E-02	1.65E+00	2.71E-01	2.08E+00	7.31E-01	2.41E-22	1.60E-05	6.20E-05	3.58E-04	3.00E-03	1.22E-07	
BATCH-383	8/5/23	146	15.2	0.24	2.00E-03	1.00E-03	6.10E-02	4.80E-02	4.70E-02	2.23E+00	3.67E-01	2.81E+00	9.90E-01	3.27E-22	2.17E-05	8.39E-05	4.84E-04	4.00E-03	1.65E-07
BATCH-384	8/16/23	15	1.5	0.24	4.92E-05	2.03E-05	2.17E-04	3.80E-04	1.00E-03	2.10E-02	4.00E-03	8.40E-02	8.00E-03	8.82E-24	1.75E-07	1.84E-06	1.20E-05	1.49E-04	1.27E-10
BATCH-385	8/18/23	94	9.8	0.24	1.00E-03	8.22E-04	3.90E-02	3.10E-02	3.00E-02	1.43E+00	2.35E-01	1.81E+00	6.36E-01	2.10E-22	1.39E-05	5.39E-05	3.11E-04	2.00E-03	1.06E-07
BATCH-386	8/21/23	94	9.8	0.24	1.00E-03	8.28E-04	3.90E-02	3.10E-02	3.10E-02	1.44E+00	2.37E-01	1.82E+00	6.41E-01	2.11E-22	1.40E-05	5.43E-05	3.13E-04	2.00E-03	1.07E-07
BATCH-387	8/28/23	146	15.2	0.24	2.00E-03	1.00E-03	6.00E-02	4.80E-02	4.70E-02	2.22E+00	3.66E-01	2.80E+00	9.88E-01	3.26E-22	2.16E-05	8.37E-05	4.83E-04	4.00E-03	1.64E-07
BATCH-388	8/31/23	94	9.8	0.24	1.00E-03	8.26E-04	3.90E-02	3.10E-02	3.10E-02	1.44E+00	2.36E-01	1.81E+00	6.39E-01	2.11E-22	1.40E-05	5.41E-05	3.12E-04	2.00E-03	1.06E-07
BATCH-389	9/10/23	148	15.5	0.24	2.00E-03	1.00E-03	4.20E-02	9.30E-02	5.60E-02	1.90E+00	3.20E-01	2.99E+00	9.04E-01	8.48E-22	1.99E-05	9.76E-05	1.00E-03	9.00E-03	2.46E-08
BATCH-390	9/12/23	131	13.7	0.24	2.00E-03	1.00E-03	3.50E-02	8.60E-02	5.00E-02	1.66E+00	2.79E-01	2.66E+00	7.92E-01	7.85E-22	1.74E-05	8.71E-05	1.00E-03	8.00E-03	1.22E-08
BATCH-391	9/25/23	84	8.8	0.24	1.00E-03	7.29E-04	2.30E-02	5.50E-02	3.20E-02	1.06E+00	1.79E-01	1.71E+00	5.09E-01	5.04E-22	1.12E-05	5.59E-05	7.68E-04	5.00E-03	7.83E-09

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-343	3/30/23	96	10.0	0.24	6.00E-03	8.27E+01	1.61E-06	2.58E-04	1.32E-06	1.30E-10	8.00E-03	6.90E-02	1.10E-05	2.00E-03	2.11E+01	0.00E+00	1.00E-03	8.21E+00	2.16E-04
BATCH-344	4/4/23	78	8.1	0.24	6.81E-13	6.73E+01	1.31E-06	2.10E-04	1.08E-06	2.88E-20	6.00E-03	5.60E-02	8.96E-06	2.00E-03	1.72E+01	0.00E+00	9.51E-14	6.68E+00	1.62E-04
BATCH-345	4/9/23	55	5.7	0.24	1.28E+02	0.00E+00	1.23E-06	7.86E-04	1.28E-06	3.28E-06	4.00E-03	1.73E-01	1.05E-05	5.00E-03	4.47E+00	0.00E+00	1.97E+01	0.00E+00	1.89E-04
BATCH-346	4/13/23	95	9.9	0.24	5.00E-03	8.25E+01	1.61E-06	2.58E-04	1.32E-06	1.27E-10	8.00E-03	6.90E-02	1.10E-05	2.00E-03	2.11E+01	0.00E+00	1.00E-03	8.19E+00	2.16E-04
BATCH-347	4/15/23	74	7.8	0.24	4.00E-03	5.26E+01	9.14E-07	1.53E-04	1.50E-06	1.05E-10	9.00E-03	4.02E-01	1.19E-05	8.10E-02	1.44E+01	0.00E+00	8.68E-04	6.54E+00	2.16E-04
BATCH-348	4/23/23	53	5.5	0.24	1.27E-02	0.00E+00	5.71E-07	6.45E-05	6.09E-07	2.86E-06	5.00E-03	1.66E-01	3.69E-06	4.00E-03	4.00E+00	0.00E+00	2.19E-01	0.00E+00	1.08E-04
BATCH-349	4/23/23	50	5.2	0.24	2.29E-06	2.30E+01	2.51E-07	5.15E-05	1.50E-06	5.39E-14	8.00E-03	6.40E-01	1.15E-05	1.39E-01	7.58E+00	0.00E+00	4.47E-07	4.56E+00	2.16E-04
BATCH-350	4/28/23	41	4.3	0.24	3.47E-16	1.87E+01	2.05E-07	4.19E-05	1.22E-06	1.47E-23	7.00E-03	5.21E-01	9.34E-06	1.13E-01	6.17E+00	0.00E+00	4.85E-17	3.72E+00	1.62E-04
BATCH-351	4/28/23	20	2.1	0.24	3.55E-01	0.00E+00	3.40E-07	2.18E-04	3.55E-07	9.11E-07	1.00E-03	4.80E-02	2.91E-06	1.00E-03	1.24E+00	0.00E+00	5.48E+00	0.00E+00	5.39E-05
BATCH-352	5/1/23	44	4.6	0.24	2.10E-06	2.02E+01	2.21E-07	4.53E-05	1.32E-06	4.96E-14	7.00E-03	5.64E-01	1.01E-05	1.22E-01	6.68E+00	0.00E+00	4.09E-07	4.02E+00	1.89E-04
BATCH-353	5/3/23	50	5.2	0.24	2.23E-06	2.29E+01	2.51E-07	5.14E-05	1.50E-06	5.27E-14	8.00E-03	6.39E-01	1.15E-05	1.39E-01	7.57E+00	0.00E+00	4.33E-07	4.56E+00	2.16E-04
BATCH-354	5/5/23	19	2.0	0.24	3.43E+01	0.00E+00	1.54E-07	1.74E-05	1.64E-07	7.71E-07	1.00E-03	4.50E-02	9.97E-07	1.00E-03	1.08E+00	0.00E+00	5.90E+00	0.00E+00	2.70E-05
BATCH-355	5/8/23	35	3.6	0.24	1.36E-09	1.60E+01	1.75E-07	3.58E-05	1.05E-06	3.21E-17	6.00E-03	4.46E-01	8.00E-06	9.70E-02	5.28E+00	0.00E+00	2.66E-10	3.18E+00	1.62E-04
BATCH-356	5/8/23	131	13.6	0.24	5.43E+02	0.00E+00	6.39E-07	8.81E-05	7.97E-07	4.88E-12	1.00E-02	6.72E-01	5.89E-06	3.10E-02	5.98E+00	0.00E+00	3.34E+01	0.00E+00	1.89E-04
BATCH-357	5/11/23	57	6.0	0.24	5.00E-03	2.62E+01	2.86E-07	5.87E-05	1.72E-06	1.37E-10	9.00E-03	7.31E-01	1.31E-05	1.59E-01	8.65E+00	0.00E+00	8.22E-04	5.21E+00	2.43E-04
BATCH-358	5/18/23	132	13.7	0.24	5.70E+02	0.00E+00	3.05E-07	5.24E-05	6.67E-07	3.07E-11	1.20E-02	7.82E-01	5.22E-06	4.50E-02	5.37E+00	0.00E+00	1.85E+01	0.00E+00	1.08E-04
BATCH-359	5/22/23	29	3.0	0.24	9.28E-10	1.43E+01	7.10E-08	1.46E-05	4.24E-07	2.19E-17	3.00E-03	2.53E-01	3.27E-06	4.60E-02	5.50E+00	0.00E+00	1.80E-10	2.26E+00	5.39E-05
BATCH-360	5/25/23	50	5.2	0.24	5.00E-03	2.69E+01	1.44E-09	5.21E-07	5.79E-09	1.16E-10	4.00E-03	2.50E-01	1.33E-07	2.40E-02	1.15E+01	0.00E+00	8.88E-04	3.33E+00	1.52E-05
BATCH-361	5/30/23	163	16.9	0.24	7.34E+02	0.00E+00	2.79E-07	5.01E-05	8.60E-07	1.26E-11	1.50E-02	1.04E+00	6.66E-06	6.80E-02	5.74E+00	0.00E+00	2.45E+01	0.00E+00	1.35E-04
BATCH-362	6/1/23	35	3.6	0.24	2.89E-06	1.88E+01	1.15E-09	3.95E-07	4.97E-09	7.43E-14	3.00E-03	1.75E-01	1.00E-07	1.70E-02	8.05E+00	0.00E+00	4.47E-07	2.33E+00	1.08E-05
BATCH-363	6/5/23	46	4.8	0.24	1.70E+02	0.00E+00	2.00E-07	2.75E-05	2.49E-07	1.53E-12	3.00E-03	2.10E-01	1.84E-06	1.00E-02	1.87E+00	0.00E+00	1.04E+01	0.00E+00	5.39E-05
BATCH-364	6/10/23	169	17.6	0.24	7.22E+02	0.00E+00	2.83E-07	5.08E-05	8.78E-07	1.24E-11	1.50E-02	1.08E+00	6.80E-06	7.00E-02	6.23E+00	0.00E+00	2.37E+01	0.00E+00	1.35E-04
BATCH-365	6/17/23	37	3.8	0.24	2.66E-06	1.98E+01	1.04E-09	3.82E-07	4.25E-09	5.99E-14	3.00E-03	1.84E-01	9.79E-08	1.80E-02	8.48E+00	0.00E+00	4.59E-07	2.46E+00	1.12E-05
BATCH-366	6/20/23	34	3.5	0.24	1.28E+02	0.00E+00	6.84E-08	1.18E-05	1.50E-07	6.88E-12	3.00E-03	1.75E-01	1.17E-06	1.00E-02	1.20E+00	0.00E+00	4.16E+00	0.00E+00	2.19E-05
BATCH-367	6/24/23	130	13.5	0.24	5.94E+02	0.00E+00	8.09E-08	1.66E-05	4.84E-07	3.85E-11	1.20E-02	9.89E-01	3.71E-06	4.90E-02	4.32E+00	0.00E+00	1.49E+01	0.00E+00	8.09E-05
BATCH-368	6/27/23	16	1.7	0.24	3.97E+01	0.00E+00	4.67E-08	6.44E-06	5.83E-08	3.57E-13	7.21E-04	4.90E-02	4.31E-07	2.00E-03	4.37E-01	0.00E+00	2.44E+00	0.00E+00	1.30E-05
BATCH-369	6/29/23	46	4.8	0.24	1.82E+02	0.00E+00	6.91E-08	1.24E-05	2.13E-07	3.12E-12	4.00E-03	2.57E-01	1.65E-06	1.70E-02	1.42E+00	0.00E+00	6.07E+00	0.00E+00	2.70E-05
BATCH-370	7/4/23	109	11.3	0.24	5.00E+02	0.00E+00	5.52E-10	2.01E-07	2.23E-09	2.58E-11	7.00E-03	8.75E-01	5.12E-08	9.00E-03	4.44E+00	0.00E+00	9.38E-01	0.00E+00	5.86E-06
BATCH-371	7/8/23	12	1.3	0.24	3.04E+01	0.00E+00	1.62E-08	2.79E-06	3.55E-08	1.63E-12	6.56E-04	4.20E-02	2.78E-07	2.00E-03	2.86E-01	0.00E+00	9.88E-01	0.00E+00	5.20E-06
BATCH-372	7/9/23	45	4.7	0.24	1.70E+02	0.00E+00	6.65E-08	1.20E-05	2.07E-07	2.92E-12	3.00E-03	2.53E-01	1.60E-06	1.70E-02	1.47E+00	0.00E+00	5.57E+00	0.00E+00	2.70E-05
BATCH-373	7/14/23	50	5.2	0.24	5.00E-03	2.68E+01	1.42E-09	5.19E-07	5.77E-09	4.28E-17	4.00E-03	2.50E-01	1.33E-07	2.40E-02	1.15E+01	0.00E+00	2.93E-04	3.33E+00	1.52E-05
BATCH-374	7/16/23	16	1.7	0.24	4.28E+01	0.00E+00	1.62E-08	2.92E-06	5.02E-08	7.33E-13	8.96E-04	6.00E-02	3.88E-07	4.00E-03	3.34E-01	0.00E+00	1.43E+00	0.00E+00	7.26E-06
BATCH-375	7/18/23	39	4.0	0.24	1.56E+02	0.00E+00	2.13E-08	4.37E-06	1.27E-07	1.01E-11	3.00E-03	2.60E-01	9.75E-07	1.30E-02	1.14E+00	0.00E+00	3.91E+00	0.00E+00	1.88E-05
BATCH-376	7/19/23	50	5.2	0.24	4.00E-03	2.68E+01	1.42E-09	5.18E-07	5.76E-09	2.39E-16	4.00E-03	2.50E-01	1.33E-07	2.40E-02	1.15E+01	0.00E+00	1.45E-04	3.33E+00	1.52E-05
BATCH-377	7/22/23	16	1.7	0.24	3.99E+01	0.00E+00	1.56E-08	2.81E-06	4.85E-08	6.85E-13	8.19E-04	5.90E-02	3.75E-07	4.00E-03	3.44E-01	0.00E+00	1.31E+00	0.00E+00	7.04E-06
BATCH-378	7/24/23	40	4.1	0.24	1.60E+02	0.00E+00	1.76E-10	6.41E-08	7.12E-10	8.23E-12	2.00E-03	2.79E-01	1.64E-08	3.00E-03	1.42E+00	0.00E+00	2.99E+00	0.00E+00	1.87E-06
BATCH-379	7/25/23	108	11.2	0.24	2.88E-06	7.33E+01	4.07E-08	9.39E-06	2.42E-07	2.59E-20	1.10E-02	5.18E-01	1.74E-06	4.00E-03	1.31E+01	0.00E+00	1.77E-07	7.62E+00	1.08E-04
BATCH-380	7/28/23	52	5.4	0.24	4.00E-03	3.02E+01	6.73E-09	1.69E-06	3.80E-08	7.11E-17	4.00E-03	2.59E-01	3.41E-07	1.90E-02	1.04E+01	0.00E+00	1.38E-04	3.54E+00	2.59E-05
BATCH-381	8/3/23	14	1.5	0.24	3.70E+01	0.00E+00	5.04E-09	1.04E-06	3.01E-08	2.40E-12	7.71E-04	6.20E-02	2.31E-07	3.00E-03	2.69E-01	0.00E+00	9.25E-01	0.00E+00	4.46E-06
BATCH-382	8/5/23	108	11.2	0.24	2.69E-06	7.33E+01	4.07E-08	9.38E-06	2.42E-07	1.45E-19	1.10E-02	5.18E-01	1.74E-06	4.00E-03	1.31E+01	0.00E+00	8.75E-08	7.61E+00	1.08E-04
BATCH-383	8/5/23	146	15.2	0.24	6.00E-03	9.92E+01	5.52E-08	1.27E-05	3.28E-07	9.47E-17	1.50E-02	7.01E-01	2.36E-06	6.00E-03	1.77E+01	0.00E+00	1.81E-04	1.03E+01	1.35E-04
BATCH-384	8/16/23	15	1.5	0.24	3.78E+01	0.00E+00	4.17E-11	1.52E-08	1.69E-10	1.95E-12	5.37E-04	6.60E-02	3.88E-09	7.11E-04	3.35E-01	0.00E+00	7.09E-01	0.00E+00	4.43E-07
BATCH-385	8/18/23	94	9.8	0.24	2.88E-06	6.37E+01	3.54E-08	8.16E-06	2.11E-07	4.93E-20	9.00E-03	4.50E-01	1.51E-06	4.00E-03	1.14E+01	0.00E+00	9.59E-08	6.62E+00	8.09E-05
BATCH-386	8/21/23	94	9.8	0.24	1.98E-09	6.42E+01	3.57E-08	8.22E-06	2.12E-07	1.78E-23	9.00E-03	4.54E-01	1.53E-06	4.00E-03	1.15E+01	0.00E+00	1.22E-10	6.67E+00	8.09E-05
BATCH-387	8/28/23	146	15.2	0.24	5.00E-03	9.90E+01	5.50E-08	1.27E-05	3.27E-07	3.50E-16	1.50E-02	6.99E-01	2.35E-06	6.00E-03	1.77E+01	0.00E+00	1.35E-04	1.03E+01	1.35E-04
BATCH-388	8/31/23	94	9.8	0.24	1.85E-09	6.40E+01	3.56E-08	8.20E-06	2.12E-07	9.96E-23	9.00E-03	4.52E-01	1.52E-06	4.00E-03	1.14E+01	0.00E+00	6.03E-11	6.65E+00	8.09E-05
BATCH-389	9/10/23	148	15.5	0.24	4.00E-03	2.00E+02	3.57E-08	6.42E-01	5.30E-08	1.99E-16	9.00E-03	5.73E-01	4.74E-07	3.00E-03	6.00E+01	0.00E+00	7.25E-05	6.67E+00	2.97E-04
BATCH-390	9/12/23	131	13.7	0.24	2.42E-06	1.83E+02	3.02E-08	6.10E-01	2.80E-08	4.17E-20	7.00E-03	4.97E-01	2.90E-07	2.00E-03	5.58E+01	0.00E+00	7.94E-08	5.64E+00	2.70E-04
BATCH-391	9/25/23	84	8.8	0.24	1.97E-09	1.18E+02	1.94E-08	3.92E-01	1.80E-08	3.37E-23	5.00E-03	3.19E-01	1.87E-07	1.00E-03	3.59E+01	0.00E+00	6.56E-11	3.62E+00	1.62E-04

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2 kg-mol	F- kg-mol	Fe+3 kg-mol	H+ kg-mol	H2O kg-mol	Hg+2 kg-mol	K+ kg-mol	La+3 kg-mol	Li+ kg-mol	Mg+2 kg-mol	Mn+4 kg-mol	Mo+6 kg-mol	Na+ kg-mol	NH3 kg-mol	Ni+2 kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-343	3/30/23	96	10.0	0.24	1.49E-07	2.42E+01	2.30E-02	0.00E+00	0.00E+00	4.00E-04	6.48E+00	2.26E-07	1.16E-05	4.74E-05	1.95E-01	3.76E-08	1.63E+03	0.00E+00	7.10E-02
BATCH-344	4/4/23	78	8.1	0.24	1.21E-07	1.97E+01	1.90E-02	0.00E+00	0.00E+00	2.00E-04	5.28E+00	1.78E-07	9.46E-06	3.85E-05	1.59E-01	1.38E-08	1.33E+03	0.00E+00	5.80E-02
BATCH-345	4/9/23	55	5.7	0.24	1.40E-07	6.76E+00	1.38E-01	0.00E+00	0.00E+00	6.04E-05	1.79E+00	4.08E-05	2.20E-05	3.42E-04	3.20E-02	1.21E-04	9.36E+02	0.00E+00	1.10E-02
BATCH-346	4/13/23	95	9.9	0.24	1.48E-07	2.42E+01	2.30E-02	0.00E+00	0.00E+00	4.00E-04	6.47E+00	2.25E-07	1.16E-05	4.73E-05	1.95E-01	3.70E-08	1.63E+03	0.00E+00	7.00E-02
BATCH-347	4/15/23	74	7.8	0.24	5.41E-07	2.99E+01	1.24E-01	0.00E+00	0.00E+00	6.00E-04	5.69E+00	7.20E-06	1.33E-05	2.59E-05	1.10E-01	4.22E-06	1.27E+03	0.00E+00	7.70E-02
BATCH-348	4/23/23	53	5.5	0.24	1.36E-08	6.40E+00	1.54E-01	0.00E+00	0.00E+00	6.93E-05	1.37E+00	3.97E-06	1.46E-06	1.01E-05	3.60E-02	4.33E-06	9.05E+02	0.00E+00	7.00E-03
BATCH-349	4/23/23	50	5.2	0.24	8.15E-07	3.19E+01	1.96E-01	0.00E+00	0.00E+00	8.00E-04	4.51E+00	1.23E-05	1.35E-05	5.73E-06	3.00E-02	7.28E-06	8.57E+02	0.00E+00	7.50E-02
BATCH-350	4/28/23	41	4.3	0.24	6.63E-07	2.60E+01	1.59E-01	0.00E+00	0.00E+00	6.00E-04	3.67E+00	1.00E-05	1.10E-05	4.66E-06	2.40E-02	5.93E-06	6.98E+02	0.00E+00	6.10E-02
BATCH-351	4/28/23	20	2.1	0.24	3.88E-08	1.88E+00	3.80E-02	0.00E+00	0.00E+00	1.68E-05	4.97E-01	1.13E-05	6.10E-06	9.51E-05	9.00E-03	3.36E-05	3.38E+02	0.00E+00	3.00E-03
BATCH-352	5/1/23	44	4.6	0.24	7.18E-07	2.81E+01	1.72E-01	0.00E+00	0.00E+00	6.00E-04	3.98E+00	1.08E-05	1.19E-05	5.04E-06	2.60E-02	6.42E-06	7.55E+02	0.00E+00	6.60E-02
BATCH-353	5/3/23	50	5.2	0.24	8.14E-07	3.18E+01	1.95E-01	0.00E+00	0.00E+00	8.00E-04	4.51E+00	1.23E-05	1.35E-05	5.72E-06	3.00E-02	7.28E-06	8.57E+02	0.00E+00	7.50E-02
BATCH-354	5/5/23	19	2.0	0.24	3.68E-09	1.73E+00	4.20E-02	0.00E+00	0.00E+00	1.87E-05	3.70E-01	1.07E-06	3.94E-07	2.73E-06	1.00E-02	1.17E-06	3.24E+02	0.00E+00	2.00E-03
BATCH-355	5/8/23	35	3.6	0.24	5.68E-07	2.22E+01	1.36E-01	0.00E+00	0.00E+00	6.00E-04	3.14E+00	8.57E-06	9.39E-06	3.98E-06	2.10E-02	5.08E-06	5.98E+02	0.00E+00	5.20E-02
BATCH-356	5/8/23	131	13.6	0.24	2.28E-07	1.26E+01	4.16E-01	0.00E+00	0.00E+00	2.00E-04	2.49E+00	5.48E-06	8.07E-06	1.72E-05	5.70E-02	3.15E-06	2.23E+03	0.00E+00	2.90E-02
BATCH-357	5/11/23	57	6.0	0.24	9.31E-07	3.64E+01	2.23E-01	0.00E+00	0.00E+00	8.00E-04	5.15E+00	1.41E-05	1.54E-05	6.53E-06	3.40E-02	8.33E-06	9.79E+02	0.00E+00	8.60E-02
BATCH-358	5/18/23	132	13.7	0.24	2.83E-07	1.36E+01	3.46E-01	0.00E+00	0.00E+00	2.00E-04	2.35E+00	3.99E-06	5.95E-06	8.41E-06	3.70E-02	2.35E-06	2.25E+03	0.00E+00	3.40E-02
BATCH-359	5/22/23	29	3.0	0.24	2.31E-07	1.21E+01	7.70E-02	0.00E+00	0.00E+00	8.00E-04	2.14E+00	7.76E-06	3.83E-06	1.69E-06	1.90E-02	2.06E-06	4.90E+02	0.00E+00	3.80E-02
BATCH-360	5/25/23	50	5.2	0.24	3.96E-09	1.06E+01	7.40E-02	0.00E+00	0.00E+00	1.80E-03	2.97E+00	1.47E-05	1.17E-07	2.91E-07	3.50E-02	2.38E-08	8.49E+02	0.00E+00	5.60E-02
BATCH-361	5/30/23	163	16.9	0.24	4.12E-07	1.79E+01	4.66E-01	0.00E+00	0.00E+00	4.00E-04	2.83E+00	6.02E-06	7.69E-06	7.37E-06	3.30E-02	3.56E-06	2.78E+03	0.00E+00	4.30E-02
BATCH-362	6/1/23	35	3.6	0.24	3.28E-09	7.42E+00	5.20E-02	0.00E+00	0.00E+00	1.20E-03	2.08E+00	1.03E-05	9.04E-08	2.07E-07	2.40E-02	2.11E-08	5.94E+02	0.00E+00	3.90E-02
BATCH-363	6/5/23	46	4.8	0.24	7.13E-08	3.95E+00	1.30E-01	0.00E+00	0.00E+00	7.84E-05	7.77E-01	1.71E-06	2.52E-06	5.36E-06	1.80E-02	9.82E-07	7.89E+02	0.00E+00	9.00E-03
BATCH-364	6/10/23	169	17.6	0.24	4.21E-07	1.86E+01	5.84E-01	0.00E+00	0.00E+00	4.00E-04	2.98E+00	6.66E-06	7.85E-06	7.48E-06	3.50E-02	3.64E-06	2.88E+03	0.00E+00	4.60E-02
BATCH-365	6/17/23	37	3.8	0.24	2.92E-09	7.80E+00	5.50E-02	0.00E+00	0.00E+00	1.20E-03	2.19E+00	1.08E-05	8.65E-08	2.14E-07	2.60E-02	1.74E-08	6.26E+02	0.00E+00	4.10E-02
BATCH-366	6/20/23	34	3.5	0.24	6.35E-08	3.06E+00	7.80E-02	0.00E+00	0.00E+00	6.30E-05	5.28E-01	8.96E-07	1.34E-06	1.89E-06	8.00E-03	5.28E-07	5.73E+02	0.00E+00	8.00E-03
BATCH-367	6/24/23	130	13.5	0.24	2.63E-07	1.20E+01	6.67E-01	0.00E+00	0.00E+00	6.00E-04	1.94E+00	6.37E-06	4.36E-06	1.89E-06	1.50E-02	2.35E-06	2.22E+03	0.00E+00	3.30E-02
BATCH-368	6/27/23	16	1.7	0.24	1.67E-08	9.24E-01	3.00E-02	0.00E+00	0.00E+00	1.84E-05	1.82E-01	4.00E-07	5.90E-07	1.26E-06	4.00E-03	2.30E-07	2.75E+02	0.00E+00	2.00E-03
BATCH-369	6/29/23	46	4.8	0.24	1.02E-07	4.44E+00	1.16E-01	0.00E+00	0.00E+00	9.70E-05	7.01E-01	1.49E-06	1.91E-06	1.83E-06	8.00E-03	8.82E-07	7.80E+02	0.00E+00	1.10E-02
BATCH-370	7/4/23	109	11.3	0.24	1.53E-09	4.08E+00	1.00E+00	0.00E+00	0.00E+00	6.00E-04	1.15E+00	5.66E-06	4.53E-08	1.12E-07	1.30E-02	9.15E-09	1.86E+03	0.00E+00	2.20E-02
BATCH-371	7/8/23	12	1.3	0.24	1.51E-08	7.26E-01	1.80E-02	0.00E+00	0.00E+00	1.50E-05	1.25E-01	2.13E-07	3.17E-07	4.48E-07	2.00E-03	1.25E-07	2.06E+02	0.00E+00	2.00E-03
BATCH-372	7/9/23	45	4.7	0.24	9.91E-08	4.38E+00	1.38E-01	0.00E+00	0.00E+00	1.08E-04	7.02E-01	1.57E-06	1.85E-06	1.76E-06	8.00E-03	8.56E-07	7.69E+02	0.00E+00	1.10E-02
BATCH-373	7/14/23	50	5.2	0.24	3.96E-09	1.06E+01	7.40E-02	0.00E+00	0.00E+00	1.80E-03	2.97E+00	1.47E-05	1.17E-07	2.91E-07	3.50E-02	2.36E-08	8.48E+02	0.00E+00	5.60E-02
BATCH-374	7/16/23	16	1.7	0.24	2.40E-08	1.04E+00	2.70E-02	0.00E+00	0.00E+00	2.28E-05	1.65E-01	3.51E-07	4.48E-07	4.30E-07	2.00E-03	2.07E-07	2.74E+02	0.00E+00	3.00E-03
BATCH-375	7/18/23	39	4.0	0.24	6.91E-08	3.15E+00	1.75E-01	0.00E+00	0.00E+00	1.38E-04	5.09E-01	1.67E-06	1.14E-06	4.96E-07	4.00E-03	6.17E-07	6.63E+02	0.00E+00	9.00E-03
BATCH-376	7/19/23	50	5.2	0.24	3.95E-09	1.06E+01	7.40E-02	0.00E+00	0.00E+00	1.80E-03	2.97E+00	1.47E-05	1.17E-07	2.90E-07	3.50E-02	2.36E-08	8.48E+02	0.00E+00	5.60E-02
BATCH-377	7/22/23	16	1.7	0.24	2.32E-08	1.03E+00	3.20E-02	0.00E+00	0.00E+00	2.54E-05	1.65E-01	3.68E-07	4.34E-07	4.13E-07	2.00E-03	2.01E-07	2.71E+02	0.00E+00	3.00E-03
BATCH-378	7/24/23	40	4.1	0.24	4.88E-10	1.30E+00	3.21E-01	0.00E+00	0.00E+00	2.00E-04	3.66E-01	1.81E-06	1.45E-08	3.58E-08	4.00E-03	2.92E-09	6.78E+02	0.00E+00	7.00E-03
BATCH-379	7/25/23	108	11.2	0.24	1.30E-07	5.83E+01	2.27E-01	0.00E+00	0.00E+00	8.00E-04	6.97E+00	6.44E-07	2.38E-06	1.05E-06	4.70E-02	1.10E-06	1.84E+03	0.00E+00	1.26E-01
BATCH-380	7/28/23	52	5.4	0.24	2.10E-08	1.60E+01	8.70E-02	0.00E+00	0.00E+00	1.40E-03	3.19E+00	1.10E-05	4.19E-07	3.63E-07	3.20E-02	1.71E-07	8.90E+02	0.00E+00	5.90E-02
BATCH-381	8/3/23	14	1.5	0.24	1.64E-08	7.47E-01	4.20E-02	0.00E+00	0.00E+00	3.27E-05	1.21E-01	3.96E-07	2.71E-07	1.18E-07	9.48E-04	1.46E-07	2.40E+02	0.00E+00	2.00E-03
BATCH-382	8/5/23	108	11.2	0.24	1.30E-07	5.83E+01	2.27E-01	0.00E+00	0.00E+00	8.00E-04	6.96E+00	6.44E-07	2.38E-06	1.05E-06	4.70E-02	1.10E-06	1.84E+03	0.00E+00	1.26E-01
BATCH-383	8/5/23	146	15.2	0.24	1.75E-07	7.90E+01	3.07E-01	0.00E+00	0.00E+00	1.00E-03	9.43E+00	8.60E-07	3.22E-06	1.42E-06	6.40E-02	1.50E-06	2.49E+03	0.00E+00	1.71E-01
BATCH-384	8/16/23	15	1.5	0.24	1.16E-10	3.09E-01	7.60E-02	0.00E+00	0.00E+00	5.10E-05	8.70E-02	4.28E-07	3.42E-09	8.49E-09	1.00E-03	6.92E-10	2.48E+02	0.00E+00	2.00E-03
BATCH-385	8/18/23	94	9.8	0.24	1.13E-07	5.07E+01	1.97E-01	0.00E+00	0.00E+00	6.00E-04	6.06E+00	5.60E-07	2.07E-06	9.12E-07	4.10E-02	9.60E-07	1.60E+03	0.00E+00	1.10E-01
BATCH-386	8/21/23	94	9.8	0.24	1.14E-07	5.11E+01	1.98E-01	0.00E+00	0.00E+00	6.00E-04	6.10E+00	5.57E-07	2.08E-06	9.19E-07	4.10E-02	9.67E-07	1.61E+03	0.00E+00	1.10E-01
BATCH-387	8/28/23	146	15.2	0.24	1.75E-07	7.88E+01	3.06E-01	0.00E+00	0.00E+00	1.00E-03	9.40E+00	8.58E-07	3.21E-06	1.42E-06	6.30E-02	1.49E-06	2.49E+03	0.00E+00	1.70E-01
BATCH-388	8/31/23	94	9.8	0.24	1.13E-07	5.09E+01	1.98E-01	0.00E+00	0.00E+00	6.00E-04	6.08E+00	5.55E-07	2.08E-06	9.16E-07	4.10E-02	9.64E-07	1.61E+03	0.00E+00	1.10E-01
BATCH-389	9/10/23	148	15.5	0.24	1.83E-08	4.22E+01	3.13E-01	0.00E+00	0.00E+00	1.20E-03	1.93E+01	3.32E-07	5.37E-07	1.27E-06	2.08E-01	1.41E-07	2.54E+03	0.00E+00	2.32E-01
BATCH-390	9/12/23	131	13.7	0.24	5.44E-09	3.48E+01	2.77E-01	0.00E+00	0.00E+00	1.00E-03	1.78E+01	2.57E-07	2.91E-07	1.11E-06	1.93E-01	3.22E-08	2.24E+03	0.00E+00	2.09E-01
BATCH-391	9/25/23	84	8.8	0.24	3.52E-09	2.23E+01	1.78E-01	0.00E+00	0.00E+00	6.00E-04	1.14E+01	1.65E-07	1.87E-07	7.12E-07	1.24E-01	2.09E-08	1.44E+03	0.00E+00	1.34E-01

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-343	3/30/23	96	10.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.01E-01	1.79E-07	4.97E+00	3.34E+01	2.20E-02	2.51E-09	0.00E+00	5.00E-03	2.00E-03	7.00E-03
BATCH-344	4/4/23	78	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.45E+01	1.46E-07	4.05E+00	2.72E+01	1.80E-02	4.08E-12	0.00E+00	4.00E-03	2.00E-03	5.00E-03
BATCH-345	4/9/23	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.78E-04	1.34E+01	1.42E-07	2.81E+00	6.65E+00	3.00E-03	1.45E-05	0.00E+00	4.00E-03	8.66E-04	4.00E-03
BATCH-346	4/13/23	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.01E+01	1.79E-07	4.96E+00	3.34E+01	2.20E-02	2.45E-09	0.00E+00	5.00E-03	2.00E-03	7.00E-03
BATCH-347	4/15/23	74	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	4.51E+01	9.55E-08	6.37E+00	3.16E+01	1.40E-02	4.44E-07	0.00E+00	3.00E-03	2.00E-03	7.00E-03
BATCH-348	4/23/23	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.51E-04	1.41E+01	2.31E-08	3.28E+00	6.36E+00	3.00E-03	6.78E-09	0.00E+00	3.00E-03	9.58E-05	3.00E-03
BATCH-349	4/23/23	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	5.34E+01	1.75E-08	6.94E+00	2.73E+01	6.00E-03	7.66E-07	0.00E+00	8.84E-04	2.00E-03	7.00E-03
BATCH-350	4/28/23	41	4.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.35E+01	1.42E-08	5.65E+00	2.22E+01	5.00E-03	6.24E-07	0.00E+00	7.20E-04	2.00E-03	5.00E-03
BATCH-351	4/28/23	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-04	3.71E+00	3.95E-08	7.79E-01	1.85E+00	7.39E-04	4.04E-06	0.00E+00	1.00E-03	2.41E-04	1.00E-03
BATCH-352	5/1/23	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.71E+01	1.54E-08	6.12E+00	2.40E+01	5.00E-03	6.75E-07	0.00E+00	7.78E-04	2.00E-03	6.00E-03
BATCH-353	5/3/23	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	5.33E+01	1.74E-08	6.94E+00	2.72E+01	6.00E-03	7.66E-07	0.00E+00	8.83E-04	2.00E-03	7.00E-03
BATCH-354	5/5/23	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E-04	3.81E+00	6.24E-09	8.87E-01	1.72E+00	6.96E-04	1.83E-09	0.00E+00	9.42E-04	2.59E-05	8.44E-04
BATCH-355	5/8/23	35	3.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	3.72E+01	1.21E-08	4.84E+00	1.90E+01	4.00E-03	5.34E-07	0.00E+00	6.15E-04	1.00E-03	5.00E-03
BATCH-356	5/8/23	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.29E+01	4.99E-08	3.48E+01	1.44E+01	6.00E-03	1.89E-07	0.00E+00	3.00E-03	7.64E-04	4.00E-03
BATCH-357	5/11/23	57	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	6.10E+01	1.99E-08	7.93E+00	3.11E+01	7.00E-03	8.76E-07	0.00E+00	1.00E-03	2.00E-03	8.00E-03
BATCH-358	5/18/23	132	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.84E+01	3.05E-08	5.17E+01	1.43E+01	5.00E-03	2.47E-07	0.00E+00	1.00E-03	8.89E-04	3.00E-03
BATCH-359	5/22/23	29	3.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.93E+01	4.91E-09	3.32E+00	1.17E+01	5.00E-03	2.17E-07	0.00E+00	1.32E-01	5.49E-04	8.00E-03
BATCH-360	5/25/23	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.45E+01	5.72E-11	4.66E+00	1.38E+01	1.30E-02	2.48E-09	0.00E+00	4.51E-01	9.62E-05	2.20E-02
BATCH-361	5/30/23	163	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	6.29E+01	2.58E-08	6.40E+01	1.76E+01	5.00E-03	3.74E-07	0.00E+00	1.00E-03	1.00E-03	4.00E-03
BATCH-362	6/1/23	35	3.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.02E+01	5.01E-11	3.26E+00	9.64E+00	9.00E-03	2.21E-09	0.00E+00	3.15E-01	6.84E-05	1.60E-02
BATCH-363	6/5/23	46	4.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.34E+01	1.56E-08	1.09E+01	4.51E+00	2.00E-03	5.91E-08	0.00E+00	1.00E-03	2.39E-04	1.00E-03
BATCH-364	6/10/23	169	17.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	6.13E+01	2.62E-08	5.83E+01	1.83E+01	6.00E-03	3.82E-07	0.00E+00	1.70E-02	1.00E-03	5.00E-03
BATCH-365	6/17/23	37	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.07E+01	4.14E-11	3.43E+00	1.01E+01	9.00E-03	1.83E-09	0.00E+00	3.32E-01	7.09E-05	1.60E-02
BATCH-366	6/20/23	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.09E+01	6.84E-09	1.16E+01	3.21E+00	1.00E-03	5.55E-08	0.00E+00	2.80E-04	2.00E-04	6.96E-04
BATCH-367	6/24/23	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.59E+01	5.61E-09	5.06E+01	1.17E+01	4.00E-03	2.47E-07	0.00E+00	7.40E-02	6.12E-04	6.00E-03
BATCH-368	6/27/23	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.09E-04	3.14E+00	3.65E-09	2.55E+00	1.06E+00	4.11E-04	1.38E-08	0.00E+00	2.47E-04	5.59E-05	2.84E-04
BATCH-369	6/29/23	46	4.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.56E+01	6.41E-09	1.59E+01	4.38E+00	1.00E-03	9.27E-08	0.00E+00	3.38E-04	2.75E-04	9.74E-04
BATCH-370	7/4/23	109	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.98E+01	2.19E-11	2.37E+01	5.53E+00	5.00E-03	9.57E-10	0.00E+00	1.74E-01	3.71E-05	9.00E-03
BATCH-371	7/8/23	12	1.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.94E-04	2.58E+00	1.62E-09	2.75E+00	7.61E-01	2.70E-04	1.32E-08	0.00E+00	6.64E-05	4.74E-05	1.65E-04
BATCH-372	7/9/23	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.44E+01	6.18E-09	1.37E+01	4.32E+00	1.00E-03	9.00E-08	0.00E+00	4.00E-03	2.67E-04	1.00E-03
BATCH-373	7/14/23	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.45E+01	5.66E-11	4.65E+00	1.37E+01	1.30E-02	2.48E-09	0.00E+00	4.50E-01	9.61E-05	2.20E-02
BATCH-374	7/16/23	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.56E-04	3.67E+00	1.51E-09	3.73E+00	1.03E+00	3.00E-04	2.18E-08	0.00E+00	7.94E-05	6.45E-05	2.29E-04
BATCH-375	7/18/23	39	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.21E+01	1.47E-09	1.33E+01	3.08E+00	1.00E-03	6.50E-08	0.00E+00	2.00E-02	1.61E-04	2.00E-03
BATCH-376	7/19/23	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.44E+01	5.64E-11	4.65E+00	1.37E+01	1.30E-02	2.48E-09	0.00E+00	4.50E-01	9.60E-05	2.20E-02
BATCH-377	7/22/23	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-04	3.38E+00	1.45E-09	3.22E+00	1.01E+00	3.13E-04	2.11E-08	0.00E+00	9.38E-04	6.25E-05	2.64E-04
BATCH-378	7/24/23	40	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.31E+00	6.99E-12	7.55E+00	1.77E+00	2.00E-03	3.06E-10	0.00E+00	5.60E-02	1.18E-05	3.00E-03
BATCH-379	7/25/23	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	7.19E+01	2.63E-09	7.56E+00	4.14E+01	6.00E-03	1.16E-07	0.00E+00	2.00E-03	4.40E-05	1.50E-02
BATCH-380	7/28/23	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	2.08E+01	4.09E-10	4.52E+00	1.60E+01	1.00E-02	1.80E-08	0.00E+00	3.36E-01	7.78E-05	1.90E-02
BATCH-381	8/3/23	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E-04	2.86E+00	3.49E-10	3.15E+00	7.31E-01	2.54E-04	1.54E-08	0.00E+00	5.00E-03	3.81E-05	3.61E-04
BATCH-382	8/5/23	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	7.18E+01	2.63E-09	7.55E+00	4.14E+01	6.00E-03	1.16E-07	0.00E+00	2.00E-03	4.39E-05	1.50E-02
BATCH-383	8/5/23	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	9.73E+01	3.57E-09	1.02E+01	5.60E+01	8.00E-03	1.57E-07	0.00E+00	2.00E-03	5.95E-05	2.00E-02
BATCH-384	8/16/23	15	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.41E-04	1.50E+00	1.66E-12	1.79E+00	4.19E-01	3.75E-04	7.24E-11	0.00E+00	1.30E-02	2.81E-06	6.46E-04
BATCH-385	8/18/23	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	6.25E+01	2.29E-09	6.57E+00	3.60E+01	5.00E-03	1.01E-07	0.00E+00	2.00E-03	3.82E-05	1.30E-02
BATCH-386	8/21/23	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	6.30E+01	2.31E-09	6.62E+00	3.63E+01	5.00E-03	1.02E-07	0.00E+00	1.00E-03	3.85E-05	1.30E-02
BATCH-387	8/28/23	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	9.71E+01	3.56E-09	1.02E+01	5.59E+01	8.00E-03	1.57E-07	0.00E+00	2.00E-03	5.93E-05	2.00E-02
BATCH-388	8/31/23	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	6.28E+01	2.30E-09	6.60E+00	3.61E+01	5.00E-03	1.01E-07	0.00E+00	1.00E-03	3.83E-05	1.30E-02
BATCH-389	9/10/23	148	15.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	6.87E+01	3.72E-09	5.40E+00	2.97E+01	9.00E-03	1.58E-08	0.00E+00	3.57E-01	9.00E-03	3.10E-02
BATCH-390	9/12/23	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.87E+01	3.30E-09	4.43E+00	2.44E+01	8.00E-03	4.28E-09	0.00E+00	3.39E-01	9.00E-03	2.80E-02
BATCH-391	9/25/23	84	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.77E+01	2.12E-09	2.85E+00	1.57E+01	5.00E-03	2.77E-09	0.00E+00	2.18E-01	6.00E-03	1.80E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-392	9/26/23	108	11.2	0.24	0.00E+00	0.00E+00	1.90E-02	1.50E-02	1.52E+00	1.34E-01	1.61E+03	1.70E-01	2.80E-02	1.00E+01	3.40E-13	1.87E-01	1.00E-03	4.00E-02	2.25E-03
BATCH-393	10/4/23	107	11.2	0.24	0.00E+00	0.00E+00	1.90E-02	1.50E-02	1.51E+00	1.34E-01	1.61E+03	1.70E-01	2.80E-02	9.97E+00	3.38E-13	1.87E-01	1.00E-03	3.90E-02	2.25E-03
BATCH-394	10/8/23	131	13.7	0.24	0.00E+00	0.00E+00	1.28E-01	8.90E-02	1.01E+01	8.42E-01	2.62E+03	8.79E-01	1.81E-01	1.31E+01	6.41E-13	9.12E-01	8.00E-03	2.62E-01	9.75E-03
BATCH-395	10/16/23	112	11.7	0.24	0.00E+00	0.00E+00	1.10E-01	7.60E-02	8.64E+00	7.23E-01	2.25E+03	7.54E-01	1.55E-01	1.12E+01	5.49E-13	7.82E-01	7.00E-03	2.24E-01	8.50E-03
BATCH-396	10/22/23	98	10.2	0.24	0.00E+00	0.00E+00	9.50E-02	6.70E-02	7.51E+00	6.28E-01	1.95E+03	6.55E-01	1.35E-01	9.73E+00	4.77E-13	6.80E-01	6.00E-03	1.95E-01	7.25E-03
BATCH-397	10/28/23	147	15.3	0.24	0.00E+00	0.00E+00	3.30E-02	3.10E-02	2.62E+00	2.67E-01	2.30E+03	2.53E-01	4.60E-02	1.46E+01	2.94E-13	2.84E-01	2.00E-03	6.50E-02	3.00E-03
BATCH-398	11/1/23	43	4.5	0.24	0.00E+00	0.00E+00	7.00E-03	5.00E-03	5.36E-01	4.77E-02	5.69E+02	6.00E-02	1.00E-02	3.53E+00	1.20E-13	6.60E-02	3.78E-04	1.40E-02	7.50E-04
BATCH-399	11/5/23	43	4.5	0.24	0.00E+00	0.00E+00	7.00E-03	5.00E-03	5.34E-01	4.77E-02	5.67E+02	6.00E-02	1.00E-02	3.52E+00	1.19E-13	6.60E-02	3.77E-04	1.40E-02	7.50E-04
BATCH-400	11/10/23	98	10.2	0.24	0.00E+00	0.00E+00	9.50E-02	6.60E-02	7.50E+00	6.27E-01	1.95E+03	6.55E-01	1.34E-01	9.72E+00	4.76E-13	6.79E-01	6.00E-03	1.95E-01	7.25E-03
BATCH-401	11/12/23	122	12.7	0.24	0.00E+00	0.00E+00	4.60E-02	3.10E-02	3.61E+00	2.94E-01	1.08E+03	3.22E-01	6.50E-02	1.21E+01	2.78E-13	3.33E-01	3.00E-03	9.40E-02	3.75E-03
BATCH-402	11/20/23	140	14.6	0.24	0.00E+00	0.00E+00	5.10E-02	3.20E-02	4.00E+00	3.09E-01	1.29E+03	3.71E-01	7.30E-02	1.40E+01	4.13E-13	3.80E-01	3.00E-03	1.06E-01	4.50E-03
BATCH-403	11/25/23	15	1.6	0.24	0.00E+00	0.00E+00	2.00E-03	1.00E-03	1.27E-01	1.17E-02	1.35E+02	1.40E-02	2.00E-03	8.39E-01	2.85E-14	1.60E-02	8.98E-05	3.00E-03	1.95E-04
BATCH-404	11/27/23	15	1.6	0.24	0.00E+00	0.00E+00	2.00E-03	1.00E-03	1.27E-01	1.17E-02	1.35E+02	1.40E-02	2.00E-03	8.36E-01	2.84E-14	1.60E-02	8.95E-05	3.00E-03	1.95E-04
BATCH-405	11/29/23	47	4.9	0.24	0.00E+00	0.00E+00	1.00E-02	9.00E-03	7.48E-01	7.65E-02	6.56E+02	7.20E-02	1.30E-02	4.72E+00	8.40E-14	8.10E-02	5.48E-04	1.90E-02	7.50E-04
BATCH-406	12/4/23	140	14.6	0.24	0.00E+00	0.00E+00	5.10E-02	3.20E-02	3.98E+00	3.08E-01	1.29E+03	3.70E-01	7.30E-02	1.39E+01	4.11E-13	3.79E-01	3.00E-03	1.05E-01	4.50E-03
BATCH-407	12/5/23	58	6.0	0.24	0.00E+00	0.00E+00	2.00E-02	1.30E-02	1.55E+00	1.27E-01	4.65E+02	1.38E-01	2.80E-02	5.74E+00	1.19E-13	1.43E-01	1.00E-03	4.10E-02	1.50E-03
BATCH-408	12/12/23	143	14.9	0.24	0.00E+00	0.00E+00	1.29E-01	7.90E-02	1.01E+01	7.44E-01	2.55E+03	8.63E-01	1.82E-01	1.42E+01	1.53E-12	8.86E-01	8.00E-03	2.57E-01	1.00E-02
BATCH-409	12/19/23	150	15.6	0.24	0.00E+00	0.00E+00	1.32E-01	7.70E-02	1.04E+01	7.30E-01	2.50E+03	8.79E-01	1.87E-01	1.49E+01	1.86E-12	8.99E-01	8.00E-03	2.62E-01	1.03E-02
BATCH-410	12/27/23	16	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	2.00E-03	1.79E-01	1.80E-02	1.57E+02	1.70E-02	3.00E-03	1.30E+00	2.01E-14	1.90E-02	1.31E-04	4.00E-03	2.06E-04
BATCH-411	12/29/23	62	6.4	0.24	0.00E+00	0.00E+00	2.10E-02	1.30E-02	1.62E+00	1.25E-01	5.23E+02	1.50E-01	3.00E-02	6.15E+00	1.68E-13	1.54E-01	1.00E-03	4.30E-02	1.75E-03
BATCH-412	1/3/24	19	2.0	0.24	0.00E+00	0.00E+00	5.00E-03	3.00E-03	3.77E-01	3.06E-02	1.11E+02	3.40E-02	7.00E-03	1.91E+00	1.47E-14	3.30E-02	2.27E-04	1.00E-02	5.00E-04
BATCH-413	1/4/24	62	6.4	0.24	0.00E+00	0.00E+00	2.10E-02	1.10E-02	1.61E+00	1.25E-01	5.10E+02	1.50E-01	2.80E-02	6.14E+00	8.41E-14	1.47E-01	9.58E-04	4.30E-02	1.75E-03
BATCH-414	1/6/24	105	10.9	0.24	0.00E+00	0.00E+00	9.20E-02	4.70E-02	7.20E+00	5.09E-01	1.70E+03	6.14E-01	1.24E-01	1.04E+01	6.53E-13	5.99E-01	4.00E-03	1.83E-01	7.25E-03
BATCH-415	1/11/24	150	15.6	0.24	0.00E+00	0.00E+00	1.32E-01	6.80E-02	1.03E+01	7.29E-01	2.44E+03	8.78E-01	1.77E-01	1.49E+01	9.35E-13	8.57E-01	6.00E-03	2.61E-01	1.03E-02
BATCH-416	1/17/24	109	11.4	0.24	0.00E+00	0.00E+00	9.60E-02	4.90E-02	7.49E+00	5.30E-01	1.77E+03	6.38E-01	1.29E-01	1.08E+01	6.80E-13	6.23E-01	5.00E-03	1.90E-01	7.50E-03
BATCH-417	1/27/24	22	2.3	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	4.58E-01	3.60E-02	1.45E+02	4.30E-02	8.00E-03	2.19E+00	2.40E-14	4.20E-02	2.73E-04	1.20E-02	5.00E-04
BATCH-418	1/28/24	150	15.6	0.24	0.00E+00	0.00E+00	1.32E-01	6.80E-02	1.03E+01	7.27E-01	2.43E+03	8.77E-01	1.77E-01	1.49E+01	9.33E-13	8.55E-01	6.00E-03	2.61E-01	1.03E-02
BATCH-419	1/29/24	22	2.3	0.24	0.00E+00	0.00E+00	6.00E-03	3.00E-03	4.56E-01	3.51E-02	1.45E+02	4.30E-02	8.00E-03	2.19E+00	2.39E-14	4.20E-02	2.72E-04	1.20E-02	5.00E-04
BATCH-420	2/1/24	154	16.0	0.24	0.00E+00	0.00E+00	5.60E-02	3.10E-02	4.36E+00	3.29E-01	1.10E+03	3.75E-01	7.50E-02	1.53E+01	3.08E-13	3.68E-01	3.00E-03	1.12E-01	4.25E-03
BATCH-421	2/13/24	95	9.9	0.24	0.00E+00	0.00E+00	8.50E-02	3.80E-02	6.65E+00	3.94E-01	1.90E+03	6.39E-01	1.17E-01	9.44E+00	2.22E-12	6.29E-01	4.00E-03	1.77E-01	8.00E-03
BATCH-422	2/17/24	148	15.5	0.24	0.00E+00	0.00E+00	5.00E-02	2.60E-02	3.94E+00	2.79E-01	9.33E+02	3.36E-01	6.80E-02	1.48E+01	3.58E-13	3.28E-01	2.00E-03	1.00E-01	4.00E-03
BATCH-423	2/23/24	145	15.1	0.24	0.00E+00	0.00E+00	1.35E-01	4.60E-02	1.05E+01	4.37E-01	2.89E+03	1.18E+00	1.90E-01	1.44E+01	7.43E-12	1.17E+00	6.00E-03	3.00E-01	1.58E-02
BATCH-424	3/4/24	145	15.1	0.24	0.00E+00	0.00E+00	1.35E-01	4.60E-02	1.05E+01	4.36E-01	2.89E+03	1.18E+00	1.90E-01	1.44E+01	7.42E-12	1.17E+00	6.00E-03	3.00E-01	1.58E-02
BATCH-425	3/10/24	105	11.0	0.24	0.00E+00	0.00E+00	9.80E-02	3.30E-02	7.62E+00	3.18E-01	2.10E+03	8.59E-01	1.38E-01	1.05E+01	5.40E-12	8.54E-01	4.00E-03	2.18E-01	1.15E-02
BATCH-426	3/19/24	57	5.9	0.24	0.00E+00	0.00E+00	1.90E-02	1.00E-02	1.45E+00	1.09E-01	3.66E+02	1.25E-01	2.50E-02	5.64E+00	1.02E-13	1.22E-01	8.75E-04	3.70E-02	1.50E-03
BATCH-427	3/21/24	156	16.2	0.24	0.00E+00	0.00E+00	5.60E-02	2.90E-02	4.37E+00	3.07E-01	1.05E+03	3.75E-01	7.50E-02	1.55E+01	4.47E-13	3.66E-01	3.00E-03	1.11E-01	4.50E-03
BATCH-428	3/25/24	58	6.1	0.24	0.00E+00	0.00E+00	1.80E-02	9.00E-03	1.40E+00	9.90E-02	3.31E+02	1.19E-01	2.40E-02	5.79E+00	1.27E-13	1.17E-01	8.47E-04	3.60E-02	1.50E-03
BATCH-429	3/31/24	129	13.5	0.24	0.00E+00	0.00E+00	1.20E-01	4.10E-02	9.35E+00	3.90E-01	2.58E+03	1.05E+00	1.70E-01	1.29E+01	6.63E-12	1.05E+00	5.00E-03	2.68E-01	1.40E-02
BATCH-430	4/6/24	129	13.4	0.24	0.00E+00	0.00E+00	1.20E-01	4.10E-02	9.34E+00	3.89E-01	2.58E+03	1.05E+00	1.70E-01	1.28E+01	6.62E-12	1.05E+00	5.00E-03	2.67E-01	1.40E-02
BATCH-431	4/14/24	94	9.8	0.24	0.00E+00	0.00E+00	8.70E-02	3.00E-02	6.78E+00	2.83E-01	1.87E+03	7.64E-01	1.23E-01	9.33E+00	4.81E-12	7.60E-01	4.00E-03	1.94E-01	1.03E-02
BATCH-432	4/20/24	19	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.42E-01	2.61E-02	8.62E+01	2.90E-02	6.00E-03	1.84E+00	2.42E-14	2.90E-02	2.06E-04	9.00E-03	2.50E-04
BATCH-433	4/22/24	19	2.0	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.36E-01	2.34E-02	7.96E+01	2.90E-02	6.00E-03	1.78E+00	3.05E-14	2.80E-02	2.03E-04	9.00E-03	2.50E-04
BATCH-434	4/24/24	52	5.4	0.24	0.00E+00	0.00E+00	1.70E-02	9.00E-03	1.32E+00	9.27E-02	3.17E+02	1.13E-01	2.30E-02	5.18E+00	1.35E-13	1.10E-01	7.96E-04	3.40E-02	1.25E-03
BATCH-435	4/24/24	107	11.2	0.24	0.00E+00	0.00E+00	8.40E-02	3.30E-02	6.54E+00	2.61E-01	2.15E+03	6.33E-01	1.06E-01	1.07E+01	2.21E-12	7.38E-01	4.00E-03	1.82E-01	8.75E-03
BATCH-436	4/30/24	107	11.2	0.24	0.00E+00	0.00E+00	7.90E-02	3.20E-02	6.15E+00	2.41E-01	2.14E+03	5.59E-01	9.60E-02	1.07E+01	1.21E-12	6.97E-01	3.00E-03	1.70E-01	7.75E-03
BATCH-437	5/5/24	134	14.0	0.24	0.00E+00	0.00E+00	9.80E-02	4.00E-02	7.69E+00	3.02E-01	2.68E+03	6.98E-01	1.20E-01	1.34E+01	1.51E-12	8.72E-01	4.00E-03	2.12E-01	9.75E-03
BATCH-438	5/11/24	119	12.4	0.24	0.00E+00	0.00E+00	4.00E-02	1.90E-02	3.16E+00	1.95E-01	9.67E+02	2.96E-01	5.50E-02	1.18E+01	8.91E-13	2.91E-01	2.00E-03	8.30E-02	3.75E-03
BATCH-439	5/20/24	134	14.0	0.24	0.00E+00	0.00E+00	9.80E-02	4.00E-02	7.69E+00	3.02E-01	2.68E+03	6.98E-01	1.19E-01	1.33E+01	1.51E-12	8.71E-01	4.00E-03	2.12E-01	9.50E-03
BATCH-440	5/23/24	18	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.17E-01	2.25E-02	7.62E+01	2.70E-02	5.00E-03	1.66E+00	3.24E-14	2.70E-02	1.91E-04	8.00E-03	2.50E-04

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-392	9/26/23	108	11.2	0.24	4.20E-07	3.22E+02	7.01E+01	7.00E-03	1.11E+00	1.78E-01	1.63E-04	2.60E-06	5.34E-05	2.37E-05	4.36E-05	8.72E-05	3.00E-03	1.40E-02	1.40E-02
BATCH-393	10/4/23	107	11.2	0.24	4.19E-07	3.22E+02	6.98E+01	7.00E-03	1.11E+00	1.77E-01	1.62E-04	2.59E-06	5.33E-05	2.36E-05	4.34E-05	8.69E-05	3.00E-03	1.40E-02	1.40E-02
BATCH-394	10/8/23	131	13.7	0.24	1.02E-06	3.93E+02	2.99E+02	3.10E-02	1.88E+00	1.50E-01	1.37E-04	1.10E-05	3.14E-04	1.14E-04	3.56E-04	3.99E-04	1.40E-02	7.20E-02	4.70E-02
BATCH-395	10/16/23	112	11.7	0.24	8.70E-07	3.37E+02	2.56E+02	2.70E-02	1.61E+00	1.28E-01	1.17E-04	9.46E-06	2.69E-04	9.80E-05	3.05E-04	3.42E-04	1.20E-02	6.10E-02	4.00E-02
BATCH-396	10/22/23	98	10.2	0.24	7.57E-07	2.93E+02	2.23E+02	2.30E-02	1.40E+00	1.12E-01	1.02E-04	8.22E-06	2.34E-04	8.52E-05	2.65E-04	2.98E-04	1.10E-02	5.30E-02	3.50E-02
BATCH-397	10/28/23	147	15.3	0.24	7.20E-07	4.41E+02	9.10E+01	1.00E-02	1.60E+00	2.65E-01	1.04E-04	3.27E-06	1.01E-04	4.02E-05	8.03E-05	1.54E-04	4.00E-03	2.20E-02	2.20E-02
BATCH-398	11/1/23	43	4.5	0.24	1.48E-07	1.29E+02	2.47E+01	2.00E-03	3.93E-01	6.30E-02	5.76E-05	9.20E-07	1.89E-05	8.37E-06	1.54E-05	3.08E-05	9.59E-04	5.00E-03	5.00E-03
BATCH-399	11/5/23	43	4.5	0.24	1.48E-07	1.29E+02	2.46E+01	2.00E-03	3.92E-01	6.30E-02	5.73E-05	9.16E-07	1.88E-05	8.34E-06	1.53E-05	3.07E-05	9.55E-04	5.00E-03	5.00E-03
BATCH-400	11/10/23	98	10.2	0.24	7.56E-07	2.93E+02	2.22E+02	2.30E-02	1.40E+00	1.11E-01	1.01E-04	8.22E-06	2.34E-04	8.51E-05	2.65E-04	2.97E-04	1.10E-02	5.30E-02	3.50E-02
BATCH-401	11/12/23	122	12.7	0.24	3.52E-07	3.65E+02	1.12E+02	1.10E-02	7.01E-01	5.50E-02	7.84E-05	4.16E-06	1.10E-04	4.08E-05	1.27E-04	1.41E-04	5.00E-03	2.60E-02	1.70E-02
BATCH-402	11/20/23	140	14.6	0.24	3.64E-07	4.21E+02	1.35E+02	1.30E-02	8.31E-01	6.30E-02	1.51E-04	5.06E-06	1.17E-04	4.48E-05	1.39E-04	1.51E-04	6.00E-03	2.90E-02	1.90E-02
BATCH-403	11/25/23	15	1.6	0.24	3.53E-08	4.63E+01	5.88E+00	5.75E-04	9.30E-02	1.50E-02	1.37E-05	2.19E-07	4.48E-06	1.99E-06	3.66E-06	7.32E-06	2.28E-04	1.00E-03	1.00E-03
BATCH-404	11/27/23	15	1.6	0.24	3.52E-08	4.62E+01	5.86E+00	5.73E-04	9.30E-02	1.50E-02	1.36E-05	2.18E-07	4.47E-06	1.98E-06	3.64E-06	7.29E-06	2.27E-04	1.00E-03	1.00E-03
BATCH-405	11/29/23	47	4.9	0.24	2.06E-07	1.42E+02	2.60E+01	3.00E-03	4.57E-01	7.60E-02	2.98E-05	9.33E-07	2.89E-05	1.15E-05	2.29E-05	4.41E-05	1.00E-03	6.00E-03	6.00E-03
BATCH-406	12/4/23	140	14.6	0.24	3.63E-07	4.20E+02	1.34E+02	1.30E-02	8.28E-01	6.30E-02	1.51E-04	5.04E-06	1.17E-04	4.47E-05	1.39E-04	1.51E-04	6.00E-03	2.90E-02	1.90E-02
BATCH-407	12/5/23	58	6.0	0.24	1.52E-07	1.73E+02	4.82E+01	5.00E-03	3.01E-01	2.40E-02	3.37E-05	1.79E-06	4.75E-05	1.76E-05	5.46E-05	6.07E-05	2.00E-03	1.10E-02	7.00E-03
BATCH-408	12/12/23	143	14.9	0.24	1.04E-06	4.28E+02	2.72E+02	2.60E-02	1.65E+00	1.23E-01	7.62E-04	1.03E-05	3.07E-04	9.92E-05	3.69E-04	3.11E-04	1.30E-02	6.40E-02	3.20E-02
BATCH-409	12/19/23	150	15.6	0.24	1.08E-06	4.50E+02	2.70E+02	2.60E-02	1.62E+00	1.18E-01	9.89E-04	1.03E-05	3.12E-04	9.65E-05	3.82E-04	2.90E-04	1.30E-02	6.40E-02	2.70E-02
BATCH-410	12/27/23	16	1.7	0.24	4.91E-08	4.94E+01	6.21E+00	7.15E-04	1.09E-01	1.80E-02	7.12E-06	2.23E-07	6.92E-06	2.74E-06	5.48E-06	1.05E-05	2.95E-04	1.00E-03	1.00E-03
BATCH-411	12/29/23	62	6.4	0.24	1.48E-07	1.85E+02	5.47E+01	5.00E-03	3.37E-01	2.60E-02	6.14E-05	2.05E-06	4.76E-05	1.82E-05	5.65E-05	6.15E-05	2.00E-03	1.20E-02	8.00E-03
BATCH-412	1/3/24	19	2.0	0.24	2.65E-08	5.74E+01	1.17E+01	1.00E-03	6.80E-02	5.00E-03	8.24E-06	4.24E-07	1.05E-05	4.30E-06	1.34E-05	1.48E-05	5.33E-04	3.00E-03	2.00E-03
BATCH-413	1/4/24	62	6.4	0.24	1.05E-07	1.85E+02	5.41E+01	5.00E-03	3.10E-01	2.20E-02	6.12E-05	1.98E-06	4.28E-05	1.81E-05	5.64E-05	6.13E-05	2.00E-03	1.20E-02	8.00E-03
BATCH-414	1/6/24	105	10.9	0.24	5.37E-07	3.14E+02	1.87E+02	1.70E-02	1.04E+00	7.10E-02	6.90E-04	6.93E-06	1.96E-04	6.74E-05	2.66E-04	2.02E-04	9.00E-03	4.40E-02	1.90E-02
BATCH-415	1/11/24	150	15.6	0.24	7.68E-07	4.49E+02	2.67E+02	2.40E-02	1.49E+00	1.02E-01	9.88E-04	9.92E-06	2.81E-04	9.64E-05	3.81E-04	2.89E-04	1.20E-02	6.30E-02	2.70E-02
BATCH-416	1/17/24	109	11.4	0.24	5.58E-07	3.26E+02	1.94E+02	1.80E-02	1.08E+00	7.40E-02	7.18E-04	7.21E-06	2.04E-04	7.01E-05	2.77E-04	2.10E-04	9.00E-03	4.60E-02	2.00E-02
BATCH-417	1/27/24	22	2.3	0.24	3.00E-08	6.60E+01	1.54E+01	1.00E-03	8.80E-02	6.00E-03	1.75E-05	5.66E-07	1.22E-05	5.17E-06	1.61E-05	1.75E-05	6.59E-04	3.00E-03	2.00E-03
BATCH-418	1/28/24	150	15.6	0.24	7.67E-07	4.48E+02	2.67E+02	2.40E-02	1.49E+00	1.02E-01	9.86E-04	9.90E-06	2.81E-04	9.62E-05	3.81E-04	2.89E-04	1.20E-02	6.30E-02	2.70E-02
BATCH-419	1/29/24	22	2.3	0.24	2.99E-08	6.59E+01	1.54E+01	1.00E-03	8.80E-02	6.00E-03	1.74E-05	5.63E-07	1.22E-05	5.15E-06	1.60E-05	1.74E-05	6.57E-04	3.00E-03	2.00E-03
BATCH-420	2/1/24	154	16.0	0.24	3.22E-07	4.61E+02	1.19E+02	1.10E-02	6.73E-01	4.80E-02	2.95E-04	4.35E-06	1.20E-04	4.39E-05	1.59E-04	1.40E-04	6.00E-03	2.80E-02	1.50E-02
BATCH-421	2/13/24	95	9.9	0.24	4.64E-07	2.84E+02	2.40E+02	2.00E-02	1.51E+00	1.24E-01	4.98E-04	9.02E-06	1.76E-04	7.16E-05	2.31E-04	2.11E-04	1.00E-02	5.10E-02	2.40E-02
BATCH-422	2/17/24	148	15.5	0.24	2.94E-07	4.45E+02	1.02E+02	9.00E-03	5.70E-01	3.90E-02	3.78E-04	3.80E-06	1.08E-04	3.69E-05	1.46E-04	1.11E-04	5.00E-03	2.40E-02	1.10E-02
BATCH-423	2/23/24	145	15.1	0.24	6.51E-07	4.34E+02	5.40E+02	4.10E-02	3.71E+00	3.37E-01	4.46E-04	2.06E-05	2.62E-04	1.35E-04	3.27E-04	3.90E-04	2.00E-02	1.04E-01	5.20E-02
BATCH-424	3/4/24	145	15.1	0.24	6.51E-07	4.34E+02	5.40E+02	4.10E-02	3.70E+00	3.37E-01	4.46E-04	2.05E-05	2.62E-04	1.35E-04	3.27E-04	3.89E-04	2.00E-02	1.04E-01	5.20E-02
BATCH-425	3/10/24	105	11.0	0.24	4.74E-07	3.16E+02	3.93E+02	3.00E-02	2.69E+00	2.45E-01	3.25E-04	1.50E-05	1.90E-04	9.84E-05	2.38E-04	2.83E-04	1.50E-02	7.60E-02	3.80E-02
BATCH-426	3/19/24	57	5.9	0.24	1.07E-07	1.70E+02	3.94E+01	4.00E-03	2.24E-01	1.60E-02	9.81E-05	1.45E-06	4.00E-05	1.46E-05	5.29E-05	4.66E-05	2.00E-03	9.00E-03	5.00E-03
BATCH-427	3/21/24	156	16.2	0.24	3.25E-07	4.67E+02	1.16E+02	1.00E-02	6.49E-01	4.50E-02	4.15E-04	4.29E-06	1.19E-04	4.12E-05	1.61E-04	1.24E-04	5.00E-03	2.70E-02	1.20E-02
BATCH-428	3/25/24	58	6.1	0.24	1.04E-07	1.74E+02	3.64E+01	3.00E-03	2.03E-01	1.40E-02	1.34E-04	1.35E-06	3.82E-05	1.31E-05	5.19E-05	3.94E-05	2.00E-03	9.00E-03	4.00E-03
BATCH-429	3/31/24	129	13.5	0.24	5.81E-07	3.87E+02	4.82E+02	3.60E-02	3.31E+00	3.01E-01	3.98E-04	1.83E-05	2.34E-04	1.21E-04	2.92E-04	3.48E-04	1.80E-02	9.30E-02	4.60E-02
BATCH-430	4/6/24	129	13.4	0.24	5.80E-07	3.87E+02	4.82E+02	3.60E-02	3.30E+00	3.00E-01	3.97E-04	1.83E-05	2.33E-04	1.21E-04	2.92E-04	3.47E-04	1.80E-02	9.30E-02	4.60E-02
BATCH-431	4/14/24	94	9.8	0.24	4.22E-07	2.81E+02	3.50E+02	2.60E-02	2.40E+00	2.18E-01	2.89E-04	1.33E-05	1.69E-04	8.76E-05	2.12E-04	2.52E-04	1.30E-02	6.80E-02	3.30E-02
BATCH-432	4/20/24	19	1.9	0.24	2.52E-08	5.55E+01	9.30E+00	8.73E-04	5.30E-02	4.00E-03	2.31E-05	3.41E-07	9.44E-06	3.44E-06	1.25E-05	1.10E-05	4.34E-04	2.00E-03	1.00E-03
BATCH-433	4/22/24	19	2.0	0.24	2.51E-08	5.71E+01	8.73E+00	7.92E-04	4.90E-02	3.00E-03	3.23E-05	3.24E-07	9.18E-06	3.15E-06	1.25E-05	9.45E-06	4.05E-04	2.00E-03	8.97E-04
BATCH-434	4/24/24	52	5.4	0.24	9.80E-08	1.56E+02	3.48E+01	3.00E-03	1.96E-01	1.40E-02	1.25E-04	1.29E-06	3.59E-05	1.24E-05	4.87E-05	3.73E-05	2.00E-03	8.00E-03	4.00E-03
BATCH-435	4/24/24	107	11.2	0.24	7.59E-07	3.22E+02	3.27E+02	2.90E-02	3.47E+00	4.37E-01	1.00E-03	1.24E-05	5.25E-04	1.86E-04	1.72E-04	4.32E-04	1.80E-02	9.40E-02	3.60E-02
BATCH-436	4/30/24	107	11.2	0.24	8.41E-07	3.22E+02	3.04E+02	2.80E-02	3.68E+00	4.93E-01	1.00E-03	1.15E-05	6.24E-04	2.12E-04	1.50E-04	4.75E-04	1.90E-02	1.00E-01	3.50E-02
BATCH-437	5/5/24	134	14.0	0.24	1.05E-06	4.02E+02	3.81E+02	3.50E-02	4.61E+00	6.17E-01	2.00E-03	1.43E-05	7.81E-04	2.65E-04	1.87E-04	5.93E-04	2.40E-02	1.24E-01	4.40E-02
BATCH-438	5/11/24	119	12.4	0.24	2.23E-07	3.57E+02	1.07E+02	9.00E-03	6.61E-01	5.30E-02	2.51E-04	4.02E-06	8.39E-05	3.30E-05	1.11E-04	9.76E-05	5.00E-03	2.30E-02	1.10E-02
BATCH-439	5/20/24	134	14.0	0.24	1.05E-06	4.02E+02	3.80E+02	3.50E-02	4.60E+00	6.16E-01	2.00E-03	1.43E-05	7.81E-04	2.65E-04	1.87E-04	5.93E-04	2.40E-02	1.24E-01	4.40E-02
BATCH-440	5/23/24	18	1.9	0.24	2.35E-08	5.37E+01	8.37E+00	7.55E-04	4.70E-02	3.00E-03	3.01E-05	3.11E-07	8.63E-06	2.98E-06	1.17E-05	8.95E-06	3.86E-04	2.00E-03	8.57E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-392	9/26/23	108	11.2	0.24	5.80E-04	2.96E-04	9.00E-03	8.00E-03	1.40E-02	4.11E-01	7.00E-02	9.44E-01	1.75E-01	1.02E-22	3.78E-06	2.32E-05	1.44E-04	1.00E-03	1.99E-08
BATCH-393	10/4/23	107	11.2	0.24	5.78E-04	2.95E-04	9.00E-03	8.00E-03	1.40E-02	4.10E-01	6.90E-02	9.41E-01	1.75E-01	1.02E-22	3.77E-06	2.31E-05	1.43E-04	1.00E-03	1.98E-08
BATCH-394	10/8/23	131	13.7	0.24	2.00E-03	1.00E-03	3.50E-02	8.60E-02	5.00E-02	1.65E+00	2.79E-01	2.65E+00	7.92E-01	7.84E-22	1.74E-05	8.70E-05	1.00E-03	8.00E-03	1.21E-08
BATCH-395	10/16/23	112	11.7	0.24	2.00E-03	9.72E-04	3.00E-02	7.30E-02	4.20E-02	1.42E+00	2.39E-01	2.27E+00	6.78E-01	6.72E-22	1.49E-05	7.46E-05	1.00E-03	7.00E-03	1.04E-08
BATCH-396	10/22/23	98	10.2	0.24	1.00E-03	8.45E-04	2.60E-02	6.40E-02	3.70E-02	1.23E+00	2.08E-01	1.98E+00	5.90E-01	5.85E-22	1.30E-05	6.48E-05	8.91E-04	6.00E-03	9.00E-09
BATCH-397	10/28/23	147	15.3	0.24	9.19E-04	4.53E-04	1.10E-02	1.90E-02	2.30E-02	5.87E-01	1.01E-01	1.45E+00	2.58E-01	2.24E-22	5.58E-06	3.71E-05	3.24E-04	3.00E-03	1.26E-08
BATCH-398	11/1/23	43	4.5	0.24	2.05E-04	1.05E-04	3.00E-03	3.00E-03	5.00E-03	1.45E-01	2.50E-02	3.33E-01	6.20E-02	3.62E-23	1.34E-06	8.20E-06	5.08E-05	5.28E-04	7.03E-09
BATCH-399	11/5/23	43	4.5	0.24	2.04E-04	1.04E-04	3.00E-03	3.00E-03	5.00E-03	1.45E-01	2.40E-02	3.32E-01	6.20E-02	3.61E-23	1.33E-06	8.17E-06	5.06E-05	5.27E-04	7.00E-09
BATCH-400	11/10/23	98	10.2	0.24	1.00E-03	8.45E-04	2.60E-02	6.40E-02	3.70E-02	1.23E+00	2.08E-01	1.98E+00	5.89E-01	5.84E-22	1.30E-05	6.48E-05	8.90E-04	6.00E-03	8.99E-09
BATCH-401	11/12/23	122	12.7	0.24	7.06E-04	4.13E-04	1.30E-02	3.00E-02	1.80E-02	6.10E-01	1.03E-01	9.61E-01	2.90E-01	2.72E-22	6.39E-06	3.13E-05	4.15E-04	3.00E-03	7.94E-09
BATCH-402	11/20/23	140	14.6	0.24	7.87E-04	4.70E-04	1.60E-02	3.20E-02	2.00E-02	7.13E-01	1.20E-01	1.09E+00	3.35E-01	2.82E-22	7.37E-06	3.49E-05	4.28E-04	3.00E-03	1.67E-08
BATCH-403	11/25/23	15	1.6	0.24	4.87E-05	2.49E-05	7.19E-04	6.99E-04	1.00E-03	3.40E-02	6.00E-03	7.90E-02	1.50E-02	8.60E-24	3.17E-07	1.95E-06	1.21E-05	1.26E-04	1.67E-09
BATCH-404	11/27/23	15	1.6	0.24	4.85E-05	2.48E-05	7.16E-04	6.96E-04	1.00E-03	3.40E-02	6.00E-03	7.90E-02	1.50E-02	8.57E-24	3.16E-07	1.94E-06	1.20E-05	1.25E-04	1.66E-09
BATCH-405	11/29/23	47	4.9	0.24	2.63E-04	1.29E-04	3.00E-03	5.00E-03	6.00E-03	1.68E-01	2.90E-02	4.15E-01	7.40E-02	6.39E-23	1.59E-06	1.06E-05	9.26E-05	8.48E-04	3.59E-09
BATCH-406	12/4/23	140	14.6	0.24	7.85E-04	4.68E-04	1.60E-02	3.20E-02	2.00E-02	7.10E-01	1.19E-01	1.08E+00	3.34E-01	2.81E-22	7.35E-06	3.48E-05	4.27E-04	3.00E-03	1.66E-08
BATCH-407	12/5/23	58	6.0	0.24	3.03E-04	1.78E-04	6.00E-03	1.30E-02	8.00E-03	2.62E-01	4.40E-02	4.13E-01	1.25E-01	1.17E-22	2.75E-06	1.35E-05	1.78E-04	1.00E-03	3.41E-09
BATCH-408	12/12/23	143	14.9	0.24	1.00E-03	8.50E-04	3.40E-02	8.80E-02	3.40E-02	1.60E+00	2.73E-01	2.45E+00	7.33E-01	8.22E-22	1.63E-05	7.98E-05	1.00E-03	9.00E-03	8.57E-08
BATCH-409	12/19/23	150	15.6	0.24	1.00E-03	7.75E-04	3.40E-02	9.20E-02	3.00E-02	1.62E+00	2.77E-01	2.44E+00	7.32E-01	8.55E-22	1.64E-05	7.94E-05	1.00E-03	9.00E-03	1.12E-07
BATCH-410	12/27/23	16	1.7	0.24	6.28E-05	3.09E-05	7.34E-04	1.00E-03	2.00E-03	4.00E-02	7.00E-03	9.90E-02	1.80E-02	1.53E-23	3.81E-07	2.53E-06	2.21E-05	2.03E-04	8.58E-10
BATCH-411	12/29/23	62	6.4	0.24	3.20E-04	1.91E-04	7.00E-03	1.30E-02	8.00E-03	2.89E-01	4.90E-02	4.40E-01	1.36E-01	1.14E-22	2.99E-06	1.42E-05	1.74E-04	1.00E-03	6.77E-09
BATCH-412	1/3/24	19	2.0	0.24	7.42E-05	4.34E-05	1.00E-03	3.00E-03	2.00E-03	6.40E-02	1.10E-02	1.01E-01	2.90E-02	6.08E-24	6.72E-07	3.30E-06	4.26E-05	2.91E-04	8.35E-10
BATCH-413	1/4/24	62	6.4	0.24	3.19E-04	1.90E-04	7.00E-03	1.30E-02	8.00E-03	2.88E-01	4.80E-02	4.38E-01	1.29E-01	2.42E-23	2.98E-06	1.41E-05	1.69E-04	1.00E-03	6.74E-09
BATCH-414	1/6/24	105	10.9	0.24	7.91E-04	5.41E-04	2.40E-02	6.30E-02	2.10E-02	1.13E+00	1.94E-01	1.70E+00	4.87E-01	1.27E-22	1.14E-05	5.54E-05	8.91E-04	6.00E-03	7.84E-08
BATCH-415	1/11/24	150	15.6	0.24	1.00E-03	7.74E-04	3.40E-02	9.10E-02	3.00E-02	1.62E+00	2.77E-01	2.43E+00	6.97E-01	1.81E-22	1.64E-05	7.93E-05	1.00E-03	9.00E-03	1.12E-07
BATCH-416	1/17/24	109	11.4	0.24	8.22E-04	5.63E-04	2.50E-02	6.60E-02	2.20E-02	1.18E+00	2.01E-01	1.77E+00	5.06E-01	1.32E-22	1.19E-05	5.76E-05	9.27E-04	6.00E-03	8.16E-08
BATCH-417	1/27/24	22	2.3	0.24	9.09E-05	5.42E-05	2.00E-03	4.00E-03	2.00E-03	8.20E-02	1.40E-02	1.25E-01	3.70E-02	6.91E-24	8.51E-07	4.03E-06	4.83E-05	3.30E-04	1.92E-09
BATCH-418	1/28/24	150	15.6	0.24	1.00E-03	7.73E-04	3.40E-02	9.10E-02	3.00E-02	1.61E+00	2.77E-01	2.43E+00	6.95E-01	1.81E-22	1.63E-05	7.91E-05	1.00E-03	9.00E-03	1.12E-07
BATCH-419	1/29/24	22	2.3	0.24	9.05E-05	5.40E-05	2.00E-03	4.00E-03	2.00E-03	8.20E-02	1.40E-02	1.24E-01	3.70E-02	6.88E-24	8.47E-07	4.02E-06	4.81E-05	3.29E-04	1.91E-09
BATCH-420	2/1/24	154	16.0	0.24	6.07E-04	3.85E-04	1.50E-02	3.80E-02	1.60E-02	6.96E-01	1.19E-01	1.07E+00	3.06E-01	7.53E-23	7.15E-06	3.50E-05	5.29E-04	4.00E-03	3.30E-08
BATCH-421	2/13/24	95	9.9	0.24	9.75E-04	6.74E-04	2.90E-02	5.10E-02	2.50E-02	1.34E+00	2.26E-01	1.88E+00	5.83E-01	9.62E-23	1.35E-05	5.84E-05	7.28E-04	6.00E-03	6.41E-08
BATCH-422	2/17/24	148	15.5	0.24	4.33E-04	2.97E-04	1.30E-02	3.50E-02	1.10E-02	6.19E-01	1.06E-01	9.31E-01	2.67E-01	6.94E-23	6.27E-06	3.04E-05	4.88E-04	3.00E-03	4.30E-08
BATCH-423	2/23/24	145	15.1	0.24	2.00E-03	1.00E-03	6.50E-02	6.30E-02	5.50E-02	2.81E+00	4.71E-01	3.62E+00	1.24E+00	1.01E-22	2.84E-05	1.09E-04	9.15E-04	8.00E-03	8.08E-08
BATCH-424	3/4/24	145	15.1	0.24	2.00E-03	1.00E-03	6.50E-02	6.30E-02	5.50E-02	2.81E+00	4.70E-01	3.61E+00	1.24E+00	1.01E-22	2.84E-05	1.09E-04	9.14E-04	8.00E-03	8.08E-08
BATCH-425	3/10/24	105	11.0	0.24	2.00E-03	1.00E-03	4.70E-02	4.60E-02	4.00E-02	2.05E+00	3.42E-01	2.63E+00	9.02E-01	7.33E-23	2.07E-05	7.95E-05	6.66E-04	6.00E-03	5.88E-08
BATCH-426	3/19/24	57	5.9	0.24	2.02E-04	1.28E-04	5.00E-03	1.30E-02	5.00E-03	2.32E-01	3.90E-02	3.56E-01	1.02E-01	2.50E-23	2.38E-06	1.17E-05	1.76E-04	1.00E-03	1.10E-08
BATCH-427	3/21/24	156	16.2	0.24	4.88E-04	3.34E-04	1.50E-02	3.80E-02	1.30E-02	6.95E-01	1.19E-01	1.04E+00	3.00E-01	7.63E-23	7.03E-06	3.39E-05	5.38E-04	4.00E-03	4.74E-08
BATCH-428	3/25/24	58	6.1	0.24	1.54E-04	1.05E-04	5.00E-03	1.20E-02	4.00E-03	2.20E-01	3.80E-02	3.31E-01	9.50E-02	2.47E-23	2.23E-06	1.08E-05	1.74E-04	1.00E-03	1.53E-08
BATCH-429	3/31/24	129	13.5	0.24	2.00E-03	1.00E-03	5.80E-02	5.70E-02	4.90E-02	2.51E+00	4.20E-01	3.23E+00	1.11E+00	8.98E-23	2.54E-05	9.75E-05	8.16E-04	7.00E-03	7.21E-08
BATCH-430	4/6/24	129	13.4	0.24	2.00E-03	1.00E-03	5.80E-02	5.60E-02	4.90E-02	2.51E+00	4.19E-01	3.22E+00	1.11E+00	8.97E-23	2.53E-05	9.74E-05	8.15E-04	7.00E-03	7.21E-08
BATCH-431	4/14/24	94	9.8	0.24	1.00E-03	9.59E-04	4.20E-02	4.10E-02	3.50E-02	1.82E+00	3.05E-01	2.34E+00	8.03E-01	6.51E-23	1.84E-05	7.08E-05	5.92E-04	5.00E-03	5.23E-08
BATCH-432	4/20/24	19	1.9	0.24	4.76E-05	3.02E-05	1.00E-03	3.00E-03	1.00E-03	5.50E-02	9.00E-03	8.40E-02	2.40E-02	5.90E-24	5.61E-07	2.75E-06	4.15E-05	2.83E-04	2.59E-09
BATCH-433	4/22/24	19	2.0	0.24	3.70E-05	2.53E-05	1.00E-03	3.00E-03	9.67E-04	5.30E-02	9.00E-03	7.90E-02	2.30E-02	5.92E-24	5.35E-07	2.59E-06	4.17E-05	2.85E-04	3.67E-09
BATCH-434	4/24/24	52	5.4	0.24	1.47E-04	1.01E-04	4.00E-03	1.20E-02	4.00E-03	2.10E-01	3.60E-02	3.14E-01	9.00E-02	2.30E-23	2.12E-06	1.02E-05	1.62E-04	1.00E-03	1.43E-08
BATCH-435	4/24/24	107	11.2	0.24	1.00E-03	9.55E-04	4.20E-02	4.20E-02	3.90E-02	1.83E+00	3.16E-01	2.89E+00	8.48E-01	1.04E-22	1.96E-05	8.29E-05	7.49E-04	5.00E-03	1.53E-07
BATCH-436	4/30/24	107	11.2	0.24	1.00E-03	9.11E-04	3.10E-02	4.10E-02	3.90E-02	1.83E+00	3.05E-01	2.95E+00	8.25E-01	1.13E-22	1.91E-05	8.33E-05	7.69E-04	5.00E-03	1.81E-07
BATCH-437	5/5/24	134	14.0	0.24	2.00E-03	1.00E-03	3.80E-02	5.10E-02	4.90E-02	2.29E+00	3.82E-01	3.69E+00	1.03E+00	1.41E-22	2.39E-05	1.04E-04	9.62E-04	6.00E-03	2.26E-07
BATCH-438	5/11/24	119	12.4	0.24	4.38E-04	3.02E-04	1.30E-02	2.50E-02	1.10E-02	6.05E-01	1.03E-01	8.52E-01	2.63E-01	4.78E-23	6.12E-06	2.70E-05	3.55E-04	3.00E-03	3.13E-08
BATCH-439	5/20/24	134	14.0	0.24	2.00E-03	1.00E-03	3.80E-02	5.10E-02	4.80E-02	2.29E+00	3.81E-01	3.69E+00	1.03E+00	1.41E-22	2.39E-05	1.04E-04	9.61E-04	6.00E-03	2.26E-07
BATCH-440	5/23/24	18	1.9	0.24	3.53E-05	2.42E-05	1.00E-03	3.00E-03	9.24E-04	5.00E-02	9.00E-03	7.50E-02	2.20E-02	5.53E-24	5.10E-07	2.45E-06	3.90E-05	2.68E-04	3.43E-09

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-392	9/26/23	108	11.2	0.24	4.38E+02	0.00E+00	6.65E-09	1.57E-06	3.90E-08	9.19E-18	1.00E-02	6.74E-01	3.00E-07	6.00E-03	4.51E+00	0.00E+00	1.57E+01	0.00E+00	1.95E-05
BATCH-393	10/4/23	107	11.2	0.24	4.37E+02	0.00E+00	6.62E-09	1.57E-06	3.88E-08	5.13E-17	1.00E-02	6.73E-01	2.99E-07	6.00E-03	4.49E+00	0.00E+00	1.56E+01	0.00E+00	1.95E-05
BATCH-394	10/8/23	131	13.7	0.24	2.37E-06	1.83E+02	3.02E-08	6.10E-01	2.80E-08	1.54E-19	7.00E-03	4.97E-01	2.90E-07	2.00E-03	5.58E+01	0.00E+00	5.94E-08	5.64E+00	2.70E-04
BATCH-395	10/16/23	112	11.7	0.24	1.98E-06	1.57E+02	2.59E-08	5.23E-01	2.39E-08	1.02E-19	6.00E-03	4.26E-01	2.48E-07	2.00E-03	4.78E+01	0.00E+00	3.72E-08	4.83E+00	2.43E-04
BATCH-396	10/22/23	98	10.2	0.24	1.43E-09	1.37E+02	2.25E-08	4.55E-01	2.08E-08	2.46E-23	6.00E-03	3.70E-01	2.15E-07	2.00E-03	4.16E+01	0.00E+00	4.68E-11	4.20E+00	2.16E-04
BATCH-397	10/28/23	147	15.3	0.24	4.87E+02	0.00E+00	7.80E-09	8.40E-02	2.46E-08	3.05E-17	1.00E-02	9.33E-01	2.18E-07	8.00E-03	1.24E+01	0.00E+00	2.41E+01	0.00E+00	5.39E-05
BATCH-398	11/1/23	43	4.5	0.24	1.55E+02	0.00E+00	2.35E-09	5.56E-07	1.38E-08	3.25E-18	4.00E-03	2.38E-01	1.06E-07	2.00E-03	1.59E+00	0.00E+00	5.52E+00	0.00E+00	6.90E-06
BATCH-399	11/5/23	43	4.5	0.24	1.54E+02	0.00E+00	2.34E-09	5.54E-07	1.37E-08	1.81E-17	4.00E-03	2.38E-01	1.05E-07	2.00E-03	1.59E+00	0.00E+00	5.52E+00	0.00E+00	6.88E-06
BATCH-400	11/10/23	98	10.2	0.24	1.40E-09	1.36E+02	2.25E-08	4.54E-01	2.07E-08	9.06E-23	6.00E-03	3.70E-01	2.15E-07	2.00E-03	4.16E+01	0.00E+00	3.50E-11	4.19E+00	2.16E-04
BATCH-401	11/12/23	122	12.7	0.24	3.37E+02	0.00E+00	1.15E-08	2.06E-01	1.71E-08	6.46E-17	6.00E-03	8.79E-01	1.53E-07	8.40E-04	1.93E+01	0.00E+00	3.39E+01	0.00E+00	1.08E-04
BATCH-402	11/20/23	140	14.6	0.24	4.11E+02	0.00E+00	1.41E-08	2.00E-01	3.44E-08	7.31E-18	9.00E-03	9.26E-01	2.76E-07	1.00E-03	1.96E+01	0.00E+00	3.78E+01	0.00E+00	1.08E-04
BATCH-403	11/25/23	15	1.6	0.24	3.68E+01	0.00E+00	5.58E-10	1.32E-07	3.27E-09	7.72E-19	8.62E-04	5.70E-02	2.52E-08	4.95E-04	3.78E-01	0.00E+00	1.32E+00	0.00E+00	1.64E-06
BATCH-404	11/27/23	15	1.6	0.24	3.67E+01	0.00E+00	5.56E-10	1.32E-07	3.26E-09	4.30E-18	8.60E-04	5.60E-02	2.51E-08	4.93E-04	3.77E-01	0.00E+00	1.31E+00	0.00E+00	1.63E-06
BATCH-405	11/29/23	47	4.9	0.24	1.39E+02	0.00E+00	2.23E-09	2.40E-02	7.03E-09	8.71E-18	3.00E-03	2.66E-01	6.24E-08	2.00E-03	3.54E+00	0.00E+00	1.44E-05	0.00E+00	1.44E-05
BATCH-406	12/4/23	140	14.6	0.24	4.10E+02	0.00E+00	1.41E-08	1.99E-01	3.43E-08	2.69E-17	9.00E-03	9.24E-01	2.75E-07	1.00E-03	1.96E+01	0.00E+00	3.77E+01	0.00E+00	1.08E-04
BATCH-407	12/5/23	58	6.0	0.24	1.45E+02	0.00E+00	4.93E-09	8.90E-02	7.35E-09	2.78E-17	3.00E-03	3.78E-01	6.56E-08	3.61E-04	8.28E+00	0.00E+00	1.46E+01	0.00E+00	5.39E-05
BATCH-408	12/12/23	143	14.9	0.24	3.00E-03	2.01E+02	5.58E-08	6.81E-01	1.76E-07	6.25E-23	8.00E-03	5.27E-01	1.31E-06	3.00E-03	6.19E+01	0.00E+00	1.07E-04	5.75E+00	3.24E-04
BATCH-409	12/19/23	150	15.6	0.24	4.00E-03	2.12E+02	6.57E-08	7.21E-01	2.30E-07	4.93E-22	8.00E-03	5.50E-01	1.68E-06	4.00E-03	6.54E+01	0.00E+00	1.50E-04	5.92E+00	3.24E-04
BATCH-410	12/27/23	16	1.7	0.24	3.33E+01	0.00E+00	5.32E-10	6.00E-03	1.68E-09	2.08E-18	6.73E-04	6.40E-02	1.49E-08	5.75E-04	8.46E-01	0.00E+00	1.65E+00	0.00E+00	3.45E-06
BATCH-411	12/29/23	62	6.4	0.24	1.67E+02	0.00E+00	5.73E-09	8.10E-02	1.40E-08	2.97E-18	4.00E-03	3.76E-01	1.12E-07	4.59E-04	7.96E+00	0.00E+00	1.53E+01	0.00E+00	5.39E-05
BATCH-412	1/3/24	19	2.0	0.24	3.55E+01	0.00E+00	1.21E-09	2.20E-02	1.80E-09	6.79E-18	6.39E-04	9.20E-02	1.61E-08	8.83E-05	2.03E+00	0.00E+00	3.57E+00	0.00E+00	9.99E-06
BATCH-413	1/4/24	62	6.4	0.24	1.67E+02	0.00E+00	5.72E-09	8.10E-02	1.39E-08	1.09E-17	4.00E-03	3.75E-01	1.12E-07	4.58E-04	7.95E+00	0.00E+00	1.53E+01	0.00E+00	2.70E-05
BATCH-414	1/6/24	105	10.9	0.24	1.61E-06	1.48E+02	4.58E-08	5.03E-01	1.60E-07	3.38E-26	6.00E-03	3.84E-01	1.17E-06	3.00E-03	4.57E+01	0.00E+00	5.76E-08	4.14E+00	2.43E-04
BATCH-415	1/11/24	150	15.6	0.24	4.00E-03	2.12E+02	6.56E-08	7.21E-01	2.29E-07	2.60E-22	8.00E-03	5.49E-01	1.68E-06	4.00E-03	6.54E+01	0.00E+00	2.06E-04	5.92E+00	3.24E-04
BATCH-416	1/17/24	109	11.4	0.24	2.18E-06	1.54E+02	4.77E-08	5.24E-01	1.67E-07	2.56E-25	6.00E-03	3.99E-01	1.22E-06	3.00E-03	4.75E+01	0.00E+00	7.81E-08	4.30E+00	2.43E-04
BATCH-417	1/27/24	22	2.3	0.24	4.74E+01	0.00E+00	1.63E-09	2.30E-02	3.97E-09	8.44E-19	1.00E-03	1.07E-01	3.19E-08	1.31E-04	2.26E+00	0.00E+00	4.36E+00	0.00E+00	1.15E-05
BATCH-418	1/28/24	150	15.6	0.24	5.00E-03	2.11E+02	6.55E-08	7.19E-01	2.29E-07	8.86E-22	8.00E-03	5.48E-01	1.67E-06	4.00E-03	6.53E+01	0.00E+00	4.65E-04	5.91E+00	3.24E-04
BATCH-419	1/29/24	22	2.3	0.24	4.73E+01	0.00E+00	1.62E-09	2.30E-02	3.95E-09	3.10E-18	1.00E-03	1.07E-01	3.17E-08	1.30E-04	2.26E+00	0.00E+00	4.35E+00	0.00E+00	1.15E-05
BATCH-420	2/1/24	154	16.0	0.24	4.56E+02	0.00E+00	2.27E-08	2.91E-01	6.79E-08	3.80E-23	8.00E-03	1.17E+00	5.09E-07	1.00E-03	2.65E+01	0.00E+00	3.80E+01	0.00E+00	1.62E-04
BATCH-421	2/13/24	95	9.9	0.24	1.73E-06	1.11E+02	3.52E-08	2.90E-01	1.23E-07	1.08E-25	5.00E-03	2.84E-01	9.85E-07	3.00E-03	3.14E+01	0.00E+00	8.55E-08	4.65E+00	1.35E-04
BATCH-422	2/17/24	148	15.5	0.24	4.65E+02	0.00E+00	2.51E-08	2.76E-01	8.79E-08	1.09E-22	8.00E-03	1.19E+00	6.42E-07	1.00E-03	2.50E+01	0.00E+00	3.78E+01	0.00E+00	1.62E-04
BATCH-423	2/23/24	145	15.1	0.24	9.00E-03	1.13E+02	3.79E-08	3.10E-02	1.32E-07	1.65E-22	9.00E-03	2.75E-01	1.31E-06	6.00E-03	2.31E+01	0.00E+00	8.49E-04	9.34E+00	1.35E-04
BATCH-424	3/4/24	145	15.1	0.24	9.00E-03	1.13E+02	3.79E-08	3.10E-02	1.32E-07	6.04E-22	9.00E-03	2.75E-01	1.31E-06	6.00E-03	2.31E+01	0.00E+00	8.46E-04	9.34E+00	1.35E-04
BATCH-425	3/10/24	105	11.0	0.24	2.88E-06	8.25E+01	2.76E-08	2.30E-02	9.60E-08	5.51E-25	7.00E-03	2.00E-01	9.56E-07	4.00E-03	1.68E+01	0.00E+00	2.90E-07	6.79E+00	1.08E-04
BATCH-426	3/19/24	57	5.9	0.24	1.52E+02	0.00E+00	7.56E-09	9.70E-02	2.26E-08	1.26E-23	3.00E-03	3.89E-01	1.69E-07	4.60E-04	8.82E+00	0.00E+00	1.26E-01	0.00E+00	5.39E-05
BATCH-427	3/21/24	156	16.2	0.24	4.56E+02	0.00E+00	2.76E-08	3.00E-01	9.66E-08	6.06E-23	8.00E-03	1.18E+00	7.09E-07	2.00E-03	2.74E+01	0.00E+00	3.61E+01	0.00E+00	1.35E-04
BATCH-428	3/25/24	58	6.1	0.24	1.65E+02	0.00E+00	8.92E-09	9.80E-02	3.12E-08	3.89E-23	3.00E-03	4.21E-01	2.28E-07	5.24E-04	8.89E+00	0.00E+00	1.34E+01	0.00E+00	5.39E-05
BATCH-429	3/31/24	129	13.5	0.24	4.69E-06	1.01E+02	3.39E-08	2.70E-02	1.18E-07	8.34E-26	8.00E-03	2.45E-01	1.17E-06	5.00E-03	2.06E+01	0.00E+00	4.31E-07	8.33E+00	1.08E-04
BATCH-430	4/6/24	129	13.4	0.24	4.67E-06	1.01E+02	3.38E-08	2.70E-02	1.18E-07	3.06E-25	8.00E-03	2.45E-01	1.17E-06	5.00E-03	2.06E+01	0.00E+00	4.29E-07	8.32E+00	1.08E-04
BATCH-431	4/14/24	94	9.8	0.24	2.01E-09	7.34E+01	2.46E-08	2.00E-02	8.54E-08	3.84E-28	6.00E-03	1.78E-01	8.51E-07	4.00E-03	1.50E+01	0.00E+00	2.02E-10	6.05E+00	8.09E-05
BATCH-432	4/20/24	19	1.9	0.24	3.57E+01	0.00E+00	1.78E-09	2.30E-02	5.33E-09	2.98E-24	6.33E-04	9.20E-02	3.99E-08	1.08E-04	2.08E+00	0.00E+00	2.98E+00	0.00E+00	1.05E-05
BATCH-433	4/22/24	19	2.0	0.24	3.97E+01	0.00E+00	2.14E-09	2.40E-02	7.49E-09	9.34E-24	6.91E-04	1.01E-01	5.48E-08	1.28E-04	2.14E+00	0.00E+00	3.22E+00	0.00E+00	1.10E-05
BATCH-434	4/24/24	52	5.4	0.24	1.37E+02	0.00E+00	8.33E-09	9.10E-02	2.91E-08	1.83E-23	3.00E-03	3.54E-01	2.14E-07	4.97E-04	8.27E+00	0.00E+00	1.09E-01	0.00E+00	5.39E-05
BATCH-435	4/24/24	107	11.2	0.24	2.32E-09	9.70E+01	6.23E-08	6.00E-03	2.78E-07	4.12E-29	7.90E-02	7.40E-01	2.06E-06	8.00E-03	1.86E+01	0.00E+00	2.13E-10	4.36E+00	1.08E-04
BATCH-436	4/30/24	107	11.2	0.24	2.61E-09	1.01E+02	7.26E-08	6.78E-04	3.32E-07	1.71E-28	1.01E-01	9.02E-01	2.39E-06	9.00E-03	1.90E+01	0.00E+00	2.40E-10	3.57E+00	1.08E-04
BATCH-437	5/5/24	134	14.0	0.24	5.00E-03	1.26E+02	9.08E-08	8.32E-04	4.16E-07	4.38E-28	1.27E-01	1.13E+00	2.99E-06	1.20E-02	2.38E+01	0.00E+00	4.38E-04	4.46E+00	1.35E-04
BATCH-438	5/11/24	119	12.4	0.24	3.64E+02	0.00E+00	1.74E-08	1.55E-01	6.09E-08	1.88E-22	7.00E-03	9.98E-01	4.78E-07	1.00E-03	1.60E+01	0.00E+00	2.92E+01	0.00E+00	8.09E-05
BATCH-439	5/20/24	134	14.0	0.24	6.00E-03	1.26E+02	9.08E-08	8.32E-04	4.16E-07	1.41E-27	1.27E-01	1.13E+00	2.99E-06	1.20E-02	2.38E+01	0.00E+00	4.86E-04	4.46E+00	1.35E-04
BATCH-440	5/23/24	18	1.9	0.24	3.30E+01	0.00E+00	2.00E-09	2.20E-02	7.00E-09	4.39E-24	6.01E-04	8.50E-02	5.14E-08	1.20E-04	1.99E+00	0.00E+00	2.62E+00	0.00E+00	1.02E-05

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-392	9/26/23	108	11.2	0.24	2.10E-08	1.14E+01	7.04E-01	0.00E+00	0.00E+00	4.00E-04	1.72E+00	3.25E-06	3.96E-07	2.26E-07	1.50E-02	1.77E-07	1.84E+03	0.00E+00	3.20E-02
BATCH-393	10/4/23	107	11.2	0.24	2.10E-08	1.13E+01	7.03E-01	0.00E+00	0.00E+00	4.00E-04	1.72E+00	3.24E-06	3.94E-07	2.25E-07	1.50E-02	1.76E-07	1.83E+03	0.00E+00	3.20E-02
BATCH-394	10/8/23	131	13.7	0.24	5.43E-09	3.48E+01	2.77E-01	0.00E+00	0.00E+00	1.00E-03	1.77E+01	2.57E-07	2.91E-07	1.11E-06	1.93E-01	3.21E-08	2.24E+03	0.00E+00	2.09E-01
BATCH-395	10/16/23	112	11.7	0.24	4.60E-09	2.98E+01	2.37E-01	0.00E+00	0.00E+00	8.00E-04	1.52E+01	2.20E-07	2.48E-07	9.49E-07	1.66E-01	2.71E-08	1.92E+03	0.00E+00	1.79E-01
BATCH-396	10/22/23	98	10.2	0.24	3.99E-09	2.59E+01	2.06E-01	0.00E+00	0.00E+00	8.00E-04	1.32E+01	1.91E-07	2.16E-07	8.25E-07	1.44E-01	2.35E-08	1.67E+03	0.00E+00	1.55E-01
BATCH-397	10/28/23	147	15.3	0.24	1.21E-08	1.27E+01	9.07E-01	0.00E+00	0.00E+00	8.00E-04	3.94E+00	4.78E-06	2.63E-07	3.28E-07	4.10E-02	9.82E-08	2.51E+03	0.00E+00	5.70E-02
BATCH-398	11/1/23	43	4.5	0.24	7.43E-09	4.01E+00	2.49E-01	0.00E+00	0.00E+00	1.75E-04	6.08E-01	1.15E-06	1.40E-07	7.98E-08	5.00E-03	6.26E-08	7.34E+02	0.00E+00	1.10E-02
BATCH-399	11/5/23	43	4.5	0.24	7.40E-09	4.00E+00	2.48E-01	0.00E+00	0.00E+00	1.75E-04	6.06E-01	1.14E-06	1.39E-07	7.95E-08	5.00E-03	6.23E-08	7.32E+02	0.00E+00	1.10E-02
BATCH-400	11/10/23	98	10.2	0.24	3.99E-09	2.59E+01	2.06E-01	0.00E+00	0.00E+00	8.00E-04	1.32E+01	1.91E-07	2.16E-07	8.24E-07	1.44E-01	2.35E-08	1.67E+03	0.00E+00	1.55E-01
BATCH-401	11/12/23	122	12.7	0.24	5.92E-09	1.36E+01	7.35E-01	0.00E+00	0.00E+00	4.00E-04	6.21E+00	1.07E-07	1.73E-07	4.07E-07	6.70E-02	4.57E-08	2.08E+03	0.00E+00	7.40E-02
BATCH-402	11/20/23	140	14.6	0.24	1.53E-08	1.75E+01	7.69E-01	0.00E+00	0.00E+00	4.00E-04	6.53E+00	1.50E-07	3.43E-07	4.72E-07	6.80E-02	1.26E-07	2.40E+03	0.00E+00	8.10E-02
BATCH-403	11/25/23	15	1.6	0.24	1.77E-09	9.54E-01	5.90E-02	0.00E+00	0.00E+00	4.16E-05	1.45E-01	2.73E-07	3.32E-08	1.90E-08	1.00E-03	1.49E-08	2.64E+02	0.00E+00	3.00E-03
BATCH-404	11/27/23	15	1.6	0.24	1.76E-09	9.50E-01	5.90E-02	0.00E+00	0.00E+00	4.15E-05	1.44E-01	2.72E-07	3.31E-08	1.89E-08	1.00E-03	1.48E-08	2.63E+02	0.00E+00	3.00E-03
BATCH-405	11/29/23	47	4.9	0.24	3.47E-09	3.64E+00	2.59E-01	0.00E+00	0.00E+00	2.00E-04	1.13E+00	1.37E-06	7.52E-08	9.36E-08	1.20E-02	2.81E-08	8.09E+02	0.00E+00	1.60E-02
BATCH-406	12/4/23	140	14.6	0.24	1.52E-08	1.74E+01	7.67E-01	0.00E+00	0.00E+00	4.00E-04	6.51E+00	1.50E-07	3.42E-07	4.70E-07	6.80E-02	1.25E-07	2.39E+03	0.00E+00	8.10E-02
BATCH-407	12/5/23	58	6.0	0.24	2.55E-09	5.84E+00	3.16E-01	0.00E+00	0.00E+00	1.52E-04	2.67E+00	4.60E-08	7.44E-08	1.75E-07	2.90E-02	1.96E-08	9.86E+02	0.00E+00	3.20E-02
BATCH-408	12/12/23	143	14.9	0.24	8.37E-08	3.70E+01	7.30E-01	0.00E+00	0.00E+00	4.00E-04	1.96E+01	1.14E-05	1.71E-06	1.64E-06	2.02E-01	7.04E-07	2.44E+03	0.00E+00	2.57E-01
BATCH-409	12/19/23	150	15.6	0.24	1.12E-07	3.87E+01	8.99E-01	0.00E+00	0.00E+00	2.00E-04	2.07E+01	1.54E-05	2.23E-06	1.86E-06	2.09E-01	9.46E-07	2.56E+03	0.00E+00	2.79E-01
BATCH-410	12/27/23	16	1.7	0.24	8.28E-10	8.69E-01	6.20E-02	0.00E+00	0.00E+00	5.15E-05	2.69E-01	3.27E-07	1.80E-08	2.24E-08	3.00E-03	6.71E-09	2.81E+02	0.00E+00	4.00E-03
BATCH-411	12/29/23	62	6.4	0.24	6.21E-09	7.09E+00	3.12E-01	0.00E+00	0.00E+00	1.63E-04	2.65E+00	6.11E-08	1.39E-07	1.92E-07	2.80E-02	5.10E-08	1.06E+03	0.00E+00	3.30E-02
BATCH-412	1/3/24	19	2.0	0.24	6.22E-10	1.43E+00	7.70E-02	0.00E+00	0.00E+00	3.72E-05	6.53E-01	1.12E-08	1.82E-08	4.28E-08	7.00E-03	4.80E-09	3.27E+02	0.00E+00	8.00E-03
BATCH-413	1/4/24	62	6.4	0.24	6.18E-09	7.06E+00	3.12E-01	0.00E+00	0.00E+00	1.62E-04	2.65E+00	6.08E-08	1.39E-07	1.91E-07	2.80E-02	5.08E-08	1.05E+03	0.00E+00	3.30E-02
BATCH-414	1/6/24	105	10.9	0.24	7.81E-08	2.70E+01	6.28E-01	0.00E+00	0.00E+00	2.00E-04	1.45E+01	1.08E-05	1.55E-06	1.30E-06	1.46E-01	6.60E-07	1.79E+03	0.00E+00	1.95E-01
BATCH-415	1/11/24	150	15.6	0.24	1.12E-07	3.87E+01	8.98E-01	0.00E+00	0.00E+00	2.00E-04	2.07E+01	1.54E-05	2.23E-06	1.86E-06	2.09E-01	9.45E-07	2.56E+03	0.00E+00	2.79E-01
BATCH-416	1/17/24	109	11.4	0.24	8.13E-08	2.81E+01	6.53E-01	0.00E+00	0.00E+00	2.00E-04	1.50E+01	1.12E-05	1.62E-06	1.35E-06	1.52E-01	6.87E-07	1.86E+03	0.00E+00	2.03E-01
BATCH-417	1/27/24	22	2.3	0.24	1.77E-09	2.02E+00	8.90E-02	0.00E+00	0.00E+00	4.62E-05	7.54E-01	1.74E-08	3.96E-08	5.45E-08	8.00E-03	1.45E-08	3.76E+02	0.00E+00	9.00E-03
BATCH-418	1/28/24	150	15.6	0.24	1.12E-07	3.86E+01	8.97E-01	0.00E+00	0.00E+00	2.00E-04	2.06E+01	1.54E-05	2.22E-06	1.86E-06	2.09E-01	9.43E-07	2.55E+03	0.00E+00	2.78E-01
BATCH-419	1/29/24	22	2.3	0.24	1.75E-09	2.01E+00	8.80E-02	0.00E+00	0.00E+00	4.61E-05	7.51E-01	1.73E-08	3.94E-08	5.42E-08	8.00E-03	1.44E-08	3.75E+02	0.00E+00	9.00E-03
BATCH-420	2/1/24	154	16.0	0.24	3.19E-08	1.59E+01	6.39E-01	0.00E+00	0.00E+00	2.00E-04	8.40E+00	4.32E-06	6.62E-07	6.82E-07	8.70E-02	2.67E-07	2.63E+03	0.00E+00	1.09E-01
BATCH-421	2/13/24	95	9.9	0.24	6.24E-08	2.74E+01	5.31E-01	0.00E+00	0.00E+00	2.00E-04	1.05E+01	1.08E-05	1.25E-06	1.21E-06	1.04E-01	5.21E-07	1.62E+03	0.00E+00	1.60E-01
BATCH-422	2/17/24	148	15.5	0.24	4.28E-08	1.48E+01	6.10E-01	0.00E+00	0.00E+00	1.13E-04	7.92E+00	5.89E-06	8.52E-07	7.12E-07	8.00E-02	3.62E-07	2.54E+03	0.00E+00	1.07E-01
BATCH-423	2/23/24	145	15.1	0.24	7.46E-08	4.91E+01	7.16E-01	0.00E+00	0.00E+00	8.00E-04	9.42E+00	1.92E-05	1.53E-06	1.94E-06	8.70E-02	6.05E-07	2.47E+03	0.00E+00	2.04E-01
BATCH-424	3/4/24	145	15.1	0.24	7.45E-08	4.91E+01	7.16E-01	0.00E+00	0.00E+00	8.00E-04	9.42E+00	1.92E-05	1.53E-06	1.94E-06	8.70E-02	6.05E-07	2.47E+03	0.00E+00	2.04E-01
BATCH-425	3/10/24	105	11.0	0.24	5.43E-08	3.57E+01	5.21E-01	0.00E+00	0.00E+00	6.00E-04	6.86E+00	1.40E-05	1.11E-06	1.41E-06	6.40E-02	4.40E-07	1.80E+03	0.00E+00	1.49E-01
BATCH-426	3/19/24	57	5.9	0.24	1.06E-08	5.30E+00	2.12E-01	0.00E+00	0.00E+00	7.58E-05	2.79E+00	1.44E-06	2.20E-07	2.27E-07	2.90E-02	8.89E-08	9.68E+02	0.00E+00	3.60E-02
BATCH-427	3/21/24	156	16.2	0.24	4.72E-08	1.65E+01	6.42E-01	0.00E+00	0.00E+00	1.29E-04	8.69E+00	6.56E-06	9.38E-07	7.90E-07	8.80E-02	3.98E-07	2.66E+03	0.00E+00	1.18E-01
BATCH-428	3/25/24	58	6.1	0.24	1.52E-08	5.26E+00	2.17E-01	0.00E+00	0.00E+00	4.02E-05	2.81E+00	2.09E-06	3.03E-07	2.53E-07	2.80E-02	1.29E-07	9.93E+02	0.00E+00	3.80E-02
BATCH-429	3/31/24	129	13.5	0.24	6.65E-08	4.38E+01	6.39E-01	0.00E+00	0.00E+00	6.00E-04	8.41E+00	1.72E-05	1.36E-06	1.73E-06	7.80E-02	5.40E-07	2.21E+03	0.00E+00	1.82E-01
BATCH-430	4/6/24	129	13.4	0.24	6.65E-08	4.37E+01	6.38E-01	0.00E+00	0.00E+00	6.00E-04	8.40E+00	1.71E-05	1.36E-06	1.73E-06	7.80E-02	5.39E-07	2.20E+03	0.00E+00	1.82E-01
BATCH-431	4/14/24	94	9.8	0.24	4.83E-08	3.18E+01	4.64E-01	0.00E+00	0.00E+00	4.00E-04	6.10E+00	1.25E-05	9.88E-07	1.26E-06	5.70E-02	3.92E-07	1.60E+03	0.00E+00	1.32E-01
BATCH-432	4/20/24	19	1.9	0.24	2.50E-09	1.25E+00	5.00E-02	0.00E+00	0.00E+00	1.79E-05	6.58E-01	3.38E-07	5.19E-08	5.35E-08	7.00E-03	2.10E-08	3.16E+02	0.00E+00	9.00E-03
BATCH-433	4/22/24	19	2.0	0.24	3.65E-09	1.26E+00	5.20E-02	0.00E+00	0.00E+00	9.65E-06	6.76E-01	5.03E-07	7.27E-08	6.08E-08	7.00E-03	3.09E-08	3.26E+02	0.00E+00	9.00E-03
BATCH-434	4/24/24	52	5.4	0.24	1.42E-08	4.97E+00	1.94E-01	0.00E+00	0.00E+00	3.88E-05	2.62E+00	1.98E-06	2.83E-07	2.38E-07	2.60E-02	1.20E-07	8.89E+02	0.00E+00	3.50E-02
BATCH-435	4/24/24	107	11.2	0.24	1.52E-07	3.58E+01	2.97E-01	0.00E+00	0.00E+00	2.00E-04	6.87E+00	1.46E-05	2.88E-06	1.71E-06	9.90E-02	1.28E-06	1.84E+03	0.00E+00	1.50E-01
BATCH-436	4/30/24	107	11.2	0.24	1.81E-07	3.56E+01	2.26E-01	0.00E+00	0.00E+00	2.00E-04	6.83E+00	1.46E-05	3.41E-06	1.79E-06	1.09E-01	1.53E-06	1.83E+03	0.00E+00	1.50E-01
BATCH-437	5/5/24	134	14.0	0.24	2.26E-07	4.45E+01	2.82E-01	0.00E+00	0.00E+00	2.00E-04	8.54E+00	1.83E-05	4.26E-06	2.24E-06	1.37E-01	1.91E-06	2.29E+03	0.00E+00	1.87E-01
BATCH-438	5/11/24	119	12.4	0.24	3.06E-08	1.28E+01	5.17E-01	0.00E+00	0.00E+00	1.31E-04	5.26E+00	5.05E-06	6.13E-07	5.75E-07	5.20E-02	2.57E-07	2.03E+03	0.00E+00	7.80E-02
BATCH-439	5/20/24	134	14.0	0.24	2.26E-07	4.44E+01	2.82E-01	0.00E+00	0.00E+00	2.00E-04	8.54E+00	1.83E-05	4.26E-06	2.24E-06	1.37E-01	1.91E-06	2.29E+03	0.00E+00	1.87E-01
BATCH-440	5/23/24	18	1.9	0.24	3.42E-09	1.20E+00	4.70E-02	0.00E+00	0.00E+00	9.32E-06	6.29E-01	4.75E-07	6.80E-08	5.72E-08	6.00E-03	2.89E-08	3.06E+02	0.00E+00	9.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Si+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-392	9/26/23	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	2.73E+01	4.23E-10	1.76E+01	1.03E+01	4.00E-03	1.86E-08	0.00E+00	9.70E-02	2.75E-05	7.00E-03
BATCH-393	10/4/23	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	2.72E+01	4.21E-10	1.75E+01	1.03E+01	4.00E-03	1.86E-08	0.00E+00	9.70E-02	2.74E-05	7.00E-03
BATCH-394	10/8/23	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.87E+01	3.29E-09	4.43E+00	2.44E+01	8.00E-03	4.27E-09	0.00E+00	3.39E-01	9.00E-03	2.80E-02
BATCH-395	10/16/23	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-02	5.03E+01	2.82E-09	3.80E+00	2.09E+01	7.00E-03	3.61E-09	0.00E+00	2.91E-01	8.00E-03	2.40E-02
BATCH-396	10/22/23	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-02	4.37E+01	2.45E-09	3.30E+00	1.82E+01	6.00E-03	3.13E-09	0.00E+00	2.53E-01	7.00E-03	2.10E-02
BATCH-397	10/28/23	147	15.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	3.31E+01	6.78E-10	1.95E+01	1.16E+01	6.00E-03	1.05E-08	0.00E+00	1.91E-01	1.00E-03	1.20E-02
BATCH-398	11/1/23	43	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	9.63E+00	1.49E-10	6.20E+00	3.63E+00	1.00E-03	6.58E-09	0.00E+00	3.40E-02	9.70E-06	2.00E-03
BATCH-399	11/5/23	43	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	9.60E+00	1.49E-10	6.19E+00	3.62E+00	1.00E-03	6.55E-09	0.00E+00	3.40E-02	9.67E-06	2.00E-03
BATCH-400	11/10/23	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-02	4.37E+01	2.45E-09	3.30E+00	1.82E+01	6.00E-03	3.13E-09	0.00E+00	2.52E-01	7.00E-03	2.10E-02
BATCH-401	11/12/23	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	3.36E+01	1.20E-09	1.04E+01	9.81E+00	3.00E-03	5.10E-09	0.00E+00	1.15E-01	3.00E-03	1.00E-02
BATCH-402	11/20/23	140	14.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	4.05E+01	1.35E-09	1.22E+01	1.30E+01	3.00E-03	1.35E-08	0.00E+00	1.12E-01	3.00E-03	1.10E-02
BATCH-403	11/25/23	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-04	2.29E+00	3.55E-11	1.47E+00	8.63E-01	3.05E-04	1.56E-09	0.00E+00	8.00E-03	2.31E-06	5.91E-04
BATCH-404	11/27/23	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.25E-04	2.28E+00	3.53E-11	1.47E+00	8.60E-01	3.04E-04	1.56E-09	0.00E+00	8.00E-03	2.30E-06	5.89E-04
BATCH-405	11/29/23	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	9.46E+00	1.94E-10	5.56E+00	3.32E+00	2.00E-03	2.99E-09	0.00E+00	5.50E-02	3.57E-04	3.00E-03
BATCH-406	12/4/23	140	14.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	4.04E+01	1.35E-09	1.22E+01	1.30E+01	3.00E-03	1.35E-08	0.00E+00	1.12E-01	3.00E-03	1.10E-02
BATCH-407	12/5/23	58	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.45E+01	5.14E-10	4.46E+00	4.22E+00	1.00E-03	2.20E-09	0.00E+00	5.00E-02	1.00E-02	4.00E-03
BATCH-408	12/12/23	143	14.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.30E-02	6.86E+01	5.02E-09	4.04E+00	2.66E+01	9.00E-03	7.50E-08	0.00E+00	1.24E-01	1.00E-02	2.20E-02
BATCH-409	12/19/23	150	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-02	7.35E+01	5.71E-09	4.00E+00	2.80E+01	9.00E-03	1.01E-07	0.00E+00	5.60E-02	1.00E-02	2.00E-02
BATCH-410	12/27/23	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.52E-04	2.26E+00	4.63E-11	1.33E+00	7.95E-01	3.84E-04	7.14E-10	0.00E+00	1.30E-02	8.52E-05	8.27E-04
BATCH-411	12/29/23	62	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.64E+01	5.49E-10	4.95E+00	5.28E+00	1.00E-03	5.49E-09	0.00E+00	4.50E-02	1.00E-02	4.00E-03
BATCH-412	1/3/24	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.54E+00	1.26E-10	1.09E+00	1.03E+00	2.97E-04	5.37E-10	0.00E+00	1.20E-02	3.13E-04	1.00E-03
BATCH-413	1/4/24	62	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.64E+01	5.47E-10	4.94E+00	5.27E+00	1.00E-03	5.46E-09	0.00E+00	4.50E-02	1.00E-03	4.00E-03
BATCH-414	1/6/24	105	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.80E-02	5.13E+01	3.99E-09	2.79E+00	1.96E+01	6.00E-03	7.01E-08	0.00E+00	3.90E-02	7.00E-03	1.40E-02
BATCH-415	1/11/24	150	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-02	7.35E+01	5.71E-09	4.00E+00	2.80E+01	9.00E-03	1.00E-07	0.00E+00	5.60E-02	1.00E-02	2.00E-02
BATCH-416	1/17/24	109	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	5.34E+01	4.15E-09	2.91E+00	2.04E+01	7.00E-03	7.30E-08	0.00E+00	4.00E-02	8.00E-03	1.50E-02
BATCH-417	1/27/24	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.67E+00	1.56E-10	1.41E+00	1.50E+00	3.64E-04	1.56E-09	0.00E+00	1.30E-02	3.33E-04	1.00E-03
BATCH-418	1/28/24	150	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-02	7.33E+01	5.70E-09	3.99E+00	2.80E+01	9.00E-03	1.00E-07	0.00E+00	5.50E-02	1.00E-02	2.00E-02
BATCH-419	1/29/24	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.65E+00	1.55E-10	1.40E+00	1.50E+00	3.62E-04	1.55E-09	0.00E+00	1.30E-02	3.32E-04	1.00E-03
BATCH-420	2/1/24	154	16.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	4.76E+01	2.08E-09	1.03E+01	1.17E+01	4.00E-03	2.85E-08	0.00E+00	6.70E-02	4.00E-03	1.00E-02
BATCH-421	2/13/24	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	4.56E+01	2.82E-09	3.05E+00	2.08E+01	8.00E-03	5.47E-08	0.00E+00	3.90E-02	4.00E-03	1.50E-02
BATCH-422	2/17/24	148	15.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	4.78E+01	2.19E-09	9.80E+00	1.10E+01	4.00E-03	3.84E-08	0.00E+00	2.20E-02	4.00E-03	8.00E-03
BATCH-423	2/23/24	145	15.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	6.72E+01	2.34E-09	5.93E+00	3.94E+01	1.90E-02	6.16E-08	0.00E+00	7.00E-02	4.50E-04	3.00E-02
BATCH-424	3/4/24	145	15.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	6.72E+01	2.34E-09	5.92E+00	3.93E+01	1.90E-02	6.16E-08	0.00E+00	7.00E-02	4.50E-04	3.00E-02
BATCH-425	3/10/24	105	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.89E+01	1.70E-09	4.31E+00	2.86E+01	1.40E-02	4.48E-08	0.00E+00	5.10E-02	3.33E-04	2.20E-02
BATCH-426	3/19/24	57	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.58E+01	6.91E-10	3.42E+00	3.89E+00	1.00E-03	9.49E-09	0.00E+00	2.20E-02	1.00E-03	3.00E-03
BATCH-427	3/21/24	156	16.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	5.07E+01	2.40E-09	1.02E+01	1.23E+01	4.00E-03	4.23E-08	0.00E+00	4.00E-02	9.00E-03	9.00E-03
BATCH-428	3/25/24	58	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.70E+01	7.76E-10	3.48E+00	3.91E+00	1.00E-03	1.37E-08	0.00E+00	8.00E-03	1.00E-03	3.00E-03
BATCH-429	3/31/24	129	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	6.00E+01	2.09E-09	5.29E+00	3.51E+01	1.70E-02	5.50E-08	0.00E+00	6.20E-02	4.01E-04	2.60E-02
BATCH-430	4/6/24	129	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	5.99E+01	2.09E-09	5.28E+00	3.51E+01	1.70E-02	5.49E-08	0.00E+00	6.20E-02	4.01E-04	2.60E-02
BATCH-431	4/14/24	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.35E+01	1.51E-09	3.84E+00	2.55E+01	1.30E-02	3.99E-08	0.00E+00	4.50E-02	2.91E-04	1.90E-02
BATCH-432	4/20/24	19	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.73E+00	1.63E-10	8.07E-01	9.18E-01	2.93E-04	2.24E-09	0.00E+00	5.00E-03	3.29E-04	7.70E-04
BATCH-433	4/22/24	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.08E+00	1.86E-10	8.36E-01	9.40E-01	3.02E-04	3.28E-09	0.00E+00	2.00E-03	3.38E-04	6.60E-04
BATCH-434	4/24/24	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.53E+01	7.22E-10	3.08E+00	3.71E+00	1.00E-03	1.28E-08	0.00E+00	7.00E-03	1.00E-03	3.00E-03
BATCH-435	4/24/24	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	4.01E+01	3.96E-09	3.28E+00	3.49E+01	3.80E-02	1.32E-07	0.00E+00	1.24E-01	9.95E-05	1.40E-02
BATCH-436	4/30/24	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.71E+01	4.64E-09	2.93E+00	3.67E+01	4.50E-02	1.58E-07	0.00E+00	1.46E-01	2.82E-05	1.20E-02
BATCH-437	5/5/24	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.64E+01	5.80E-09	3.66E+00	4.58E+01	5.60E-02	1.98E-07	0.00E+00	1.82E-01	3.51E-05	1.50E-02
BATCH-438	5/11/24	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.21E+01	1.43E-09	1.13E+01	1.01E+01	4.00E-03	2.70E-08	0.00E+00	1.90E-02	2.00E-03	7.00E-03
BATCH-439	5/20/24	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.63E+01	5.79E-09	3.66E+00	4.58E+01	5.60E-02	1.98E-07	0.00E+00	1.82E-01	3.51E-05	1.50E-02
BATCH-440	5/23/24	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.68E+00	1.74E-10	7.40E-01	8.91E-01	2.90E-04	3.06E-09	0.00E+00	2.00E-03	3.12E-04	6.26E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-441	5/25/24	93	9.7	0.24	0.00E+00	0.00E+00	6.90E-02	2.80E-02	5.35E+00	2.10E-01	1.87E+03	4.86E-01	8.30E-02	9.29E+00	1.05E-12	6.06E-01	3.00E-03	1.47E-01	6.75E-03
BATCH-442	6/3/24	94	9.8	0.24	0.00E+00	0.00E+00	6.90E-02	2.80E-02	5.40E+00	2.12E-01	1.88E+03	4.90E-01	8.40E-02	9.37E+00	1.06E-12	6.11E-01	3.00E-03	1.49E-01	6.75E-03
BATCH-443	6/4/24	113	11.8	0.24	0.00E+00	0.00E+00	9.20E-02	3.60E-02	7.14E+00	2.69E-01	2.25E+03	6.59E-01	1.12E-01	1.12E+01	1.50E-10	8.14E-01	4.00E-03	2.00E-01	8.50E-03
BATCH-444	6/13/24	53	5.6	0.24	0.00E+00	0.00E+00	1.60E-02	8.00E-03	1.28E+00	7.83E-02	3.90E+02	1.20E-01	2.20E-02	5.31E+00	3.60E-13	1.17E-01	7.53E-04	3.40E-02	1.50E-03
BATCH-445	6/16/24	154	16.1	0.24	0.00E+00	0.00E+00	2.21E-01	6.90E-02	1.72E+01	5.41E-01	3.08E+03	1.69E+00	2.81E-01	1.54E+01	1.93E-09	2.00E+00	9.00E-03	5.17E-01	1.68E-02
BATCH-446	6/19/24	136	14.2	0.24	0.00E+00	0.00E+00	1.94E-01	6.10E-02	1.51E+01	4.76E-01	2.71E+03	1.49E+00	2.47E-01	1.35E+01	1.70E-09	1.76E+00	8.00E-03	4.55E-01	1.48E-02
BATCH-447	7/3/24	95	9.9	0.24	0.00E+00	0.00E+00	1.35E-01	4.20E-02	1.05E+01	3.31E-01	1.89E+03	1.03E+00	1.72E-01	9.41E+00	1.18E-09	1.23E+00	5.00E-03	3.16E-01	1.03E-02
BATCH-448	7/3/24	95	9.9	0.24	0.00E+00	0.00E+00	1.36E-01	4.30E-02	1.06E+01	3.34E-01	1.91E+03	1.04E+00	1.74E-01	9.50E+00	1.19E-09	1.24E+00	5.00E-03	3.19E-01	1.05E-02
BATCH-449	7/13/24	113	11.8	0.24	0.00E+00	0.00E+00	1.61E-01	5.00E-02	1.26E+01	3.95E-01	2.26E+03	1.24E+00	2.05E-01	1.12E+01	1.41E-09	1.47E+00	6.00E-03	3.78E-01	1.23E-02
BATCH-450	7/13/24	18	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.02E-01	1.89E-02	9.26E+01	2.80E-02	5.00E-03	1.41E+00	8.54E-14	2.80E-02	1.79E-04	8.00E-03	2.50E-04
BATCH-451	7/15/24	137	14.3	0.24	0.00E+00	0.00E+00	1.96E-01	6.10E-02	1.53E+01	4.81E-01	2.74E+03	1.50E+00	2.50E-01	1.37E+01	1.72E-09	1.78E+00	8.00E-03	4.60E-01	1.50E-02
BATCH-452	7/25/24	121	12.6	0.24	0.00E+00	0.00E+00	1.72E-01	5.40E-02	1.34E+01	4.22E-01	2.41E+03	1.32E+00	2.19E-01	1.20E+01	1.51E-09	1.57E+00	7.00E-03	4.04E-01	1.33E-02
BATCH-453	7/30/24	117	12.2	0.24	0.00E+00	0.00E+00	3.90E-02	1.40E-02	3.02E+00	1.17E-01	1.27E+03	3.15E-01	5.20E-02	7.93E+00	8.13E-11	3.43E-01	2.00E-03	8.70E-02	4.00E-03
BATCH-454	8/6/24	116	12.0	0.24	0.00E+00	0.00E+00	3.70E-02	1.30E-02	2.89E+00	1.11E-01	1.20E+03	2.96E-01	4.90E-02	7.27E+00	8.12E-11	3.28E-01	2.00E-03	8.30E-02	3.75E-03
BATCH-455	8/11/24	134	14.0	0.24	0.00E+00	0.00E+00	3.07E-01	1.04E-01	2.40E+01	7.24E-01	2.69E+03	2.45E+00	3.98E-01	1.34E+01	1.00E-10	2.87E+00	1.30E-02	7.07E-01	2.00E-02
BATCH-456	8/19/24	88	9.2	0.24	0.00E+00	0.00E+00	2.01E-01	6.80E-02	1.57E+01	4.74E-01	1.76E+03	1.60E+00	2.61E-01	8.75E+00	5.85E-11	1.88E+00	9.00E-03	4.64E-01	1.30E-02
BATCH-457	8/25/24	107	11.2	0.24	0.00E+00	0.00E+00	2.45E-01	8.30E-02	1.91E+01	5.77E-01	2.14E+03	1.95E+00	3.18E-01	1.07E+01	7.10E-11	2.29E+00	1.00E-02	5.64E-01	1.60E-02
BATCH-458	8/28/24	94	9.8	0.24	0.00E+00	0.00E+00	2.16E-01	7.30E-02	1.68E+01	5.08E-01	1.88E+03	1.72E+00	2.80E-01	9.38E+00	6.26E-11	2.02E+00	9.00E-03	4.96E-01	1.40E-02
BATCH-459	9/6/24	54	5.6	0.24	0.00E+00	0.00E+00	1.60E-02	6.00E-03	1.26E+00	4.86E-02	5.29E+02	1.32E-01	2.20E-02	3.32E+00	3.40E-11	1.43E-01	6.84E-04	3.60E-02	1.75E-03
BATCH-460	9/7/24	54	5.7	0.24	0.00E+00	0.00E+00	1.60E-02	6.00E-03	1.23E+00	4.77E-02	5.09E+02	1.26E-01	2.10E-02	3.10E+00	3.46E-11	1.40E-01	6.63E-04	3.50E-02	1.50E-03
BATCH-461	9/11/24	125	13.0	0.24	0.00E+00	0.00E+00	2.85E-01	9.70E-02	2.23E+01	6.72E-01	2.49E+03	2.27E+00	3.70E-01	1.24E+01	8.15E-11	2.67E+00	1.20E-02	6.57E-01	1.85E-02
BATCH-462	9/13/24	81	8.5	0.24	0.00E+00	0.00E+00	1.86E-01	6.30E-02	1.46E+01	4.39E-01	1.63E+03	1.49E+00	2.42E-01	8.11E+00	5.33E-11	1.75E+00	8.00E-03	4.29E-01	1.20E-02
BATCH-463	9/22/24	99	10.3	0.24	0.00E+00	0.00E+00	2.26E-01	7.70E-02	1.77E+01	5.34E-01	1.98E+03	1.80E+00	2.94E-01	9.85E+00	6.47E-11	2.12E+00	1.00E-02	5.22E-01	1.48E-02
BATCH-464	9/25/24	91	9.5	0.24	0.00E+00	0.00E+00	1.01E-01	3.30E-02	7.90E+00	2.21E-01	1.82E+03	7.66E-01	1.24E-01	9.07E+00	8.31E-12	9.53E-01	4.00E-03	2.28E-01	7.00E-03
BATCH-465	10/2/24	19	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.17E-01	1.26E-02	1.33E+02	3.30E-02	5.00E-03	8.33E-01	8.53E-12	3.60E-02	1.72E-04	9.00E-03	5.00E-04
BATCH-466	10/4/24	19	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.10E-01	1.17E-02	1.28E+02	3.20E-02	5.00E-03	7.81E-01	8.72E-12	3.50E-02	1.67E-04	9.00E-03	5.00E-04
BATCH-467	10/4/24	114	11.9	0.24	0.00E+00	0.00E+00	4.60E-02	1.70E-02	3.62E+00	1.23E-01	1.37E+03	3.50E-01	5.80E-02	6.48E+00	1.05E-10	4.22E-01	2.00E-03	1.04E-01	3.75E-03
BATCH-468	10/7/24	122	12.8	0.24	0.00E+00	0.00E+00	1.13E-01	3.70E-02	8.86E+00	2.39E-01	2.45E+03	8.41E-01	1.36E-01	1.22E+01	4.23E-13	1.07E+00	5.00E-03	2.54E-01	8.25E-03
BATCH-469	10/17/24	98	10.2	0.24	0.00E+00	0.00E+00	9.00E-02	2.90E-02	7.07E+00	1.91E-01	1.95E+03	6.71E-01	1.09E-01	9.72E+00	3.46E-13	8.54E-01	4.00E-03	2.03E-01	6.50E-03
BATCH-470	10/20/24	105	11.0	0.24	0.00E+00	0.00E+00	4.70E-02	1.60E-02	3.67E+00	1.18E-01	1.33E+03	3.59E-01	6.00E-02	6.18E+00	2.20E-10	4.30E-01	2.00E-03	1.08E-01	3.50E-03
BATCH-471	10/27/24	142	14.8	0.24	0.00E+00	0.00E+00	1.31E-01	4.30E-02	1.02E+01	2.76E-01	2.83E+03	9.72E-01	1.58E-01	1.41E+01	4.39E-13	1.24E+00	5.00E-03	2.94E-01	9.50E-03
BATCH-472	10/31/24	141	14.7	0.24	0.00E+00	0.00E+00	1.31E-01	4.20E-02	1.02E+01	2.76E-01	2.83E+03	9.71E-01	1.57E-01	1.41E+01	4.39E-13	1.24E+00	5.00E-03	2.93E-01	9.50E-03
BATCH-473	11/11/24	48	5.1	0.24	0.00E+00	0.00E+00	1.80E-02	6.00E-03	1.37E+00	4.68E-02	5.17E+02	1.33E-01	2.20E-02	2.46E+00	3.97E-11	1.60E-01	7.24E-04	4.00E-02	1.50E-03
BATCH-474	11/15/24	114	11.8	0.24	0.00E+00	0.00E+00	1.05E-01	3.40E-02	8.21E+00	2.21E-01	2.27E+03	7.79E-01	1.26E-01	1.13E+01	3.51E-13	9.92E-01	4.00E-03	2.36E-01	7.50E-03
BATCH-475	11/16/24	90	9.4	0.24	0.00E+00	0.00E+00	8.30E-02	2.70E-02	6.53E+00	1.76E-01	1.81E+03	6.20E-01	1.01E-01	8.99E+00	2.79E-13	7.89E-01	3.00E-03	1.87E-01	6.00E-03
BATCH-476	11/26/24	49	5.1	0.24	0.00E+00	0.00E+00	2.00E-02	7.00E-03	1.54E+00	4.95E-02	5.56E+02	1.50E-01	2.50E-02	2.58E+00	9.19E-11	1.80E-01	8.03E-04	4.50E-02	1.50E-03
BATCH-477	11/27/24	128	13.3	0.24	0.00E+00	0.00E+00	1.06E-01	3.10E-02	8.24E+00	4.03E-01	2.55E+03	8.90E-01	1.52E-01	1.27E+01	2.73E-12	9.47E-01	5.00E-03	2.35E-01	1.45E-02
BATCH-478	12/1/24	128	13.3	0.24	0.00E+00	0.00E+00	1.05E-01	3.10E-02	8.18E+00	4.11E-01	2.55E+03	8.90E-01	1.52E-01	1.27E+01	2.85E-12	9.38E-01	5.00E-03	2.34E-01	1.48E-02
BATCH-479	12/10/24	17	1.8	0.24	0.00E+00	0.00E+00	4.00E-03	2.00E-03	3.27E-01	1.08E-02	1.24E+02	3.20E-02	5.00E-03	5.86E-01	9.48E-12	3.80E-02	1.73E-04	9.00E-03	2.50E-04
BATCH-480	12/12/24	99	10.3	0.24	0.00E+00	0.00E+00	5.30E-02	1.70E-02	4.13E+00	1.25E-01	1.50E+03	4.09E-01	6.70E-02	6.60E+00	2.40E-10	4.88E-01	2.00E-03	1.23E-01	3.75E-03
BATCH-481	12/15/24	103	10.7	0.24	0.00E+00	0.00E+00	8.40E-02	2.50E-02	6.57E+00	3.30E-01	2.05E+03	7.15E-01	1.22E-01	1.02E+01	2.29E-12	7.53E-01	4.00E-03	1.88E-01	1.18E-02
BATCH-482	12/23/24	17	1.8	0.24	0.00E+00	0.00E+00	5.00E-03	2.00E-03	3.68E-01	1.17E-02	1.33E+02	3.60E-02	6.00E-03	6.19E-01	2.20E-11	4.30E-02	1.93E-04	1.10E-02	2.50E-04
BATCH-483	12/25/24	105	10.9	0.24	0.00E+00	0.00E+00	8.60E-02	2.60E-02	6.72E+00	3.38E-01	2.10E+03	7.31E-01	1.25E-01	1.04E+01	2.34E-12	7.70E-01	4.00E-03	1.92E-01	1.20E-02
BATCH-484	12/26/24	137	14.3	0.24	0.00E+00	0.00E+00	1.13E-01	3.30E-02	8.77E+00	4.41E-01	2.74E+03	9.54E-01	1.63E-01	1.36E+01	3.06E-12	1.01E+00	5.00E-03	2.50E-01	1.58E-02
BATCH-485	1/5/25	104	10.8	0.24	0.00E+00	0.00E+00	8.60E-02	2.20E-02	6.61E+00	3.35E-01	2.08E+03	7.24E-01	1.18E-01	1.04E+01	1.17E-12	7.28E-01	3.00E-03	1.90E-01	1.20E-02
BATCH-486	1/9/25	52	5.5	0.24	0.00E+00	0.00E+00	2.50E-02	7.00E-03	1.95E+00	5.94E-02	6.97E+02	1.95E-01	3.00E-02	3.14E+00	5.75E-11	2.22E-01	8.04E-04	5.80E-02	1.75E-03
BATCH-487	1/15/25	76	7.9	0.24	0.00E+00	0.00E+00	7.10E-02	1.90E-02	5.48E+00	2.57E-01	1.52E+03	5.93E-01	9.60E-02	7.58E+00	9.31E-13	6.09E-01	3.00E-03	1.58E-01	9.00E-03
BATCH-488	1/16/25	136	14.2	0.24	0.00E+00	0.00E+00	1.95E-01	5.70E-02	1.51E+01	5.64E-01	2.73E+03	1.58E+00	2.51E-01	1.36E+01	2.31E-12	1.71E+00	7.00E-03	4.41E-01	1.78E-02
BATCH-489	1/23/25	85	8.9	0.24	0.00E+00	0.00E+00	1.22E-01	3.50E-02	9.42E+00	3.53E-01	1.70E+03	9.88E-01	1.57E-01	8.49E+00	1.44E-12	1.07E+00	4.00E-03	2.75E-01	1.13E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-441	5/25/24	93	9.7	0.24	7.32E-07	2.80E+02	2.65E+02	2.50E-02	3.20E+00	4.29E-01	1.00E-03	9.96E-06	5.43E-04	1.84E-04	1.30E-04	4.13E-04	1.70E-02	8.70E-02	3.00E-02
BATCH-442	6/3/24	94	9.8	0.24	7.38E-07	2.82E+02	2.67E+02	2.50E-02	3.23E+00	4.32E-01	1.00E-03	1.01E-05	5.48E-04	1.86E-04	1.31E-04	4.16E-04	1.70E-02	8.70E-02	3.10E-02
BATCH-443	6/4/24	113	11.8	0.24	9.02E-07	3.38E+02	3.59E+02	3.20E-02	3.86E+00	4.86E-01	2.13E-01	1.35E-05	6.54E-04	2.26E-04	1.76E-04	5.12E-04	2.10E-02	1.09E-01	4.00E-02
BATCH-444	6/13/24	53	5.6	0.24	9.02E-08	1.60E+02	4.32E+01	4.00E-03	2.67E-01	2.10E-02	1.01E-04	1.62E-06	3.39E-05	1.33E-05	4.49E-05	3.94E-05	2.00E-03	9.00E-03	4.00E-03
BATCH-445	6/16/24	154	16.1	0.24	1.44E-06	4.63E+02	9.22E+02	7.40E-02	5.18E+00	3.23E-01	2.57E+00	3.43E-05	8.77E-04	3.44E-04	4.38E-04	8.53E-04	3.80E-02	1.97E-01	8.60E-02
BATCH-446	6/19/24	136	14.2	0.24	1.27E-06	4.07E+02	8.11E+02	6.50E-02	4.56E+00	2.84E-01	2.26E+00	3.02E-05	7.72E-04	3.03E-04	3.86E-04	7.51E-04	3.40E-02	1.73E-01	7.50E-02
BATCH-447	7/3/24	95	9.9	0.24	8.80E-07	2.83E+02	5.64E+02	4.50E-02	3.18E+00	1.98E-01	1.58E+00	2.10E-05	5.37E-04	2.11E-04	2.68E-04	5.22E-04	2.40E-02	1.21E-01	5.20E-02
BATCH-448	7/3/24	95	9.9	0.24	8.89E-07	2.86E+02	5.70E+02	4.60E-02	3.21E+00	2.00E-01	1.59E+00	2.12E-05	5.42E-04	2.13E-04	2.71E-04	5.27E-04	2.40E-02	1.22E-01	5.30E-02
BATCH-449	7/13/24	113	11.8	0.24	1.05E-06	3.38E+02	6.74E+02	5.40E-02	3.79E+00	2.36E-01	1.88E+00	2.51E-05	6.41E-04	2.51E-04	3.20E-04	6.24E-04	2.80E-02	1.44E-01	6.30E-02
BATCH-450	7/13/24	18	1.9	0.24	2.14E-08	5.38E+01	1.03E+01	8.55E-04	6.30E-02	5.00E-03	2.40E-05	3.85E-07	8.04E-06	3.16E-06	1.07E-05	9.35E-06	4.34E-04	2.00E-03	1.00E-03
BATCH-451	7/15/24	137	14.3	0.24	1.28E-06	4.11E+02	8.19E+02	6.60E-02	4.61E+00	2.87E-01	2.29E+00	3.05E-05	7.80E-04	3.06E-04	3.90E-04	7.58E-04	3.40E-02	1.75E-01	7.60E-02
BATCH-452	7/25/24	121	12.6	0.24	1.12E-06	3.61E+02	7.20E+02	5.80E-02	4.05E+00	2.52E-01	2.01E+00	2.68E-05	6.85E-04	2.68E-04	3.42E-04	6.66E-04	3.00E-02	1.54E-01	6.70E-02
BATCH-453	7/30/24	117	12.2	0.24	2.54E-07	3.50E+02	1.56E+02	1.30E-02	1.20E+00	1.20E-01	1.07E-01	5.88E-06	1.46E-04	5.87E-05	8.56E-05	1.48E-04	7.00E-03	3.50E-02	1.50E-02
BATCH-454	8/6/24	116	12.0	0.24	2.60E-07	3.46E+02	1.49E+02	1.20E-02	1.20E+00	1.25E-01	1.07E-01	5.61E-06	1.57E-04	6.11E-05	8.02E-05	1.51E-04	7.00E-03	3.50E-02	1.50E-02
BATCH-455	8/11/24	134	14.0	0.24	6.10E-07	4.03E+02	1.28E+03	1.19E-01	7.58E+00	4.91E-01	1.32E-01	4.71E-05	1.00E-03	5.29E-04	6.68E-04	1.00E-03	7.70E-02	3.92E-01	1.17E-01
BATCH-456	8/19/24	88	9.2	0.24	3.96E-07	2.64E+02	8.38E+02	7.80E-02	4.97E+00	3.22E-01	7.70E-02	3.09E-05	7.53E-04	3.47E-04	4.38E-04	9.39E-04	5.00E-02	2.58E-01	7.60E-02
BATCH-457	8/25/24	107	11.2	0.24	4.82E-07	3.21E+02	1.02E+03	9.50E-02	6.05E+00	3.92E-01	9.40E-02	3.76E-05	9.17E-04	4.22E-04	5.34E-04	1.00E-03	6.10E-02	3.13E-01	9.30E-02
BATCH-458	8/28/24	94	9.8	0.24	4.25E-07	2.82E+02	8.98E+02	8.30E-02	5.33E+00	3.45E-01	8.20E-02	3.31E-05	8.07E-04	3.71E-04	4.70E-04	1.00E-03	5.40E-02	2.76E-01	8.20E-02
BATCH-459	9/6/24	54	5.6	0.24	1.06E-07	1.62E+02	6.52E+01	5.00E-03	5.01E-01	5.00E-02	4.50E-02	2.46E-06	6.10E-05	2.45E-05	3.58E-05	6.20E-05	3.00E-03	1.50E-02	6.00E-03
BATCH-460	9/7/24	54	5.7	0.24	1.11E-07	1.63E+02	6.33E+01	5.00E-03	5.10E-01	5.30E-02	4.60E-02	2.39E-06	6.70E-05	2.60E-05	3.41E-05	6.43E-05	3.00E-03	1.50E-02	6.00E-03
BATCH-461	9/11/24	125	13.0	0.24	5.61E-07	3.73E+02	1.19E+03	1.10E-01	7.05E+00	4.57E-01	1.07E-01	4.38E-05	1.00E-03	4.91E-04	6.21E-04	1.00E-03	7.10E-02	3.65E-01	1.08E-01
BATCH-462	9/13/24	81	8.5	0.24	3.67E-07	2.44E+02	7.76E+02	7.20E-02	4.61E+00	2.99E-01	7.00E-02	2.86E-05	6.98E-04	3.21E-04	4.06E-04	8.69E-04	4.70E-02	2.39E-01	7.10E-02
BATCH-463	9/22/24	99	10.3	0.24	4.45E-07	2.97E+02	9.43E+02	8.80E-02	5.60E+00	3.63E-01	8.50E-02	3.48E-05	8.48E-04	3.90E-04	4.93E-04	1.00E-03	5.70E-02	2.90E-01	8.60E-02
BATCH-464	9/25/24	91	9.5	0.24	1.97E-07	2.73E+02	4.17E+02	3.90E-02	2.52E+00	1.73E-01	1.10E-02	1.56E-05	4.84E-04	2.07E-04	2.02E-04	5.31E-04	2.70E-02	1.38E-01	4.00E-02
BATCH-465	10/2/24	19	1.9	0.24	2.66E-08	5.55E+01	1.64E+01	1.00E-03	1.26E-01	1.30E-02	1.10E-02	6.17E-07	1.53E-05	6.16E-06	8.98E-06	1.56E-05	7.26E-04	4.00E-03	2.00E-03
BATCH-466	10/4/24	19	1.9	0.24	2.79E-08	5.59E+01	1.60E+01	1.00E-03	1.29E-01	1.30E-02	1.10E-02	6.02E-07	1.69E-05	6.57E-06	8.61E-06	1.62E-05	7.40E-04	4.00E-03	2.00E-03
BATCH-467	10/4/24	114	11.9	0.24	2.97E-07	3.43E+02	1.88E+02	1.70E-02	1.52E+00	1.55E-01	1.40E-01	6.99E-06	2.50E-04	9.51E-05	9.39E-05	2.31E-04	1.10E-02	5.50E-02	1.90E-02
BATCH-468	10/7/24	122	12.8	0.24	2.20E-07	3.67E+02	4.66E+02	4.40E-02	2.84E+00	1.98E-01	6.66E-05	1.76E-05	5.89E-04	2.45E-04	2.19E-04	6.21E-04	3.10E-02	1.59E-01	4.50E-02
BATCH-469	10/17/24	98	10.2	0.24	1.75E-07	2.93E+02	3.72E+02	3.50E-02	2.26E+00	1.58E-01	6.47E-05	1.40E-05	4.69E-04	1.96E-04	1.74E-04	4.95E-04	2.50E-02	1.27E-01	3.60E-02
BATCH-470	10/20/24	105	11.0	0.24	2.71E-07	3.16E+02	1.94E+02	1.70E-02	1.30E+00	1.08E-01	2.93E-01	7.22E-06	2.17E-04	8.55E-05	9.51E-05	2.12E-04	1.00E-02	5.10E-02	1.90E-02
BATCH-471	10/27/24	142	14.8	0.24	2.54E-07	4.24E+02	5.39E+02	5.10E-02	3.28E+00	2.29E-01	1.14E-05	2.03E-05	6.80E-04	2.84E-04	2.52E-04	7.17E-04	3.60E-02	1.84E-01	5.20E-02
BATCH-472	10/31/24	141	14.7	0.24	2.54E-07	4.24E+02	5.38E+02	5.10E-02	3.27E+00	2.29E-01	1.14E-05	2.03E-05	6.80E-04	2.83E-04	2.52E-04	7.16E-04	3.60E-02	1.84E-01	5.20E-02
BATCH-473	*11/11/24*	*48*	*5.1*	*0.24*	*1.13E-07*	*1.45E+02*	*7.11E+01*	*6.00E-03*	*5.76E-01*	*5.90E-02*	*5.30E-02*	*2.65E-06*	*9.48E-05*	*3.60E-05*	*3.55E-05*	*8.75E-05*	*4.00E-03*	*2.10E-02*	*7.00E-03*
BATCH-474	11/15/24	114	11.8	0.24	2.04E-07	3.41E+02	4.32E+02	4.10E-02	2.63E+00	1.84E-01	7.64E-06	1.63E-05	5.46E-04	2.27E-04	2.02E-04	5.75E-04	2.90E-02	1.47E-01	4.20E-02
BATCH-475	11/16/24	90	9.4	0.24	1.62E-07	2.71E+02	3.44E+02	3.30E-02	2.09E+00	1.46E-01	6.09E-06	1.30E-05	4.34E-04	1.81E-04	1.61E-04	4.57E-04	2.30E-02	1.17E-01	3.30E-02
BATCH-476	11/26/24	49	5.1	0.24	1.13E-07	1.47E+02	8.11E+01	7.00E-03	5.44E-01	4.50E-02	1.22E-01	3.02E-06	9.08E-05	3.57E-05	3.97E-05	8.87E-05	4.00E-03	2.10E-02	8.00E-03
BATCH-477	11/27/24	128	13.3	0.24	2.93E-07	3.83E+02	4.16E+02	3.40E-02	2.37E+00	1.43E-01	3.00E-03	1.53E-05	6.75E-04	2.47E-04	2.42E-04	5.51E-04	1.80E-02	9.20E-02	4.40E-02
BATCH-478	12/1/24	128	13.3	0.24	2.97E-07	3.83E+02	4.14E+02	3.40E-02	2.33E+00	1.40E-01	3.00E-03	1.52E-05	6.78E-04	2.46E-04	2.43E-04	5.46E-04	1.70E-02	8.80E-02	4.40E-02
BATCH-479	12/10/24	17	1.8	0.24	2.69E-08	5.09E+01	1.70E+01	2.00E-03	1.38E-01	1.40E-02	1.30E-02	6.32E-07	2.26E-05	8.60E-06	8.48E-06	2.09E-05	9.65E-04	5.00E-03	2.00E-03
BATCH-480	12/12/24	99	10.3	0.24	2.26E-07	2.96E+02	2.20E+02	1.90E-02	1.28E+00	8.20E-02	3.20E-01	8.18E-06	2.14E-04	8.98E-05	1.08E-04	2.31E-04	1.10E-02	5.80E-02	2.00E-02
BATCH-481	12/15/24	103	10.7	0.24	2.38E-07	3.08E+02	3.33E+02	2.70E-02	1.88E+00	1.13E-01	3.00E-03	1.22E-05	5.44E-04	1.98E-04	1.95E-04	4.39E-04	1.40E-02	7.00E-02	3.50E-02
BATCH-482	12/23/24	17	1.8	0.24	2.71E-08	5.15E+01	1.94E+01	2.00E-03	1.30E-01	1.10E-02	2.90E-02	7.23E-07	2.18E-05	8.57E-06	9.52E-06	2.13E-05	9.97E-04	5.00E-03	2.00E-03
BATCH-483	12/25/24	105	10.9	0.24	2.44E-07	3.14E+02	3.40E+02	2.80E-02	1.92E+00	1.15E-01	3.00E-03	1.25E-05	5.56E-04	2.02E-04	2.00E-04	4.48E-04	1.40E-02	7.20E-02	3.60E-02
BATCH-484	12/26/24	137	14.3	0.24	3.18E-07	4.10E+02	4.44E+02	3.60E-02	2.50E+00	1.50E-01	4.00E-03	1.63E-05	7.26E-04	2.64E-04	2.60E-04	5.85E-04	1.80E-02	9.40E-02	4.70E-02
BATCH-485	1/5/25	104	10.8	0.24	1.72E-07	3.12E+02	3.35E+02	2.60E-02	1.75E+00	9.90E-02	3.00E-03	1.20E-05	4.98E-04	2.01E-04	1.98E-04	4.44E-04	1.40E-02	7.10E-02	3.60E-02
BATCH-486	1/9/25	52	5.5	0.24	7.68E-08	1.57E+02	1.04E+02	9.00E-03	5.61E-01	3.40E-02	1.52E-01	3.77E-06	9.20E-05	4.28E-05	5.16E-05	1.10E-04	5.00E-03	2.80E-02	1.00E-02
BATCH-487	1/15/25	76	7.9	0.24	1.35E-07	2.28E+02	2.80E+02	2.20E-02	1.48E+00	8.60E-02	2.00E-03	1.00E-05	3.93E-04	1.62E-04	1.61E-04	3.69E-04	1.30E-02	6.50E-02	2.90E-02
BATCH-488	1/16/25	136	14.2	0.24	3.10E-07	4.09E+02	7.91E+02	6.90E-02	4.32E+00	2.61E-01	5.00E-03	2.84E-05	9.45E-04	4.18E-04	4.26E-04	1.00E-03	4.30E-02	2.22E-01	7.50E-02
BATCH-489	1/23/25	85	8.9	0.24	1.93E-07	2.56E+02	4.94E+02	4.30E-02	2.70E+00	1.63E-01	3.00E-03	1.78E-05	5.90E-04	2.61E-04	2.66E-04	6.36E-04	2.70E-02	1.39E-01	4.70E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-441	5/25/24	93	9.7	0.24	1.00E-03	7.92E-04	2.70E-02	3.60E-02	3.40E-02	1.59E+00	2.65E-01	2.57E+00	7.17E-01	9.83E-23	1.66E-05	7.25E-05	6.69E-04	4.00E-03	1.57E-07
BATCH-442	6/3/24	94	9.8	0.24	1.00E-03	7.99E-04	2.70E-02	3.60E-02	3.40E-02	1.61E+00	2.68E-01	2.59E+00	7.23E-01	9.91E-23	1.68E-05	7.31E-05	6.75E-04	4.00E-03	1.59E-07
BATCH-443	6/4/24	113	11.8	0.24	2.00E-03	1.00E-03	3.60E-02	4.70E-02	4.40E-02	2.10E+00	3.47E-01	3.30E+00	9.32E-01	1.37E-22	2.17E-05	9.76E-05	1.00E-03	6.00E-03	3.84E-05
BATCH-444	6/13/24	53	5.6	0.24	1.77E-04	1.22E-04	5.00E-03	1.00E-02	5.00E-03	2.44E-01	4.10E-02	3.44E-01	1.06E-01	1.93E-23	2.47E-06	1.09E-05	1.43E-04	1.00E-03	1.26E-08
BATCH-445	6/16/24	154	16.1	0.24	4.00E-03	2.00E-03	9.30E-02	1.02E-01	9.20E-02	4.81E+00	7.66E-01	6.72E+00	1.99E+00	3.87E-22	4.69E-05	2.43E-04	5.00E-03	1.90E-02	4.66E-04
BATCH-446	6/19/24	136	14.2	0.24	3.00E-03	2.00E-03	8.20E-02	8.90E-02	8.10E-02	4.23E+00	6.74E-01	5.92E+00	1.75E+00	3.40E-22	4.13E-05	2.14E-04	4.00E-03	1.60E-02	4.10E-04
BATCH-447	7/3/24	95	9.9	0.24	2.00E-03	1.00E-03	5.70E-02	6.20E-02	5.60E-02	2.95E+00	4.69E-01	4.12E+00	1.22E+00	2.37E-22	2.87E-05	1.49E-04	3.00E-03	1.10E-02	2.85E-04
BATCH-448	7/3/24	95	9.9	0.24	2.00E-03	2.00E-03	5.70E-02	7.40E-02	6.70E-02	3.52E+00	5.60E-01	4.91E+00	1.46E+00	2.83E-22	3.43E-05	1.77E-04	3.00E-03	1.40E-02	3.40E-04
BATCH-449	7/13/24	113	11.8	0.24	3.00E-03	2.00E-03	6.80E-02	2.00E-03	1.00E-03	5.80E-02	1.00E-02	8.20E-02	2.50E-02	4.58E-24	5.86E-07	2.59E-06	3.40E-05	2.52E-04	3.00E-09
BATCH-450	7/13/24	18	1.9	0.24	4.20E-05	2.90E-05	1.00E-03	2.00E-03	1.00E-03	5.80E-02	1.00E-02	8.20E-02	2.50E-02	4.58E-24	5.86E-07	2.59E-06	3.40E-05	2.52E-04	3.00E-09
BATCH-451	7/15/24	137	14.3	0.24	3.00E-03	2.00E-03	8.20E-02	9.00E-02	8.10E-02	4.28E+00	6.82E-01	5.98E+00	1.77E+00	3.44E-22	4.17E-05	2.16E-04	4.00E-03	1.70E-02	4.14E-04
BATCH-452	7/25/24	121	12.6	0.24	3.00E-03	2.00E-03	7.20E-02	7.90E-02	7.20E-02	3.76E+00	5.98E-01	5.25E+00	1.55E+00	3.02E-22	3.67E-05	1.90E-04	4.00E-03	1.50E-02	3.64E-04
BATCH-453	7/30/24	117	12.2	0.24	6.36E-04	4.32E-04	1.70E-02	1.90E-02	1.70E-02	8.39E-01	1.39E-01	1.17E+00	3.66E-01	4.41E-23	8.48E-06	3.63E-05	4.21E-04	3.00E-03	1.93E-05
BATCH-454	8/6/24	116	12.0	0.24	6.16E-04	4.15E-04	1.60E-02	1.80E-02	1.60E-02	8.09E-01	1.34E-01	1.15E+00	3.54E-01	4.46E-23	8.20E-06	3.55E-05	4.17E-04	3.00E-03	1.93E-05
BATCH-455	8/11/24	134	14.0	0.24	5.00E-03	4.00E-03	1.24E-01	1.57E-01	1.32E-01	6.59E+00	1.12E+00	7.84E+00	3.12E+00	2.18E-22	7.30E-05	3.00E-04	1.00E-03	1.10E-02	1.26E-04
BATCH-456	8/19/24	88	9.2	0.24	3.00E-03	2.00E-03	8.10E-02	1.03E-01	8.60E-02	4.32E+00	7.34E-01	5.13E+00	2.04E+00	1.42E-22	4.79E-05	1.97E-04	9.17E-04	7.00E-03	8.14E-05
BATCH-457	8/25/24	107	11.2	0.24	4.00E-03	3.00E-03	9.90E-02	1.25E-01	1.05E-01	5.26E+00	8.94E-01	6.25E+00	2.49E+00	1.73E-22	5.83E-05	2.39E-04	1.00E-03	9.00E-03	9.90E-05
BATCH-458	8/28/24	94	9.8	0.24	3.00E-03	3.00E-03	8.70E-02	1.10E-01	9.30E-02	4.63E+00	7.86E-01	5.50E+00	2.19E+00	1.52E-22	5.13E-05	2.10E-04	9.82E-04	8.00E-03	8.71E-05
BATCH-459	9/6/24	54	5.6	0.24	2.66E-04	1.81E-04	7.00E-03	8.00E-03	7.00E-03	3.51E-01	5.80E-02	4.88E-01	1.53E-01	1.85E-23	3.54E-06	1.52E-05	1.76E-04	1.00E-03	8.07E-06
BATCH-460	9/7/24	54	5.7	0.24	2.62E-04	1.77E-04	7.00E-03	8.00E-03	7.00E-03	3.45E-01	5.70E-02	4.89E-01	1.51E-01	1.90E-23	3.49E-06	1.51E-05	1.78E-04	1.00E-03	8.23E-06
BATCH-461	9/11/24	125	13.0	0.24	4.00E-03	3.00E-03	1.15E-01	1.46E-01	1.23E-01	6.12E+00	1.04E+00	7.27E+00	2.90E+00	2.01E-22	6.78E-05	2.78E-04	1.10E-02	1.15E-04	1.52E-05
BATCH-462	9/13/24	81	8.5	0.24	3.00E-03	2.00E-03	7.50E-02	9.50E-02	8.00E-02	4.00E+00	6.80E-01	4.76E+00	1.89E+00	1.31E-22	4.43E-05	1.82E-04	8.47E-04	7.00E-03	7.52E-05
BATCH-463	9/22/24	99	10.3	0.24	3.00E-03	3.00E-03	9.10E-02	1.16E-01	9.70E-02	4.86E+00	8.26E-01	5.78E+00	2.30E+00	1.59E-22	5.39E-05	2.21E-04	1.00E-03	8.00E-03	9.14E-05
BATCH-464	9/25/24	91	9.5	0.24	2.00E-03	1.00E-03	4.00E-02	5.70E-02	4.60E-02	2.53E+00	4.33E-01	2.85E+00	1.15E+00	1.16E-22	2.68E-05	1.05E-04	8.07E-04	5.00E-03	1.14E-05
BATCH-465	10/2/24	19	1.9	0.24	6.68E-05	4.53E-05	2.00E-03	2.00E-03	2.00E-03	8.80E-02	1.50E-02	1.22E-01	3.80E-02	4.63E-24	8.90E-07	3.81E-06	4.42E-05	2.75E-04	2.03E-06
BATCH-466	10/4/24	19	1.9	0.24	6.61E-05	4.46E-05	2.00E-03	2.00E-03	2.00E-03	8.70E-02	1.40E-02	1.23E-01	3.80E-02	4.79E-24	8.81E-07	3.81E-06	4.48E-05	2.71E-04	2.08E-06
BATCH-467	10/4/24	114	11.9	0.24	7.72E-04	5.33E-04	1.90E-02	2.30E-02	2.10E-02	1.03E+00	1.71E-01	1.45E+00	4.63E-01	5.75E-23	1.06E-05	4.81E-05	4.93E-04	3.00E-03	3.10E-05
BATCH-468	10/7/24	122	12.8	0.24	2.00E-03	1.00E-03	4.50E-02	6.60E-02	5.20E-02	2.99E+00	5.14E-01	3.31E+00	1.34E+00	1.50E-22	3.12E-05	1.20E-04	1.00E-03	7.00E-03	1.47E-07
BATCH-469	10/17/24	98	10.2	0.24	1.00E-03	1.00E-03	3.50E-02	5.30E-02	4.10E-02	2.38E+00	4.10E-01	2.64E+00	1.07E+00	1.19E-22	2.49E-05	9.59E-05	8.41E-04	5.00E-03	1.30E-07
BATCH-470	10/20/24	105	11.0	0.24	7.64E-04	5.35E-04	1.90E-02	2.30E-02	2.00E-02	1.05E+00	1.72E-01	1.42E+00	4.57E-01	6.62E-23	1.07E-05	4.99E-05	6.79E-04	3.00E-03	5.71E-05
BATCH-471	10/27/24	142	14.8	0.24	2.00E-03	2.00E-03	5.10E-02	7.70E-02	6.00E-02	3.45E+00	5.94E-01	3.83E+00	1.55E+00	1.73E-22	3.61E-05	1.39E-04	1.00E-03	8.00E-03	9.83E-06
BATCH-472	10/31/24	141	14.7	0.24	2.00E-03	2.00E-03	5.10E-02	7.70E-02	6.00E-02	3.45E+00	5.93E-01	3.82E+00	1.55E+00	1.73E-22	3.60E-05	1.39E-04	1.00E-03	8.00E-03	9.82E-08
BATCH-473	11/1/24	48	5.1	0.24	2.92E-04	2.02E-04	7.00E-03	9.00E-03	8.00E-03	3.90E-01	6.50E-02	5.49E-01	1.75E-01	2.18E-23	4.10E-06	1.82E-05	1.87E-04	1.00E-03	1.17E-05
BATCH-474	11/11/24	114	11.8	0.24	2.00E-03	1.00E-03	4.10E-02	6.20E-02	4.80E-02	2.77E+00	4.76E-01	3.07E+00	1.25E+00	1.39E-22	2.89E-05	1.12E-04	9.78E-04	6.00E-03	7.86E-08
BATCH-475	11/15/24	90	9.4	0.24	1.00E-03	9.87E-04	3.30E-02	4.90E-02	3.80E-02	2.20E+00	3.79E-01	2.44E+00	9.90E-01	1.11E-22	2.30E-05	8.87E-05	7.78E-04	5.00E-03	6.25E-08
BATCH-476	11/16/24	49	5.1	0.24	3.19E-04	2.23E-04	8.00E-03	1.00E-02	9.00E-03	4.37E-01	7.20E-02	5.95E-01	1.91E-01	2.77E-23	4.48E-06	2.08E-05	2.84E-04	1.00E-03	2.39E-05
BATCH-477	11/26/24	128	13.3	0.24	2.00E-03	1.00E-03	5.10E-02	5.20E-02	4.60E-02	2.59E+00	4.13E-01	4.18E+00	1.02E+00	3.92E-22	2.30E-05	1.18E-04	2.00E-03	1.70E-02	1.18E-06
BATCH-478	12/1/24	128	13.3	0.24	2.00E-03	1.00E-03	5.10E-02	5.10E-02	4.60E-02	2.56E+00	4.06E-01	4.22E+00	9.96E-01	4.04E-22	2.25E-05	1.17E-04	3.00E-03	1.70E-02	1.24E-06
BATCH-479	12/10/24	17	1.8	0.24	6.98E-05	4.82E-05	2.00E-03	2.00E-03	2.00E-03	9.30E-02	1.50E-02	1.31E-01	4.20E-02	5.20E-24	9.78E-07	4.35E-06	4.46E-05	2.47E-04	2.80E-06
BATCH-480	12/12/24	99	10.3	0.24	8.35E-04	6.03E-04	2.20E-02	2.60E-02	2.30E-02	1.18E+00	1.95E-01	1.51E+00	5.19E-01	6.97E-23	1.22E-05	5.56E-05	7.22E-04	3.00E-03	6.43E-05
BATCH-481	12/15/24	103	10.7	0.24	1.00E-03	1.00E-03	4.10E-02	4.10E-02	3.70E-02	2.06E+00	3.26E-01	3.39E+00	8.00E-01	3.24E-22	1.81E-05	9.43E-05	2.00E-03	1.40E-02	9.94E-07
BATCH-482	12/23/24	17	1.8	0.24	7.65E-05	5.35E-05	2.00E-03	2.00E-03	2.00E-03	1.05E-01	1.70E-02	1.43E-01	4.60E-02	6.63E-24	1.07E-06	4.99E-06	6.80E-05	3.19E-04	5.72E-06
BATCH-483	12/25/24	105	10.9	0.24	1.00E-03	1.00E-03	4.20E-02	4.20E-02	3.80E-02	2.10E+00	3.33E-01	3.47E+00	8.17E-01	3.32E-22	1.85E-05	9.63E-05	2.00E-03	1.40E-02	1.02E-06
BATCH-484	12/26/24	137	14.3	0.24	2.00E-03	1.00E-03	5.50E-02	5.40E-02	4.90E-02	2.75E+00	4.35E-01	4.52E+00	1.07E+00	4.33E-22	2.41E-05	1.26E-04	3.00E-03	2.00E-03	1.33E-06
BATCH-485	1/5/25	104	10.8	0.24	1.00E-03	1.00E-03	4.20E-02	4.10E-02	3.70E-02	2.09E+00	3.30E-01	3.43E+00	7.72E-01	6.95E-23	1.83E-05	9.55E-05	2.00E-03	1.30E-02	1.01E-06
BATCH-486	1/9/25	52	5.5	0.24	3.98E-04	2.87E-04	1.00E-02	1.20E-02	1.10E-02	5.61E-01	9.30E-02	7.17E-01	2.35E-01	7.02E-24	5.80E-06	2.65E-05	3.35E-04	2.00E-03	3.06E-05
BATCH-487	1/15/25	76	7.9	0.24	1.00E-03	8.40E-04	3.40E-02	3.40E-02	3.10E-02	1.68E-01	2.70E-01	2.60E+00	6.47E-01	4.80E-23	1.54E-05	7.62E-05	1.00E-03	9.00E-03	1.69E-06
BATCH-488	1/16/25	136	14.2	0.24	3.00E-03	2.00E-03	8.50E-02	9.50E-02	8.30E-02	4.27E+00	7.16E-01	5.33E+00	1.83E+00	6.16E-23	4.44E-05	1.88E-04	2.00E-03	1.40E-02	1.09E-05
BATCH-489	1/23/25	85	8.9	0.24	2.00E-03	1.00E-03	5.30E-02	5.90E-02	5.20E-02	2.67E+00	4.48E-01	3.33E+00	1.14E+00	3.85E-23	2.77E-05	1.18E-04	1.00E-03	9.00E-03	6.79E-06

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-441	5/25/24	93	9.7	0.24	1.49E-12	8.76E+01	6.32E-08	5.80E-04	2.89E-07	2.64E-32	8.80E-02	7.85E-01	2.08E-06	8.00E-03	1.66E+01	0.00E+00	1.37E-13	3.10E+00	1.08E-04
BATCH-442	6/3/24	94	9.8	0.24	1.66E-12	8.84E+01	6.37E-08	5.82E-04	2.92E-07	1.09E-31	8.90E-02	7.92E-01	2.10E-06	8.00E-03	1.67E+01	0.00E+00	1.53E-13	3.13E+00	1.08E-04
BATCH-443	6/4/24	113	11.8	0.24	2.48E-06	1.13E+02	3.00E-05	1.00E-03	1.15E-05	2.07E-31	1.05E-01	9.42E-01	2.89E-05	1.00E-02	1.92E+01	0.00E+00	2.07E-07	4.16E+00	4.32E-04
BATCH-444	6/13/24	53	5.6	0.24	1.47E+02	0.00E+00	7.04E-09	6.30E-02	2.46E-08	7.59E-23	3.00E-03	4.03E-01	1.93E-07	5.44E-04	6.46E+00	0.00E+00	1.18E+01	0.00E+00	2.70E-05
BATCH-445	6/16/24	154	16.1	0.24	4.00E-03	2.30E+02	3.65E-04	8.00E-03	1.37E-04	5.91E-28	1.25E-01	1.23E+00	3.24E-04	1.30E-02	1.78E+01	0.00E+00	3.52E-04	1.01E+01	3.96E-03
BATCH-446	6/19/24	136	14.2	0.24	3.08E-06	2.03E+02	3.21E-04	7.00E-03	1.20E-04	7.24E-31	1.10E-01	1.08E+00	2.85E-04	1.20E-02	1.56E+01	0.00E+00	2.50E-07	8.93E+00	3.48E-03
BATCH-447	7/3/24	95	9.9	0.24	1.10E-15	1.41E+02	2.23E-04	5.00E-03	8.37E-05	1.95E-35	7.70E-02	7.53E-01	1.99E-04	8.00E-03	1.09E+01	0.00E+00	1.01E-16	6.21E+00	2.43E-03
BATCH-448	7/3/24	95	9.9	0.24	1.21E-15	1.42E+02	2.25E-04	5.00E-03	8.45E-05	7.96E-35	7.70E-02	7.61E-01	2.00E-04	8.00E-03	1.10E+01	0.00E+00	1.12E-16	6.27E+00	2.45E-03
BATCH-449	7/13/24	113	11.8	0.24	1.53E-09	1.68E+02	2.67E-04	6.00E-03	1.00E-04	1.28E-34	9.20E-02	8.99E-01	2.37E-04	1.00E-02	1.30E+01	0.00E+00	1.28E-10	7.42E+00	2.89E-03
BATCH-450	7/13/24	18	1.9	0.24	3.48E+01	0.00E+00	1.67E-09	1.50E-02	5.83E-09	1.80E-23	6.79E-04	9.60E-02	4.58E-08	1.29E-04	1.53E+00	0.00E+00	2.79E+00	0.00E+00	8.02E-06
BATCH-451	7/15/24	137	14.3	0.24	2.26E-06	2.05E+02	3.24E-04	7.00E-03	1.22E-04	3.00E-31	1.11E-01	1.09E+00	2.88E-04	1.20E-02	1.58E+01	0.00E+00	1.79E-07	9.03E+00	3.51E-03
BATCH-452	7/25/24	121	12.6	0.24	1.78E-09	1.80E+02	2.85E-04	6.00E-03	1.07E-04	4.18E-34	9.80E-02	9.61E-01	2.53E-04	1.10E-02	1.39E+01	0.00E+00	1.44E-10	7.93E+00	3.07E-03
BATCH-453	7/30/24	117	12.2	0.24	3.60E+02	0.00E+00	1.51E-05	5.00E-03	5.72E-06	1.10E-23	2.70E-02	9.91E-01	1.39E-05	2.00E-03	6.43E+00	0.00E+00	1.97E+01	0.00E+00	1.89E-04
BATCH-454	8/6/24	116	12.0	0.24	3.64E+02	0.00E+00	1.51E-05	4.00E-03	5.73E-06	4.00E-23	3.00E-02	9.94E-01	1.40E-05	3.00E-03	6.31E+00	0.00E+00	1.89E+01	0.00E+00	1.89E-04
BATCH-455	8/11/24	134	14.0	0.24	4.00E-03	2.94E+02	2.62E-04	3.60E-02	1.24E-04	2.23E-27	8.70E-02	1.66E+00	7.64E-05	1.70E-02	2.70E+01	0.00E+00	3.46E-04	1.77E+01	1.70E-03
BATCH-456	8/19/24	88	9.2	0.24	1.10E-12	1.93E+02	1.71E-04	2.40E-02	8.08E-05	9.16E-38	5.70E-02	1.09E+00	4.91E-05	1.10E-02	1.77E+01	0.00E+00	9.16E-14	1.16E+01	1.11E-03
BATCH-457	8/25/24	107	11.2	0.24	1.33E-09	2.35E+02	2.08E-04	2.90E-02	9.84E-05	1.77E-34	6.90E-02	1.32E+00	5.97E-05	1.30E-02	2.15E+01	0.00E+00	1.05E-10	1.42E+01	1.32E-03
BATCH-458	8/28/24	94	9.8	0.24	1.19E-12	2.06E+02	1.83E-04	2.50E-02	8.66E-05	2.79E-37	6.10E-02	1.16E+00	5.25E-05	1.20E-02	1.90E+01	0.00E+00	9.64E-14	1.25E+01	1.19E-03
BATCH-459	9/6/24	54	5.6	0.24	1.51E+02	0.00E+00	6.32E-06	2.00E-03	2.39E-06	4.59E-24	1.10E-02	4.14E-01	5.81E-06	1.00E-03	2.69E+00	0.00E+00	8.23E+00	0.00E+00	8.09E-05
BATCH-460	9/7/24	54	5.7	0.24	1.55E+02	0.00E+00	6.44E-06	2.00E-03	2.44E-06	1.70E-23	1.30E-02	4.23E-01	5.94E-06	1.00E-03	2.69E+00	0.00E+00	8.05E+00	0.00E+00	8.09E-05
BATCH-461	9/11/24	125	13.0	0.24	2.18E-06	2.73E+02	2.42E-04	3.40E-02	1.15E-04	1.13E-30	8.00E-02	1.54E+00	6.93E-05	1.50E-02	2.51E+01	0.00E+00	1.75E-07	1.65E+01	1.56E-03
BATCH-462	9/13/24	81	8.5	0.24	8.47E-16	1.79E+02	1.58E-04	2.20E-02	7.49E-05	7.06E-41	5.30E-02	1.01E+00	4.53E-05	1.00E-02	1.64E+01	0.00E+00	7.07E-17	1.08E+01	1.02E-03
BATCH-463	9/22/24	99	10.3	0.24	8.41E-13	2.17E+02	1.93E-04	2.70E-02	9.09E-05	1.12E-37	6.40E-02	1.22E+00	5.51E-05	1.20E-02	1.99E+01	0.00E+00	6.67E-14	1.31E+01	1.24E-03
BATCH-464	9/25/24	91	9.5	0.24	7.83E-16	1.01E+02	2.43E-05	4.00E-03	1.14E-05	1.84E-40	5.10E-02	6.51E-01	7.23E-06	7.00E-03	1.95E+01	0.00E+00	6.35E-17	4.30E+00	2.16E-04
BATCH-465	10/2/24	19	1.9	0.24	3.78E+01	0.00E+00	1.59E-06	5.44E-04	6.00E-07	1.15E-24	3.00E-03	1.04E-01	1.46E-06	2.59E-04	6.75E-01	0.00E+00	2.07E+00	0.00E+00	2.06E-05
BATCH-466	10/4/24	19	1.9	0.24	3.91E+01	0.00E+00	1.63E-06	4.57E-04	6.16E-07	4.29E-24	3.00E-03	1.07E-01	1.50E-06	2.78E-04	6.78E-01	0.00E+00	2.03E+00	0.00E+00	2.11E-05
BATCH-467	10/4/24	114	11.9	0.24	3.35E+02	0.00E+00	3.35E-05	3.00E-03	1.41E-05	3.47E-29	4.60E-02	1.37E+00	2.15E-05	4.00E-03	6.72E+00	0.00E+00	2.06E+01	0.00E+00	3.24E-04
BATCH-468	10/7/24	122	12.8	0.24	1.19E-09	1.16E+02	5.43E-07	8.37E-04	2.28E-07	6.12E-34	6.60E-02	7.76E-01	6.16E-07	9.00E-03	2.64E+01	0.00E+00	9.50E-11	4.15E+00	8.09E-05
BATCH-469	10/17/24	98	10.2	0.24	5.73E-16	9.22E+01	4.59E-07	6.71E-04	1.94E-07	7.63E-41	5.30E-02	6.18E-01	4.99E-07	7.00E-03	2.10E+01	0.00E+00	4.55E-17	3.31E+00	8.09E-05
BATCH-470	10/20/24	105	11.0	0.24	3.39E+02	0.00E+00	5.12E-05	2.00E-03	2.03E-05	1.08E-28	3.90E-02	1.21E+00	3.96E-05	3.00E-03	5.50E+00	0.00E+00	1.99E+01	0.00E+00	5.12E-04
BATCH-471	10/27/24	142	14.8	0.24	6.00E-03	1.34E+02	4.78E-07	9.47E-04	1.92E-07	1.93E-28	7.70E-02	8.96E-01	6.69E-07	1.00E-02	3.05E+01	0.00E+00	3.47E-04	4.79E+00	1.08E-04
BATCH-472	10/31/24	141	14.7	0.24	7.00E-03	1.33E+02	4.75E-07	9.47E-04	1.91E-07	7.26E-28	7.70E-02	8.95E-01	6.69E-07	1.00E-02	3.05E+01	0.00E+00	3.44E-04	4.78E+00	1.08E-04
BATCH-473	11/11/24	48	5.1	0.24	1.27E+02	0.00E+00	1.27E-05	9.83E-04	5.32E-06	1.32E-29	1.70E-02	5.19E-01	8.12E-06	1.00E-03	2.54E+00	0.00E+00	7.79E+00	0.00E+00	1.35E-04
BATCH-474	11/15/24	114	11.8	0.24	6.92E-13	1.07E+02	3.82E-07	7.60E-04	1.54E-07	3.58E-37	6.20E-02	7.19E-01	5.37E-07	8.00E-03	2.45E+01	0.00E+00	5.55E-14	3.84E+00	8.09E-05
BATCH-475	11/16/24	90	9.4	0.24	4.20E-19	8.52E+01	3.04E-07	6.04E-04	1.22E-07	5.59E-44	4.90E-02	5.72E-01	4.27E-07	6.00E-03	1.95E+01	0.00E+00	3.33E-20	3.05E+00	5.39E-05
BATCH-476	11/26/24	49	5.1	0.24	1.42E+02	0.00E+00	2.14E-05	1.00E-03	8.46E-06	4.51E-29	1.60E-02	5.04E-01	1.65E-05	1.00E-03	2.30E+00	0.00E+00	8.32E+00	0.00E+00	2.16E-04
BATCH-477	11/27/24	128	13.3	0.24	2.62E-06	3.29E+02	6.09E-07	7.38E-04	4.28E-07	7.99E-32	1.50E-02	3.12E-01	4.48E-06	4.00E-03	2.07E+01	0.00E+00	1.43E-07	8.65E+00	2.43E-04
BATCH-478	12/1/24	128	13.3	0.24	2.97E-06	3.40E+02	6.19E-07	7.32E-04	4.41E-07	3.26E-31	1.20E-02	2.86E-01	4.69E-06	4.00E-03	2.04E+01	0.00E+00	1.55E-07	8.88E+00	2.70E-04
BATCH-479	12/10/24	17	1.8	0.24	3.03E+01	0.00E+00	3.03E-06	2.35E-04	1.27E-06	3.14E-30	4.00E-03	1.24E-01	1.94E-06	3.37E-04	6.07E-01	0.00E+00	1.86E+00	0.00E+00	2.70E-05
BATCH-480	12/12/24	99	10.3	0.24	2.95E+02	0.00E+00	6.06E-05	3.00E-03	2.43E-05	3.81E-29	3.40E-02	1.43E+00	4.41E-05	3.00E-03	5.47E+00	0.00E+00	2.42E+01	0.00E+00	5.93E-04
BATCH-481	12/15/24	103	10.7	0.24	3.87E-16	2.73E+02	4.97E-07	5.88E-04	3.54E-07	2.00E-40	1.00E-02	2.30E-01	3.76E-06	3.00E-03	1.63E+01	0.00E+00	3.10E-17	7.13E+00	2.16E-04
BATCH-482	12/23/24	17	1.8	0.24	3.40E+01	0.00E+00	5.13E-06	2.42E-04	2.03E-06	1.08E-29	4.00E-03	1.21E-01	3.96E-06	3.27E-04	5.51E-01	0.00E+00	1.99E+00	0.00E+00	5.39E-05
BATCH-483	12/25/24	105	10.9	0.24	1.44E-09	2.79E+02	5.08E-07	6.01E-04	3.62E-07	4.37E-35	1.00E-02	2.34E-01	3.85E-06	3.00E-03	1.67E+01	0.00E+00	7.84E-11	7.29E+00	2.16E-04
BATCH-484	12/26/24	137	14.3	0.24	4.00E-03	3.65E+02	6.63E-07	7.84E-04	4.73E-07	3.94E-34	1.30E-02	3.06E-01	5.02E-06	4.00E-03	2.18E+01	0.00E+00	2.34E-04	9.51E+00	2.70E-04
BATCH-485	1/5/25	104	10.8	0.24	1.64E-09	2.77E+02	5.04E-07	5.96E-04	3.59E-07	1.80E-34	1.00E-02	2.32E-01	3.82E-06	3.00E-03	1.66E+01	0.00E+00	8.50E-11	7.23E+00	2.16E-04
BATCH-486	1/9/25	52	5.5	0.24	1.41E+02	0.00E+00	2.89E-05	2.00E-03	1.16E-05	1.82E-29	1.60E-02	6.82E-01	2.10E-05	2.00E-03	2.60E+00	0.00E+00	1.15E+01	0.00E+00	1.62E-04
BATCH-487	1/15/25	76	7.9	0.24	2.33E-19	2.00E+02	4.12E-07	5.42E-04	3.32E-07	1.21E-43	8.00E-03	2.13E-01	3.61E-06	3.00E-03	1.22E+01	0.00E+00	1.87E-20	5.65E+00	1.62E-04
BATCH-488	1/16/25	136	14.2	0.24	4.00E-03	3.38E+02	1.09E-06	2.00E-03	1.17E-06	1.42E-33	1.70E-02	7.33E-01	1.32E-05	9.00E-03	2.20E+01	0.00E+00	2.61E-04	1.31E+01	2.97E-04
BATCH-489	1/23/25	85	8.9	0.24	1.01E-12	2.12E+02	6.82E-07	1.00E-03	7.28E-07	3.08E-38	1.10E-02	4.58E-01	8.25E-06	6.00E-03	1.37E+01	0.00E+00	5.52E-14	8.16E+00	1.89E-04

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2 kg-mol	F- kg-mol	Fe+3 kg-mol	H+ kg-mol	H2O kg-mol	Hg+2 kg-mol	K+ kg-mol	La+3 kg-mol	Li+ kg-mol	Mg+2 kg-mol	Mn+4 kg-mol	Mo+6 kg-mol	Na+ kg-mol	NH3 kg-mol	Ni+2 kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-441	5/25/24	93	9.7	0.24	1.57E-07	3.09E+01	1.96E-01	0.00E+00	0.00E+00	1.96E-04	5.94E+00	1.27E-05	2.96E-06	1.56E-06	9.50E-02	1.33E-06	1.59E+03	0.00E+00	1.30E-01
BATCH-442	6/3/24	94	9.8	0.24	1.59E-07	3.12E+01	1.98E-01	0.00E+00	0.00E+00	1.98E-04	5.99E+00	1.28E-05	2.99E-06	1.57E-06	9.60E-02	1.34E-06	1.61E+03	0.00E+00	1.31E-01
BATCH-443	6/4/24	113	11.8	0.24	2.38E-07	3.71E+01	2.37E-01	0.00E+00	0.00E+00	4.00E-04	7.35E+00	2.67E-05	1.39E-05	3.87E-04	1.18E-01	6.36E-06	1.93E+03	0.00E+00	1.51E-01
BATCH-444	6/13/24	53	5.6	0.24	1.24E-08	5.16E+00	2.09E-01	0.00E+00	0.00E+00	5.27E-05	2.12E+00	2.04E-06	2.48E-07	2.32E-07	2.10E-02	1.04E-07	9.11E+02	0.00E+00	3.20E-02
BATCH-445	6/16/24	154	16.1	0.24	8.49E-07	4.77E+01	3.31E-01	0.00E+00	0.00E+00	1.20E-03	1.20E+01	1.59E-04	1.31E-04	5.00E-03	1.94E-01	6.02E-05	2.64E+03	0.00E+00	1.45E-01
BATCH-446	6/19/24	136	14.2	0.24	7.47E-07	4.20E+01	2.92E-01	0.00E+00	0.00E+00	1.00E-03	1.05E+01	1.40E-04	1.15E-04	4.00E-03	1.71E-01	5.29E-05	2.32E+03	0.00E+00	1.28E-01
BATCH-447	7/3/24	95	9.9	0.24	5.20E-07	2.92E+01	2.03E-01	0.00E+00	0.00E+00	8.00E-04	7.34E+00	9.72E-05	8.00E-05	3.00E-03	1.19E-01	3.68E-05	1.61E+03	0.00E+00	8.90E-02
BATCH-448	7/3/24	95	9.9	0.24	5.25E-07	2.95E+01	2.05E-01	0.00E+00	0.00E+00	8.00E-04	7.41E+00	9.81E-05	8.07E-05	3.00E-03	1.20E-01	3.72E-05	1.63E+03	0.00E+00	9.00E-02
BATCH-449	7/13/24	113	11.8	0.24	6.21E-07	3.49E+01	2.42E-01	0.00E+00	0.00E+00	8.00E-04	8.76E+00	1.16E-04	9.55E-05	3.00E-03	1.42E-01	4.40E-05	1.93E+03	0.00E+00	1.06E-01
BATCH-450	7/13/24	18	1.9	0.24	2.93E-09	1.22E+00	5.00E-02	0.00E+00	0.00E+00	1.25E-05	5.04E-01	4.84E-07	5.88E-08	5.51E-08	5.00E-03	2.46E-08	3.07E+02	0.00E+00	7.00E-03
BATCH-451	7/15/24	137	14.3	0.24	7.55E-07	4.24E+01	2.95E-01	0.00E+00	0.00E+00	1.00E-03	1.07E+01	1.41E-04	1.16E-04	4.00E-03	1.72E-01	5.35E-05	2.34E+03	0.00E+00	1.29E-01
BATCH-452	7/25/24	121	12.6	0.24	6.63E-07	3.72E+01	2.59E-01	0.00E+00	0.00E+00	1.00E-03	9.36E+00	1.24E-04	1.02E-04	4.00E-03	1.51E-01	4.70E-05	2.06E+03	0.00E+00	1.14E-01
BATCH-453	7/30/24	117	12.2	0.24	6.67E-08	1.35E+01	5.07E-01	0.00E+00	0.00E+00	1.87E-04	2.72E+00	1.12E-05	6.02E-06	1.95E-04	3.40E-02	2.75E-06	1.99E+03	0.00E+00	5.40E-02
BATCH-454	8/6/24	116	12.0	0.24	7.01E-08	1.31E+01	4.96E-01	0.00E+00	0.00E+00	1.72E-04	2.64E+00	1.11E-05	6.09E-06	1.95E-04	3.40E-02	2.78E-06	1.97E+03	0.00E+00	5.30E-02
BATCH-455	8/11/24	134	14.0	0.24	1.06E-06	8.11E+01	8.50E-02	0.00E+00	0.00E+00	7.04E-05	9.79E+00	4.58E-05	8.53E-05	7.00E-03	5.96E-01	2.29E-05	2.30E+03	0.00E+00	5.30E-02
BATCH-456	8/19/24	88	9.2	0.24	6.94E-07	5.32E+01	5.50E-02	0.00E+00	0.00E+00	4.18E-05	6.40E+00	2.96E-05	5.56E-05	5.00E-03	3.91E-01	1.48E-05	1.50E+03	0.00E+00	3.40E-02
BATCH-457	8/25/24	107	11.2	0.24	8.44E-07	6.48E+01	6.70E-02	0.00E+00	0.00E+00	5.08E-05	7.79E+00	3.60E-05	6.77E-05	6.00E-03	4.76E-01	1.81E-05	1.83E+03	0.00E+00	4.20E-02
BATCH-458	8/28/24	94	9.8	0.24	7.43E-07	5.70E+01	5.90E-02	0.00E+00	0.00E+00	4.48E-05	6.85E+00	3.17E-05	5.96E-05	5.00E-03	4.19E-01	1.59E-05	1.61E+03	0.00E+00	3.70E-02
BATCH-459	9/6/24	54	5.6	0.24	2.79E-08	5.66E+00	2.12E-01	0.00E+00	0.00E+00	7.83E-05	1.14E+00	4.67E-06	2.52E-06	8.14E-05	1.40E-02	1.15E-06	9.24E+02	0.00E+00	2.30E-02
BATCH-460	9/7/24	54	5.7	0.24	2.98E-08	5.59E+00	2.11E-01	0.00E+00	0.00E+00	7.32E-05	1.12E+00	4.71E-06	2.59E-06	8.30E-05	1.50E-02	1.19E-06	9.30E+02	0.00E+00	2.20E-02
BATCH-461	9/11/24	125	13.0	0.24	9.83E-07	7.54E+01	7.80E-02	0.00E+00	0.00E+00	5.84E-05	9.06E+00	4.18E-05	7.88E-05	6.00E-03	5.55E-01	2.10E-05	2.13E+03	0.00E+00	4.80E-02
BATCH-462	9/13/24	81	8.5	0.24	6.42E-07	4.93E+01	5.10E-02	0.00E+00	0.00E+00	3.82E-05	5.92E+00	2.73E-05	5.15E-05	4.00E-03	3.63E-01	1.37E-05	1.39E+03	0.00E+00	3.20E-02
BATCH-463	9/22/24	99	10.3	0.24	7.80E-07	5.99E+01	6.20E-02	0.00E+00	0.00E+00	4.64E-05	7.20E+00	3.32E-05	6.26E-05	5.00E-03	4.41E-01	1.67E-05	1.69E+03	0.00E+00	3.80E-02
BATCH-464	9/25/24	91	9.5	0.24	9.77E-08	3.10E+01	1.62E-01	0.00E+00	0.00E+00	5.80E-05	4.81E+00	4.44E-06	9.22E-06	6.58E-04	1.87E-01	2.08E-06	1.56E+03	0.00E+00	4.80E-02
BATCH-465	10/2/24	19	1.9	0.24	7.00E-09	1.42E+00	5.30E-02	0.00E+00	0.00E+00	1.97E-05	2.85E-01	1.17E-06	6.32E-07	2.04E-05	4.00E-03	2.89E-07	3.16E+02	0.00E+00	6.00E-03
BATCH-466	10/4/24	19	1.9	0.24	7.53E-09	1.41E+00	5.30E-02	0.00E+00	0.00E+00	1.85E-05	2.83E-01	1.19E-06	6.54E-07	2.10E-05	4.00E-03	2.99E-07	3.19E+02	0.00E+00	6.00E-03
BATCH-467	10/4/24	114	11.9	0.24	1.44E-07	1.50E+01	4.60E-01	0.00E+00	0.00E+00	1.15E-04	2.70E+00	1.40E-05	1.23E-05	6.35E-04	6.80E-02	4.71E-06	1.95E+03	0.00E+00	4.40E-02
BATCH-468	10/7/24	122	12.8	0.24	1.21E-09	3.66E+01	2.40E-01	0.00E+00	0.00E+00	8.11E-05	6.09E+00	4.91E-07	2.25E-06	2.67E-05	2.05E-01	1.14E-08	2.09E+03	0.00E+00	6.70E-02
BATCH-469	10/17/24	98	10.2	0.24	1.07E-09	2.91E+01	1.91E-01	0.00E+00	0.00E+00	6.47E-05	4.85E+00	3.96E-07	1.80E-06	2.20E-05	1.63E-01	1.14E-08	1.67E+03	0.00E+00	5.30E-02
BATCH-470	10/20/24	105	11.0	0.24	1.54E-07	1.28E+01	4.15E-01	0.00E+00	0.00E+00	1.59E-04	2.53E+00	2.10E-05	1.84E-05	8.04E-04	6.10E-02	7.78E-06	1.80E+03	0.00E+00	3.40E-02
BATCH-471	10/27/24	142	14.8	0.24	7.87E-10	4.22E+01	2.77E-01	0.00E+00	0.00E+00	9.38E-05	7.03E+00	5.42E-07	2.55E-06	2.69E-05	2.37E-01	4.85E-11	2.42E+03	0.00E+00	7.80E-02
BATCH-472	10/31/24	141	14.7	0.24	7.86E-10	4.22E+01	2.77E-01	0.00E+00	0.00E+00	9.38E-05	7.03E+00	5.41E-07	2.55E-06	2.68E-05	2.36E-01	5.06E-11	2.42E+03	0.00E+00	7.70E-02
BATCH-473	11/11/24	48	5.1	0.24	5.45E-08	5.69E+00	1.74E-01	0.00E+00	0.00E+00	4.36E-05	1.02E+00	5.30E-06	4.64E-06	2.40E-04	2.60E-02	1.78E-06	8.28E+02	0.00E+00	1.70E-02
BATCH-474	11/15/24	114	11.8	0.24	6.31E-10	3.39E+01	2.22E-01	0.00E+00	0.00E+00	7.53E-05	5.64E+00	4.34E-07	2.04E-06	2.15E-05	1.90E-01	6.67E-12	1.94E+03	0.00E+00	6.20E-02
BATCH-475	11/16/24	90	9.4	0.24	5.02E-10	2.70E+01	1.77E-01	0.00E+00	0.00E+00	5.99E-05	4.49E+00	3.46E-07	1.63E-06	1.71E-05	1.51E-01	8.33E-12	1.54E+03	0.00E+00	4.90E-02
BATCH-476	11/26/24	49	5.1	0.24	6.45E-08	5.36E+00	1.73E-01	0.00E+00	0.00E+00	6.62E-05	1.06E+00	8.77E-06	7.68E-06	3.36E-04	2.50E-02	3.25E-06	8.39E+02	0.00E+00	1.40E-02
BATCH-477	11/27/24	128	13.3	0.24	1.48E-08	1.54E+02	1.10E-01	0.00E+00	0.00E+00	8.00E-04	8.82E+00	9.07E-05	5.90E-06	5.28E-04	9.70E-02	1.47E-04	2.18E+03	0.00E+00	3.60E-02
BATCH-478	12/1/24	128	13.3	0.24	1.56E-08	1.60E+02	1.03E-01	0.00E+00	0.00E+00	1.00E-03	8.95E+00	9.54E-05	6.08E-06	5.54E-04	9.10E-02	1.55E-04	2.18E+03	0.00E+00	3.40E-02
BATCH-479	12/10/24	17	1.8	0.24	1.30E-08	1.36E+00	4.20E-02	0.00E+00	0.00E+00	1.04E-05	2.44E-01	1.27E-06	1.11E-06	5.74E-05	6.00E-03	4.26E-07	2.90E+02	0.00E+00	4.00E-03
BATCH-480	12/12/24	99	10.3	0.24	1.69E-07	1.31E+01	4.11E-01	0.00E+00	0.00E+00	1.53E-04	2.44E+00	2.21E-05	2.13E-05	1.00E-03	7.30E-02	8.72E-06	1.69E+03	0.00E+00	2.50E-02
BATCH-481	12/15/24	103	10.7	0.24	1.25E-08	1.29E+02	8.30E-02	0.00E+00	0.00E+00	8.00E-04	7.19E+00	7.66E-05	4.89E-06	4.45E-04	7.30E-02	1.24E-04	1.75E+03	0.00E+00	2.70E-02
BATCH-482	12/23/24	17	1.8	0.24	1.55E-08	1.28E+00	4.20E-02	0.00E+00	0.00E+00	1.59E-05	2.53E-01	2.10E-06	1.84E-06	8.05E-05	6.00E-03	7.79E-07	2.94E+02	0.00E+00	3.00E-03
BATCH-483	12/25/24	105	10.9	0.24	1.28E-08	1.31E+02	8.50E-02	0.00E+00	0.00E+00	8.00E-04	7.35E+00	7.83E-05	4.99E-06	4.55E-04	7.50E-02	1.27E-04	1.79E+03	0.00E+00	2.80E-02
BATCH-484	12/26/24	137	14.3	0.24	1.67E-08	1.72E+02	1.10E-01	0.00E+00	0.00E+00	1.00E-03	9.59E+00	1.02E-04	6.52E-06	5.94E-04	9.80E-02	1.66E-04	2.34E+03	0.00E+00	3.60E-02
BATCH-485	1/5/25	104	10.8	0.24	1.27E-08	1.30E+02	8.40E-02	0.00E+00	0.00E+00	8.00E-04	7.28E+00	7.77E-05	4.95E-06	4.51E-04	7.40E-02	1.26E-04	1.78E+03	0.00E+00	2.80E-02
BATCH-486	1/9/25	52	5.5	0.24	8.06E-08	6.24E+00	1.96E-01	0.00E+00	0.00E+00	7.27E-05	1.16E+00	1.05E-05	1.01E-05	4.80E-04	3.50E-02	4.15E-06	8.97E+02	0.00E+00	1.20E-02
BATCH-487	1/15/25	76	7.9	0.24	3.34E-08	9.81E+01	5.60E-02	0.00E+00	0.00E+00	6.00E-04	5.41E+00	5.71E-05	7.15E-06	3.37E-04	7.50E-02	9.94E-05	1.30E+03	0.00E+00	1.90E-02
BATCH-488	1/16/25	136	14.2	0.24	2.59E-07	1.97E+02	5.10E-02	0.00E+00	0.00E+00	6.00E-04	1.03E+01	1.04E-04	4.20E-05	6.57E-04	3.09E-01	2.36E-04	2.33E+03	0.00E+00	2.60E-02
BATCH-489	1/23/25	85	8.9	0.24	1.62E-07	1.23E+02	3.20E-02	0.00E+00	0.00E+00	4.00E-04	6.42E+00	6.51E-05	2.62E-05	4.10E-04	1.93E-01	1.47E-04	1.46E+03	0.00E+00	1.60E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUN kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-441	5/25/24	93	9.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-02	3.22E+01	4.03E-09	2.55E+00	3.19E+01	3.90E-02	1.38E-07	0.00E+00	1.27E-01	2.44E-05	1.00E-02
BATCH-442	6/3/24	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-02	3.25E+01	4.07E-09	2.57E+00	3.21E+01	3.90E-02	1.39E-07	0.00E+00	1.28E-01	2.46E-05	1.00E-02
BATCH-443	6/4/24	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	3.88E+01	1.39E-07	3.21E+00	3.89E+01	4.40E-02	2.00E-07	0.00E+00	1.41E-01	1.00E-03	1.30E-02
BATCH-444	6/13/24	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.70E+01	5.76E-10	4.56E+00	4.10E+00	2.00E-03	1.09E-08	0.00E+00	8.00E-03	9.01E-04	3.00E-03
BATCH-445	6/16/24	154	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-02	5.21E+01	1.64E-06	5.85E+00	5.76E+01	2.60E-02	6.43E-07	0.00E+00	6.40E-02	1.70E-02	2.20E-02
BATCH-446	6/19/24	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	4.58E+01	1.45E-06	5.15E+00	5.07E+01	2.30E-02	5.65E-07	0.00E+00	5.60E-02	1.50E-02	1.90E-02
BATCH-447	7/3/24	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.19E+01	1.01E-06	3.58E+00	3.53E+01	1.60E-02	3.93E-07	0.00E+00	3.90E-02	1.00E-02	1.30E-02
BATCH-448	7/3/24	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.22E+01	1.02E-06	3.62E+00	3.56E+01	1.60E-02	3.97E-07	0.00E+00	4.00E-02	1.00E-02	1.30E-02
BATCH-449	7/13/24	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	3.81E+01	1.20E-06	4.28E+00	4.21E+01	1.90E-02	4.70E-07	0.00E+00	4.70E-02	1.20E-02	1.60E-02
BATCH-450	7/13/24	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.03E+00	1.37E-10	1.08E+00	9.72E-01	3.62E-04	2.59E-09	0.00E+00	2.00E-03	2.14E-04	6.74E-04
BATCH-451	7/15/24	137	14.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	4.63E+01	1.46E-06	5.20E+00	5.12E+01	2.40E-02	5.71E-07	0.00E+00	5.70E-02	1.50E-02	1.90E-02
BATCH-452	7/25/24	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.80E-02	4.07E+01	1.28E-06	4.57E+00	4.50E+01	2.10E-02	5.02E-07	0.00E+00	5.00E-02	1.30E-02	1.70E-02
BATCH-453	7/30/24	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.02E+01	6.89E-08	1.63E+01	1.40E+01	9.00E-03	5.36E-08	0.00E+00	3.20E-02	7.72E-04	7.00E-03
BATCH-454	8/6/24	116	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	3.89E+01	6.91E-08	1.62E+01	1.40E+01	1.00E-02	5.67E-08	0.00E+00	3.40E-02	7.60E-04	6.00E-03
BATCH-455	8/11/24	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-01	9.47E+01	9.99E-07	1.33E+01	5.79E+01	6.00E-02	2.23E-07	0.00E+00	1.80E-01	3.00E-03	3.70E-02
BATCH-456	8/19/24	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	6.21E+01	6.51E-07	8.76E+00	3.79E+01	3.90E-02	1.45E-07	0.00E+00	1.18E-01	2.00E-03	2.40E-02
BATCH-457	8/25/24	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-02	7.56E+01	7.92E-07	1.07E+01	4.61E+01	4.80E-02	1.76E-07	0.00E+00	1.44E-01	2.00E-03	3.00E-02
BATCH-458	8/28/24	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	6.65E+01	6.97E-07	9.39E+00	4.06E+01	4.20E-02	1.55E-07	0.00E+00	1.26E-01	2.00E-03	2.60E-02
BATCH-459	9/6/24	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.68E+01	2.88E-08	6.81E+00	5.86E+00	4.00E-03	2.24E-08	0.00E+00	1.30E-02	3.23E-04	3.00E-03
BATCH-460	9/7/24	54	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.66E+01	2.94E-08	6.92E+00	5.96E+00	4.00E-03	2.41E-08	0.00E+00	1.50E-02	3.23E-04	3.00E-03
BATCH-461	9/11/24	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.30E-02	8.81E+01	9.22E-07	1.24E+01	5.37E+01	5.60E-02	2.05E-07	0.00E+00	1.67E-01	3.00E-03	3.40E-02
BATCH-462	9/13/24	81	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-02	5.76E+01	6.03E-07	8.12E+00	3.51E+01	3.60E-02	1.34E-07	0.00E+00	1.09E-01	2.00E-03	2.30E-02
BATCH-463	9/22/24	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-02	6.99E+01	7.32E-07	9.86E+00	4.26E+01	4.40E-02	1.62E-07	0.00E+00	1.33E-01	2.00E-03	2.70E-02
BATCH-464	9/25/24	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.96E+01	9.13E-08	2.40E+00	3.40E+01	4.80E-02	2.02E-08	0.00E+00	1.98E-01	2.93E-04	1.60E-02
BATCH-465	10/2/24	19	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.86E-04	4.22E+00	7.24E-09	1.71E+00	1.47E+00	9.52E-04	5.63E-09	0.00E+00	3.00E-03	8.10E-05	7.13E-04
BATCH-466	10/4/24	19	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.47E-04	4.18E+00	7.42E-09	1.75E+00	1.50E+00	1.00E-03	6.09E-09	0.00E+00	4.00E-03	8.16E-05	6.71E-04
BATCH-467	10/4/24	114	11.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.53E+01	1.42E-07	1.68E+01	1.64E+01	1.50E-02	8.11E-08	0.00E+00	5.30E-02	1.00E-03	6.00E-03
BATCH-468	10/7/24	122	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.81E+01	5.01E-10	1.83E+00	4.46E+01	6.60E-02	1.11E-10	0.00E+00	2.83E-01	1.65E-05	2.00E-02
BATCH-469	10/17/24	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.83E+01	4.99E-10	1.46E+00	3.56E+01	5.30E-02	1.11E-10	0.00E+00	2.25E-01	1.35E-05	1.60E-02
BATCH-470	10/20/24	105	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	3.31E+01	2.24E-07	1.45E+01	1.52E+01	1.10E-02	9.59E-08	0.00E+00	4.10E-02	2.00E-03	5.00E-03
BATCH-471	10/27/24	142	14.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.55E+01	1.22E-12	2.10E+00	5.16E+01	7.60E-02	9.45E-13	0.00E+00	3.27E-01	1.73E-05	2.30E-02
BATCH-472	10/31/24	141	14.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.55E+01	1.26E-12	2.10E+00	5.15E+01	7.60E-02	1.03E-12	0.00E+00	3.26E-01	1.73E-05	2.30E-02
BATCH-473	11/11/24	48	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.34E+01	5.36E-08	6.38E+00	6.20E+00	6.00E-03	3.07E-08	0.00E+00	2.00E-02	3.97E-04	2.00E-03
BATCH-474	11/15/24	114	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.46E+01	2.93E-13	1.69E+00	4.14E+01	6.10E-02	6.50E-14	0.00E+00	2.62E-01	1.39E-05	1.90E-02
BATCH-475	11/16/24	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	3.54E+01	3.66E-13	1.34E+00	3.29E+01	4.90E-02	8.11E-14	0.00E+00	2.08E-01	1.10E-05	1.50E-02
BATCH-476	11/26/24	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.38E+01	9.36E-08	6.04E+00	6.33E+00	5.00E-03	4.01E-08	0.00E+00	1.70E-02	8.42E-04	2.00E-03
BATCH-477	11/27/24	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	9.30E+01	1.21E-07	8.96E+00	8.69E+01	5.20E-02	2.36E-05	0.00E+00	6.10E-02	1.00E-03	6.00E-03
BATCH-478	12/1/24	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	9.52E+01	1.27E-07	9.32E+00	8.90E+01	5.10E-02	2.48E-05	0.00E+00	4.80E-02	1.00E-03	5.00E-03
BATCH-479	12/10/24	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.19E+00	1.28E-08	1.52E+00	1.48E+00	1.00E-03	7.33E-09	0.00E+00	5.00E-03	9.49E-05	5.28E-04
BATCH-480	12/12/24	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.55E+01	1.56E+01	1.55E+01	1.10E-02	9.18E-08	0.00E+00	4.50E-02	2.00E-03	6.00E-03	6.00E-03
BATCH-481	12/15/24	103	10.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.65E+01	1.02E-07	7.49E+00	7.15E+01	4.10E-02	1.99E-05	0.00E+00	3.90E-02	1.00E-03	4.00E-03
BATCH-482	12/23/24	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.31E+00	2.24E-08	1.45E+00	1.52E+00	1.00E-03	9.60E-09	0.00E+00	4.00E-03	2.02E-04	5.50E-04
BATCH-483	12/25/24	105	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.82E+01	1.04E-07	7.66E+00	7.31E+01	4.20E-02	2.04E-05	0.00E+00	4.00E-02	1.00E-03	4.00E-03
BATCH-484	12/26/24	137	14.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.02E+02	1.36E-07	1.00E+01	9.54E+01	5.40E-02	2.66E-05	0.00E+00	5.20E-02	1.00E-03	6.00E-03
BATCH-485	1/5/25	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.75E+01	1.04E-07	7.59E+00	7.25E+01	4.10E-02	2.02E-05	0.00E+00	3.90E-02	1.00E-03	4.00E-03
BATCH-486	1/9/25	52	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.69E+01	1.25E-07	7.44E+00	7.37E+00	5.00E-03	4.37E-08	0.00E+00	2.10E-02	1.00E-03	3.00E-03
BATCH-487	1/15/25	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	5.90E+01	8.51E-08	5.95E+00	5.35E+01	3.00E-02	1.50E-05	0.00E+00	3.40E-02	7.76E-04	4.00E-03
BATCH-488	1/16/25	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	1.24E+02	2.29E-07	1.39E+01	1.00E+02	5.00E-02	2.89E-05	0.00E+00	1.01E-01	2.00E-03	1.90E-02
BATCH-489	1/23/25	85	8.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	7.76E+01	1.43E-07	8.70E+00	6.25E+01	3.20E-02	1.81E-05	0.00E+00	6.30E-02	9.82E-04	1.20E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-490	1/30/25	111	11.6	0.24	0.00E+00	0.00E+00	1.59E-01	4.60E-02	1.23E+01	4.62E-01	2.23E+03	1.29E+00	2.05E-01	1.11E+01	1.88E-12	1.40E+00	5.00E-03	3.60E-01	1.45E-02
BATCH-491	2/1/25	18	1.8	0.24	0.00E+00	0.00E+00	6.00E-03	2.00E-03	4.62E-01	1.44E-02	1.65E+02	4.60E-02	7.00E-03	7.45E-01	1.36E-11	5.30E-02	1.91E-04	1.40E-02	5.00E-04
BATCH-492	2/3/25	85	8.8	0.24	0.00E+00	0.00E+00	1.21E-01	3.50E-02	9.35E+00	3.51E-01	1.69E+03	9.81E-01	1.56E-01	8.43E+00	1.43E-12	1.06E+00	4.00E-03	2.73E-01	1.10E-02
BATCH-493	2/11/25	127	13.3	0.24	0.00E+00	0.00E+00	5.70E-02	1.60E-02	4.38E+00	1.66E-01	1.98E+03	4.57E-01	7.20E-02	9.27E+00	4.93E-12	4.96E-01	2.00E-03	1.28E-01	5.50E-03
BATCH-494	2/12/25	118	12.3	0.24	0.00E+00	0.00E+00	1.68E-01	4.90E-02	1.30E+01	4.88E-01	2.36E+03	1.37E+00	2.17E-01	1.17E+01	1.99E-12	1.48E+00	6.00E-03	3.81E-01	1.55E-02
BATCH-495	2/24/25	117	12.2	0.24	0.00E+00	0.00E+00	4.00E-02	1.10E-02	3.11E+00	1.34E-01	1.55E+03	3.30E-01	5.30E-02	7.57E+00	4.49E-13	3.48E-01	1.00E-03	9.00E-02	4.75E-03
BATCH-496	2/24/25	136	14.2	0.24	0.00E+00	0.00E+00	1.94E-01	5.70E-02	1.50E+01	5.63E-01	2.72E+03	1.57E+00	2.50E-01	1.35E+01	2.30E-12	1.70E+00	7.00E-03	4.39E-01	1.78E-02
BATCH-497	3/9/25	90	9.4	0.24	0.00E+00	0.00E+00	1.40E-01	4.10E-02	1.08E+01	3.78E-01	1.80E+03	1.13E+00	1.78E-01	8.96E+00	1.29E-12	1.24E+00	5.00E-03	3.17E-01	1.18E-02
BATCH-498	3/11/25	118	12.3	0.24	0.00E+00	0.00E+00	4.00E-02	1.10E-02	3.12E+00	1.38E-01	1.57E+03	3.32E-01	5.30E-02	7.74E+00	4.66E-13	3.49E-01	1.00E-03	9.00E-02	4.75E-03
BATCH-499	3/19/25	56	5.9	0.24	0.00E+00	0.00E+00	2.30E-02	6.00E-03	1.77E+00	6.66E-02	8.01E+02	1.84E-01	2.90E-02	3.74E+00	1.99E-12	2.00E-01	7.84E-04	5.20E-02	2.25E-03
BATCH-500	3/23/25	99	10.3	0.24	0.00E+00	0.00E+00	2.07E-01	6.00E-02	1.60E+01	4.39E-01	1.98E+03	1.63E+00	2.51E-01	9.86E+00	3.56E-13	1.87E+00	7.00E-03	4.72E-01	1.33E-02
BATCH-501	3/25/25	53	5.5	0.24	0.00E+00	0.00E+00	1.60E-02	4.00E-03	1.26E+00	5.40E-02	6.29E+02	1.33E-01	2.10E-02	3.06E+00	1.82E-13	1.41E-01	5.76E-04	3.60E-02	2.00E-03
BATCH-502	3/30/25	114	11.9	0.24	0.00E+00	0.00E+00	2.39E-01	6.90E-02	1.85E+01	5.07E-01	2.29E+03	1.88E+00	2.90E-01	1.14E+01	4.11E-13	2.16E+00	8.00E-03	5.44E-01	1.53E-02
BATCH-503	4/3/25	77	8.1	0.24	0.00E+00	0.00E+00	1.61E-01	4.70E-02	1.25E+01	3.43E-01	1.54E+03	1.27E+00	1.96E-01	7.69E+00	2.78E-13	1.46E+00	5.00E-03	3.68E-01	1.03E-02
BATCH-504	4/11/25	53	5.5	0.24	0.00E+00	0.00E+00	1.60E-02	4.00E-03	1.26E+00	5.49E-02	6.33E+02	1.34E-01	2.10E-02	3.11E+00	1.87E-13	1.41E-01	5.78E-04	3.60E-02	2.00E-03
BATCH-505	4/11/25	21	2.1	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.09E-01	1.89E-02	2.30E+02	5.30E-02	8.00E-03	1.08E+00	5.72E-15	5.80E-02	2.26E-04	1.50E-02	7.50E-04
BATCH-506	4/14/25	18	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.10E-01	1.35E-02	1.55E+02	3.30E-02	5.00E-03	7.54E-01	4.47E-14	3.50E-02	1.42E-04	9.00E-03	5.00E-04
BATCH-507	4/16/25	91	9.5	0.24	0.00E+00	0.00E+00	1.91E-01	5.50E-02	1.48E+01	4.05E-01	1.83E+03	1.50E+00	2.31E-01	9.10E+00	3.28E-13	1.72E+00	6.00E-03	4.35E-01	1.20E-02
BATCH-508	4/17/25	116	12.0	0.24	0.00E+00	0.00E+00	5.40E-02	1.50E-02	4.16E+00	1.65E-01	1.89E+03	4.40E-01	7.00E-02	9.01E+00	5.80E-13	4.70E-01	2.00E-03	1.21E-01	5.50E-03
BATCH-509	4/25/25	105	11.0	0.24	0.00E+00	0.00E+00	2.20E-01	6.40E-02	1.71E+01	4.67E-01	2.11E+03	1.74E+00	2.67E-01	1.05E+01	3.78E-13	1.99E+00	7.00E-03	5.02E-01	1.40E-02
BATCH-510	4/29/25	131	13.7	0.24	0.00E+00	0.00E+00	2.74E-01	8.00E-02	2.13E+01	5.82E-01	2.63E+03	2.18E+00	3.33E-01	1.31E+01	4.71E-13	2.48E+00	9.00E-03	6.26E-01	1.75E-02
BATCH-511	5/7/25	18	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.11E-01	1.35E-02	1.56E+02	3.30E-02	5.00E-03	7.70E-01	4.63E-14	3.50E-02	1.43E-04	9.00E-03	5.00E-04
BATCH-512	5/9/25	131	13.7	0.24	0.00E+00	0.00E+00	2.37E-01	6.80E-02	1.84E+01	5.06E-01	2.62E+03	1.84E+00	2.85E-01	1.31E+01	4.05E-13	2.13E+00	8.00E-03	5.40E-01	1.55E-02
BATCH-513	5/13/25	95	9.9	0.24	0.00E+00	0.00E+00	9.80E-02	2.70E-02	7.61E+00	2.14E-01	1.09E+03	6.99E-01	1.11E-01	9.42E+00	1.62E-13	8.60E-01	3.00E-03	2.21E-01	7.00E-03
BATCH-514	5/22/25	48	5.1	0.24	0.00E+00	0.00E+00	2.00E-02	6.00E-03	1.55E+00	6.12E-02	7.04E+02	1.64E-01	2.60E-02	3.36E+00	2.16E-13	1.75E-01	7.00E-04	4.50E-02	2.00E-03
BATCH-515	5/23/25	109	11.4	0.24	0.00E+00	0.00E+00	1.13E-01	3.20E-02	8.78E+00	2.47E-01	2.18E+03	8.07E-01	1.28E-01	1.09E+01	1.87E-13	9.93E-01	4.00E-03	2.55E-01	8.25E-03
BATCH-516	5/28/25	147	15.4	0.24	0.00E+00	0.00E+00	1.53E-01	4.30E-02	1.19E+01	3.33E-01	2.95E+03	1.09E+00	1.72E-01	1.47E+01	2.52E-13	1.34E+00	5.00E-03	3.44E-01	1.10E-02
BATCH-517	6/4/25	136	14.2	0.24	0.00E+00	0.00E+00	1.41E-01	3.90E-02	1.10E+01	3.08E-01	2.72E+03	1.01E+00	1.59E-01	1.36E+01	2.33E-13	1.24E+00	5.00E-03	3.18E-01	1.03E-02
BATCH-518	6/12/25	92	9.6	0.24	0.00E+00	0.00E+00	5.20E-02	1.50E-02	4.03E+00	1.33E-01	1.65E+03	4.13E-01	6.50E-02	7.14E+00	3.83E-13	4.61E-01	2.00E-03	1.18E-01	4.25E-03
BATCH-519	6/18/25	131	13.7	0.24	0.00E+00	0.00E+00	1.36E-01	3.80E-02	1.05E+01	2.62E-03	9.68E-01	1.53E-01	1.31E+01	2.24E-13	1.19E+00	4.00E-03	9.75E-03		
BATCH-520	6/22/25	17	1.7	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	3.67E-01	1.44E-02	1.66E+02	3.90E-02	6.00E-03	7.94E-01	5.11E-14	4.10E-02	1.65E-04	1.10E-02	5.00E-04
BATCH-521	6/24/25	97	10.1	0.24	0.00E+00	0.00E+00	1.01E-01	2.80E-02	7.81E+00	2.20E-01	1.94E+03	7.17E-01	1.14E-01	9.68E+00	1.66E-13	8.83E-01	3.00E-03	2.27E-01	7.25E-03
BATCH-522	7/2/25	121	12.6	0.24	0.00E+00	0.00E+00	1.24E-01	3.40E-02	9.62E+00	3.30E-01	2.42E+03	9.85E-01	1.54E-01	1.21E+01	1.95E-13	1.09E+00	4.00E-03	2.82E-01	1.18E-02
BATCH-523	7/5/25	108	11.3	0.24	0.00E+00	0.00E+00	1.10E-01	2.90E-02	8.49E+00	3.60E-01	2.17E+03	9.86E-01	1.51E-01	1.08E+01	1.61E-13	9.64E-01	4.00E-03	2.51E-01	1.38E-02
BATCH-524	7/15/25	52	5.4	0.24	0.00E+00	0.00E+00	2.70E-02	8.00E-03	2.06E+00	6.84E-02	8.42E+02	2.11E-01	3.30E-02	3.64E+00	1.95E-13	2.35E-01	8.94E-04	6.00E-02	2.25E-03
BATCH-525	7/16/25	131	13.7	0.24	0.00E+00	0.00E+00	1.33E-01	3.50E-02	1.03E+01	4.36E-01	2.62E+03	1.19E+00	1.83E-01	1.31E+01	1.95E-13	1.17E+00	5.00E-03	3.04E-01	1.65E-02
BATCH-526	7/20/25	104	10.9	0.24	0.00E+00	0.00E+00	1.06E-01	2.80E-02	8.17E+00	3.47E-01	2.09E+03	9.49E-01	1.46E-01	1.04E+01	1.55E-13	9.28E-01	4.00E-03	2.42E-01	1.33E-02
BATCH-527	7/30/25	83	8.6	0.24	0.00E+00	0.00E+00	4.60E-02	1.30E-02	3.55E+00	1.10E-01	1.44E+03	3.55E-01	5.60E-02	5.69E+00	2.27E-13	4.07E-01	2.00E-03	1.04E-01	3.50E-03
BATCH-528	8/1/25	97	10.2	0.24	0.00E+00	0.00E+00	9.90E-02	2.60E-02	7.63E+00	3.23E-01	1.95E+03	8.86E-01	1.36E-01	9.70E+00	1.45E-13	8.66E-01	4.00E-03	2.26E-01	1.23E-02
BATCH-529	8/8/25	88	9.2	0.24	0.00E+00	0.00E+00	8.90E-02	2.40E-02	6.88E+00	2.92E-01	1.76E+03	7.99E-01	1.23E+00	8.75E+00	1.31E-13	7.81E-01	3.00E-03	2.04E-01	1.10E-02
BATCH-530	8/11/25	18	1.9	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.25E-01	1.71E-02	2.15E+02	5.40E-02	8.00E-03	9.30E-01	4.99E-14	6.00E-02	2.28E-04	1.50E-02	5.00E-04
BATCH-531	8/13/25	106	11.1	0.24	0.00E+00	0.00E+00	1.08E-01	2.80E-02	8.32E+00	3.53E-01	2.13E+03	9.67E-01	1.48E-01	1.06E+01	1.58E-13	9.45E-01	4.00E-03	2.46E-01	1.35E-02
BATCH-532	8/17/25	84	8.8	0.24	0.00E+00	0.00E+00	9.50E-02	2.60E-02	7.34E+00	2.79E-01	1.69E+03	7.82E-01	1.22E-01	8.41E+00	3.05E-13	8.35E-01	3.00E-03	2.16E-01	9.25E-03
BATCH-533	8/24/25	52	5.5	0.24	0.00E+00	0.00E+00	2.60E-02	8.00E-03	2.04E+00	6.30E-02	8.24E+02	2.04E-01	3.20E-02	3.38E+00	1.30E-13	2.33E-01	8.71E-04	6.00E-02	2.00E-03
BATCH-534	8/26/25	91	9.5	0.24	0.00E+00	0.00E+00	1.13E-01	3.20E-02	8.78E+00	3.00E-01	1.82E+03	8.62E-01	1.36E-01	9.09E+00	5.38E-13	1.00E+00	4.00E-03	2.58E-01	8.50E-03
BATCH-535	8/30/25	151	15.8	0.24	0.00E+00	0.00E+00	1.88E-01	5.30E-02	1.45E+01	4.96E-01	3.02E+03	1.43E+00	2.26E-01	1.50E+01	8.91E-13	1.66E+00	6.00E-03	4.26E-01	1.40E-02
BATCH-536	9/5/25	107	11.1	0.24	0.00E+00	0.00E+00	4.70E-02	1.30E-02	3.61E+00	1.29E-01	1.84E+03	3.88E-01	6.00E-02	8.56E+00	7.33E-14	4.13E-01	2.00E-03	1.06E-01	4.50E-03
BATCH-537	9/15/25	100	10.4	0.24	0.00E+00	0.00E+00	1.24E-01	3.50E-02	9.60E+00	3.28E-01	2.00E+03	9.42E-01	1.49E-01	9.94E+00	5.89E-13	1.09E+00	4.00E-03	2.82E-01	9.25E-03
BATCH-538	9/16/25	114	11.9	0.24	0.00E+00	0.00E+00	5.50E-02	1.50E-02	4.28E+00	1.48E-01	2.10E+03	4.55E-01	7.00E-02	9.64E+00	9.25E-14	4.89E-01	2.00E-03	1.26E-01	5.25E-03

Appendix A Nominal ILAW Inventory

TWRS08UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-490	1/30/25	111	11.6	0.24	2.53E-07	3.34E+02	6.46E+02	5.60E-02	3.53E+00	2.13E-01	4.00E-03	2.32E-05	7.71E-04	3.42E-04	3.48E-04	8.31E-04	3.50E-02	1.81E-01	6.10E-02
BATCH-491	2/1/25	18	1.8	0.24	1.82E-08	5.28E+01	2.47E+01	2.00E-03	1.33E-01	8.00E-03	3.60E-02	8.95E-07	2.18E-05	1.01E-05	1.22E-05	2.61E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-492	2/3/25	85	8.8	0.24	1.92E-07	2.54E+02	4.91E+02	4.30E-02	2.68E+00	1.62E-01	3.00E-03	1.76E-05	5.86E-04	2.60E-04	2.64E-04	6.31E-04	2.70E-02	1.38E-01	4.70E-02
BATCH-493	2/11/25	127	13.3	0.24	9.37E-08	3.82E+02	2.28E+02	1.90E-02	1.24E+00	7.50E-02	1.30E-02	8.23E-06	2.57E-04	1.15E-04	1.24E-04	2.83E-04	1.20E-02	6.30E-02	2.20E-02
BATCH-494	2/12/25	118	12.3	0.24	2.68E-07	3.53E+02	6.84E+02	5.90E-02	3.73E+00	2.26E-01	5.00E-03	2.46E-05	8.17E-04	3.62E-04	3.68E-04	8.79E-04	3.70E-02	1.92E-01	6.50E-02
BATCH-495	2/24/25	117	12.2	0.24	7.23E-08	3.51E+02	1.60E+02	1.30E-02	8.59E-01	5.10E-02	1.00E-03	5.76E-06	2.16E-04	9.10E-05	8.91E-05	2.11E-04	8.00E-03	4.10E-02	1.60E-02
BATCH-496	2/24/25	136	14.2	0.24	3.08E-07	4.07E+02	7.88E+02	6.80E-02	4.30E+00	2.60E-01	5.00E-03	2.83E-05	9.41E-04	4.17E-04	4.24E-04	1.00E-03	4.30E-02	2.21E-01	7.50E-02
BATCH-497	3/9/25	90	9.4	0.24	2.08E-07	2.70E+02	5.72E+02	5.00E-02	3.13E+00	1.90E-01	3.00E-03	2.06E-05	6.34E-04	2.88E-04	3.02E-04	7.16E-04	3.20E-02	1.65E-01	5.30E-02
BATCH-498	3/11/25	118	12.3	0.24	7.34E-08	3.55E+02	1.61E+02	1.30E-02	8.60E-01	5.10E-02	1.00E-03	5.77E-06	2.18E-04	9.16E-05	8.99E-05	2.12E-04	8.00E-03	4.00E-02	1.60E-02
BATCH-499	3/19/25	56	5.9	0.24	3.78E-08	1.68E+02	9.22E+01	8.00E-03	5.01E-01	3.00E-02	5.00E-03	3.32E-06	1.04E-04	4.66E-05	5.00E-05	1.14E-04	5.00E-03	2.60E-02	9.00E-03
BATCH-500	3/23/25	99	10.3	0.24	2.44E-07	2.97E+02	8.60E+02	7.70E-02	4.74E+00	2.90E-01	1.73E-05	3.11E-05	7.48E-04	3.75E-04	4.29E-04	9.93E-04	5.20E-02	2.68E-01	7.70E-02
BATCH-501	3/25/25	53	5.5	0.24	2.93E-08	1.58E+02	6.48E+01	5.00E-03	3.48E-01	2.10E-02	4.18E-04	2.33E-06	8.74E-05	3.68E-05	4.33E-04	4.95E-04	3.00E-03	1.60E-02	7.00E-03
BATCH-502	3/30/25	114	11.9	0.24	2.81E-07	3.43E+02	9.92E+02	8.90E-02	5.47E+00	3.35E-01	1.95E-05	3.59E-05	8.63E-04	4.33E-04	4.95E-04	1.00E-03	6.00E-02	3.10E-01	8.90E-02
BATCH-503	4/3/25	77	8.1	0.24	1.90E-07	2.32E+02	6.71E+02	6.00E-02	3.69E+00	2.26E-01	1.35E-05	2.43E-05	5.84E-04	2.92E-04	3.34E-04	7.74E-04	4.10E-02	2.09E-01	6.00E-02
BATCH-504	4/11/25	53	5.5	0.24	2.95E-08	1.59E+02	6.46E+01	5.00E-03	3.46E-01	2.00E-02	4.34E-04	2.32E-06	8.79E-05	3.69E-05	3.62E-05	8.52E-05	3.00E-03	1.60E-02	7.00E-03
BATCH-505	4/11/25	21	2.1	0.24	1.09E-08	6.16E+01	2.65E+01	2.00E-03	1.44E-01	9.00E-03	1.00E-03	9.56E-07	2.99E-05	1.34E-05	1.44E-05	3.29E-05	1.00E-03	7.00E-03	3.00E-03
BATCH-506	4/14/25	18	1.9	0.24	7.20E-09	5.40E+01	1.59E+01	1.00E-03	8.60E-02	5.00E-03	1.03E-04	5.73E-07	2.15E-05	9.06E-06	8.87E-06	2.10E-05	7.84E-04	4.00E-03	2.00E-03
BATCH-507	4/16/25	91	9.5	0.24	2.25E-07	2.74E+02	7.93E+02	7.10E-02	4.37E+00	2.68E-01	1.33E-05	2.87E-05	6.90E-04	3.46E-04	3.96E-04	9.16E-04	4.80E-02	2.47E-01	7.10E-02
BATCH-508	4/17/25	116	12.0	0.24	8.84E-08	3.46E+02	2.17E+02	1.80E-02	1.17E+00	7.00E-02	1.00E-03	7.79E-06	2.65E-04	1.16E-04	1.19E-04	2.77E-04	1.10E-02	5.80E-02	2.10E-02
BATCH-509	4/25/25	105	11.0	0.24	2.59E-07	3.16E+02	9.15E+02	8.20E-02	5.04E+00	3.09E-01	1.54E-05	3.31E-05	7.96E-04	3.99E-04	4.56E-04	1.00E-03	5.50E-02	2.85E-01	8.20E-02
BATCH-510	4/29/25	131	13.7	0.24	3.23E-07	3.94E+02	1.14E+03	1.02E-01	6.28E+00	3.85E-01	1.95E-05	4.13E-05	9.92E-04	4.97E-04	5.69E-04	1.00E-03	6.90E-02	3.56E-01	1.03E-01
BATCH-511	5/7/25	18	1.9	0.24	7.30E-09	5.42E+01	1.60E+01	1.00E-03	8.60E-02	5.00E-03	1.07E-04	5.74E-07	2.17E-05	9.11E-06	8.95E-06	2.11E-05	7.73E-04	4.00E-03	2.00E-03
BATCH-512	5/9/25	131	13.7	0.24	2.82E-07	3.94E+02	9.78E+02	8.80E-02	5.40E+00	3.32E-01	1.67E-05	3.55E-05	9.24E-04	4.49E-04	4.83E-04	1.00E-03	6.30E-02	3.24E-01	9.00E-02
BATCH-513	5/13/25	95	9.9	0.24	1.22E-07	2.84E+02	3.87E+02	3.60E-02	2.15E+00	1.35E-01	7.09E-06	1.42E-05	5.32E-04	2.29E-04	1.81E-04	5.63E-04	3.30E-02	1.72E-01	4.10E-02
BATCH-514	5/22/25	48	5.1	0.24	3.30E-08	1.45E+02	8.10E+01	7.00E-03	4.38E+01	2.60E-02	4.92E-04	2.91E-06	9.89E-05	4.32E-05	4.42E-05	1.03E-04	4.00E-03	2.20E-02	8.00E-03
BATCH-515	5/23/25	108	11.4	0.24	1.41E-07	3.28E+02	4.47E+02	4.10E-02	2.48E+00	1.56E-01	8.18E-06	1.64E-05	6.14E-04	2.64E-04	2.09E-04	6.49E-04	3.80E-02	1.98E-01	4.80E-02
BATCH-516	5/28/25	147	15.4	0.24	1.90E-07	4.42E+02	6.03E+02	5.50E-02	3.35E+00	2.10E-01	1.11E-05	2.21E-05	8.29E-04	3.56E-04	2.81E-04	8.76E-04	5.20E-02	2.67E-01	6.40E-02
BATCH-517	6/4/25	136	14.2	0.24	1.76E-07	4.09E+02	5.57E+02	5.10E-02	3.10E+00	1.94E-01	1.02E-05	2.05E-05	7.66E-04	3.29E-04	2.60E-04	8.10E-04	4.80E-02	2.47E-01	5.90E-02
BATCH-518	6/12/25	92	9.6	0.24	7.37E-08	2.76E+02	2.12E+02	1.90E-02	1.17E+00	7.10E-02	7.90E-04	7.67E-06	2.35E-04	1.07E-04	1.10E-04	2.68E-04	1.30E-02	6.60E-02	2.00E-02
BATCH-519	6/18/25	131	13.7	0.24	1.69E-07	3.93E+02	5.36E+02	4.90E-02	2.98E+00	1.87E-01	9.81E-06	1.97E-05	7.37E-04	3.17E-04	2.50E-04	7.79E-04	4.60E-02	2.38E-01	5.70E-02
BATCH-520	6/22/25	17	1.7	0.24	7.79E-09	5.02E+01	1.91E+01	2.00E-03	1.03E-01	6.00E-03	1.16E-04	6.87E-07	2.33E-05	1.02E-05	1.04E-05	2.44E-05	9.92E-04	5.00E-03	2.00E-03
BATCH-521	6/24/25	97	10.1	0.24	1.25E-07	2.91E+02	3.97E+02	3.70E-02	2.21E+00	1.39E-01	7.27E-06	1.46E-05	5.46E-04	2.35E-04	1.85E-04	5.77E-04	3.40E-02	1.76E-01	4.20E-02
BATCH-522	7/2/25	121	12.6	0.24	1.76E-07	3.63E+02	4.98E+02	4.10E-02	2.65E+00	1.56E-01	1.14E-05	1.80E-05	5.04E-04	2.34E-04	2.57E-04	5.94E-04	3.50E-02	1.80E-01	5.40E-02
BATCH-523	7/5/25	108	11.3	0.24	1.80E-07	3.25E+02	4.49E+02	3.30E-02	2.27E+00	1.21E-01	1.28E-05	1.60E-05	2.50E-04	1.43E-04	2.61E-04	3.90E-04	2.30E-02	1.16E-01	5.10E-02
BATCH-524	7/15/25	52	5.4	0.24	3.76E-08	1.56E+02	1.08E+02	1.00E-02	5.95E-01	3.60E-02	4.03E-04	3.91E-06	1.20E-04	5.47E-05	5.60E-05	1.37E-04	7.00E-03	3.40E-02	1.00E-02
BATCH-525	7/16/25	131	13.7	0.24	2.18E-07	3.94E+02	5.44E+02	3.90E-02	2.75E+00	1.46E-01	1.55E-05	1.93E-05	3.02E-04	1.73E-04	3.16E-04	4.72E-04	2.70E-02	1.41E-01	6.20E-02
BATCH-526	7/20/25	104	10.9	0.24	1.73E-07	3.13E+02	4.32E+02	3.10E-02	2.19E+00	1.16E-01	1.23E-05	1.54E-05	2.41E-04	1.38E-04	2.51E-04	3.76E-04	2.20E-02	1.12E-01	4.90E-02
BATCH-527	7/30/25	83	8.6	0.24	6.09E-08	2.47E+02	1.87E+02	1.70E-02	1.03E+00	6.30E-02	4.02E-04	6.76E-06	2.07E-04	9.46E-05	9.38E-05	2.38E-04	1.20E-02	6.30E-02	1.80E-02
BATCH-528	8/1/25	97	10.2	0.24	1.62E-07	2.92E+02	4.04E+02	2.90E-02	2.04E+00	1.09E-01	1.15E-05	1.44E-05	2.25E-04	1.29E-04	2.34E-04	3.51E-04	2.00E-02	1.05E-01	4.60E-02
BATCH-529	8/8/25	88	9.2	0.24	1.46E-07	2.63E+02	3.64E+02	2.60E-02	1.84E+00	9.80E-02	1.04E-05	1.30E-05	2.02E-04	1.16E-04	2.11E-04	3.16E-04	1.80E-02	9.40E-02	4.10E-02
BATCH-530	8/11/25	18	1.9	0.24	9.60E-09	5.46E+01	2.77E+01	2.00E-03	1.52E-01	9.00E-03	1.03E-04	9.99E-07	3.06E-05	1.40E-05	1.43E-05	3.49E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-531	8/13/25	106	11.1	0.24	1.76E-07	3.19E+02	4.40E+02	3.20E-02	2.23E+00	1.18E-01	1.26E-05	1.57E-05	2.45E-04	1.40E-04	2.56E-04	3.83E-04	2.20E-02	1.14E-01	5.00E-02
BATCH-532	8/17/25	84	8.8	0.24	1.39E-07	2.53E+02	3.80E+02	3.10E-02	2.02E+00	1.16E-01	3.22E-04	1.36E-05	3.17E-04	1.54E-04	2.06E-04	4.00E-04	2.60E-02	1.36E-01	4.20E-02
BATCH-533	8/24/25	52	5.5	0.24	3.49E-08	1.57E+02	1.07E+02	1.00E-02	5.89E-01	3.60E-02	2.30E-04	3.88E-06	1.19E-04	5.42E-05	5.38E-05	1.37E-04	7.00E-03	3.60E-02	1.00E-02
BATCH-534	8/26/25	91	9.5	0.24	1.50E-07	2.74E+02	4.46E+02	4.00E-02	2.48E+00	1.52E-01	7.10E-04	1.61E-05	4.85E-04	2.15E-04	2.26E-04	5.43E-04	3.90E-02	1.99E-01	4.90E-02
BATCH-535	8/30/25	151	15.8	0.24	2.48E-07	4.53E+02	7.39E+02	6.60E-02	4.11E+00	2.51E-01	1.00E-03	2.66E-05	8.03E-04	3.55E-04	3.74E-04	8.99E-04	6.40E-02	3.30E-01	8.10E-02
BATCH-536	9/5/25	107	11.1	0.24	6.71E-08	3.20E+02	1.90E+02	1.50E-02	1.00E+00	5.80E-02	4.47E-06	6.84E-06	1.52E-04	7.66E-05	1.02E-04	2.01E-04	1.10E-02	5.90E-02	2.00E-02
BATCH-537	9/15/25	100	10.4	0.24	1.64E-07	2.99E+02	4.88E+02	4.40E-02	2.72E+00	1.66E-01	7.76E-04	1.76E-05	5.30E-04	2.35E-04	2.47E-04	5.94E-04	4.20E-02	2.18E-01	5.40E-02
BATCH-538	9/16/25	114	11.9	0.24	7.76E-08	3.42E+02	2.25E+02	1.80E-02	1.20E+00	6.90E-02	1.45E-05	8.11E-06	1.84E-04	9.24E-05	1.20E-04	2.43E-04	1.40E-02	7.10E-02	2.30E-02

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-490	1/30/25	111	11.6	0.24	2.00E-03	2.00E-03	6.90E-02	7.80E-02	6.80E-02	3.49E+00	5.85E-01	4.36E+00	1.50E+00	5.03E-23	3.62E-05	1.54E-04	2.00E-03	1.10E-02	8.88E-06
BATCH-491	2/1/25	18	1.8	0.24	9.43E-05	6.81E-05	2.00E-03	3.00E-03	3.00E-03	1.33E-01	2.20E-02	1.70E-01	5.60E-02	1.66E-24	1.37E-06	6.27E-06	7.95E-05	3.69E-04	7.26E-06
BATCH-492	2/3/25	85	8.8	0.24	2.00E-03	1.00E-03	5.30E-02	5.90E-02	5.20E-02	2.65E+00	4.45E-01	3.31E+00	1.14E+00	3.82E-23	2.75E-05	1.17E-04	1.00E-03	8.00E-03	6.75E-06
BATCH-493	2/11/25	127	13.3	0.24	9.18E-04	6.68E-04	2.50E-02	2.90E-02	2.50E-02	1.32E+00	2.19E-01	1.80E+00	5.47E-01	2.45E-23	1.33E-05	5.91E-05	7.21E-04	5.00E-03	1.08E-05
BATCH-494	2/12/25	118	12.3	0.24	3.00E-03	2.00E-03	7.30E-02	8.20E-02	7.20E-02	3.69E+00	6.19E-01	4.61E+00	1.58E+00	5.32E-23	3.84E-05	1.63E-04	2.00E-03	1.20E-02	9.40E-06
BATCH-495	2/24/25	117	12.2	0.24	6.68E-04	4.77E-04	1.80E-02	2.00E-02	1.80E-02	9.68E-01	1.58E-01	1.40E+00	3.82E-01	2.38E-23	9.17E-06	4.29E-05	6.97E-04	5.00E-03	8.73E-07
BATCH-496	2/24/25	136	14.2	0.24	3.00E-03	2.00E-03	8.40E-02	9.50E-02	8.30E-02	4.26E+00	7.13E-01	5.31E+00	1.82E+00	6.13E-23	4.42E-05	1.88E-04	2.00E-03	1.40E-02	1.08E-05
BATCH-497	3/9/25	90	9.4	0.24	2.00E-03	2.00E-03	6.00E-02	7.00E-02	6.00E-02	3.10E+00	5.22E-01	3.77E+00	1.35E+00	3.92E-23	3.27E-05	1.35E-04	1.00E-03	9.00E-03	5.79E-06
BATCH-498	3/11/25	118	12.3	0.24	6.73E-04	4.79E-04	1.90E-02	2.00E-02	1.80E-02	9.70E-01	1.58E-01	1.42E+00	3.81E-01	2.46E-23	9.13E-06	4.32E-05	7.19E-04	5.00E-03	8.84E-07
BATCH-499	3/19/25	56	5.9	0.24	3.71E-04	2.70E-04	1.00E-02	1.20E-02	1.00E-02	5.34E-01	8.80E-02	7.27E-01	2.21E-01	9.88E-24	5.35E-06	2.39E-05	2.91E-04	2.00E-03	4.36E-06
BATCH-500	3/23/25	99	10.3	0.24	3.00E-03	2.00E-03	8.40E-02	1.09E-01	8.80E-02	4.73E+00	8.03E-01	5.32E+00	2.12E+00	3.65E-23	5.18E-05	1.99E-04	1.00E-03	9.00E-03	5.87E-09
BATCH-501	3/25/25	53	5.5	0.24	2.71E-04	1.93E-04	7.00E-03	8.00E-03	7.00E-03	3.92E-01	6.40E-02	5.68E-01	1.55E-01	9.63E-24	3.71E-06	1.74E-05	2.82E-04	2.00E-03	3.53E-07
BATCH-502	3/30/25	114	11.9	0.24	4.00E-03	3.00E-03	9.60E-02	1.26E-01	1.02E-01	5.46E+00	9.27E-01	6.14E+00	2.45E+00	4.21E-23	5.97E-05	2.29E-04	1.00E-03	1.00E-02	5.86E-09
BATCH-503	4/3/25	77	8.1	0.24	2.00E-03	2.00E-03	6.50E-02	8.50E-02	6.90E-02	3.69E+00	6.26E-01	4.15E+00	1.65E+00	2.84E-23	4.04E-05	1.55E-04	9.22E-04	7.00E-03	4.63E-09
BATCH-504	4/11/25	53	5.5	0.24	2.71E-04	1.93E-04	7.00E-03	8.00E-03	7.00E-03	3.90E-01	6.30E-02	5.73E-01	1.53E-01	9.90E-24	3.68E-06	1.74E-05	2.89E-04	2.00E-03	3.56E-07
BATCH-505	4/11/25	21	2.1	0.24	1.07E-04	7.76E-05	3.00E-03	3.00E-03	3.00E-03	1.54E-01	2.50E-02	2.09E-01	6.40E-02	2.84E-24	1.54E-06	6.87E-06	8.37E-05	5.75E-04	1.25E-06
BATCH-506	4/14/25	18	1.9	0.24	6.66E-05	4.75E-05	2.00E-03	2.00E-03	2.00E-03	9.60E-02	1.60E-02	1.40E-01	3.80E-02	2.37E-24	9.13E-07	4.28E-06	6.94E-05	4.71E-04	8.69E-08
BATCH-507	4/16/25	91	9.5	0.24	3.00E-03	2.00E-03	7.70E-02	1.01E-01	8.20E-02	4.36E+00	7.41E-01	4.91E+00	1.95E+00	3.36E-23	4.78E-05	1.83E-04	1.00E-03	8.00E-03	3.27E-11
BATCH-508	4/17/25	116	12.0	0.24	8.62E-04	6.34E-04	2.40E-02	2.60E-02	2.30E-02	1.22E+00	2.02E-01	1.65E+00	5.07E-01	2.32E-23	1.22E-05	5.41E-05	6.85E-04	5.00E-03	1.89E-06
BATCH-509	4/25/25	105	11.0	0.24	3.00E-03	3.00E-03	8.90E-02	1.16E-01	9.40E-02	5.03E+00	8.55E-01	5.66E+00	2.25E+00	3.88E-23	5.51E-05	2.11E-04	1.00E-03	9.00E-03	3.66E-11
BATCH-510	4/29/25	131	13.7	0.24	4.00E-03	3.00E-03	1.11E-01	1.45E-01	1.17E-01	6.27E+00	1.07E+00	7.06E+00	2.81E+00	4.83E-23	6.87E-05	2.63E-04	2.00E-03	1.20E-02	2.95E-10
BATCH-511	5/7/25	18	1.9	0.24	6.69E-05	4.76E-05	2.00E-03	2.00E-03	2.00E-03	9.60E-02	1.60E-02	1.42E-01	3.80E-02	2.45E-24	9.09E-07	4.30E-06	7.15E-05	4.85E-04	8.80E-08
BATCH-512	5/9/25	131	13.7	0.24	4.00E-03	3.00E-03	9.50E-02	1.27E-01	1.03E-01	5.51E+00	9.36E-01	6.18E+00	2.47E+00	4.76E-23	6.03E-05	2.30E-04	2.00E-03	1.10E-02	6.40E-09
BATCH-513	5/13/25	95	9.9	0.24	2.00E-03	1.00E-03	3.70E-02	5.70E-02	4.70E-02	2.50E+00	4.22E-01	2.74E+00	1.11E+00	3.30E-23	2.71E-05	1.02E-04	1.00E-03	7.00E-03	1.72E-08
BATCH-514	5/22/25	48	5.1	0.24	3.22E-04	2.36E-04	9.00E-03	1.00E-02	9.00E-03	4.57E-01	7.50E-02	6.15E-01	1.89E-01	8.65E-24	4.57E-06	2.02E-05	2.56E-04	2.00E-03	7.06E-07
BATCH-515	5/23/25	109	11.4	0.24	2.00E-03	1.00E-03	4.30E-02	6.60E-02	5.40E-02	2.88E+00	4.88E-01	3.16E+00	1.29E+00	3.81E-23	3.13E-05	1.17E-04	1.00E-03	8.00E-03	1.98E-08
BATCH-516	5/28/25	147	15.4	0.24	3.00E-03	2.00E-03	5.80E-02	8.90E-02	7.30E-02	3.89E+00	6.58E-01	4.26E+00	1.73E+00	5.15E-23	4.23E-05	1.58E-04	2.00E-03	1.10E-02	2.68E-08
BATCH-517	6/4/25	136	14.2	0.24	2.00E-03	2.00E-03	5.40E-02	8.20E-02	6.70E-02	3.59E+00	6.08E-01	3.94E+00	1.60E+00	4.75E-23	3.91E-05	1.46E-04	2.00E-03	1.00E-02	2.47E-08
BATCH-518	6/12/25	92	9.6	0.24	8.16E-04	6.16E-04	2.20E-02	2.70E-02	2.30E-02	1.18E+00	1.99E-01	1.40E+00	5.16E-01	1.42E-23	1.25E-05	5.07E-05	4.38E-04	3.00E-03	1.62E-06
BATCH-519	6/18/25	131	13.7	0.24	2.00E-03	2.00E-03	5.20E-02	7.90E-02	6.50E-02	3.46E+00	5.85E-01	3.79E+00	1.54E+00	4.57E-23	3.76E-05	1.41E-04	1.00E-03	9.00E-03	2.38E-08
BATCH-520	6/22/25	17	1.7	0.24	7.59E-05	5.58E-05	2.00E-03	2.00E-03	2.00E-03	1.08E-01	1.80E-02	1.45E-01	4.50E-02	2.04E-24	1.08E-06	4.77E-06	6.03E-05	4.26E-04	1.67E-07
BATCH-521	6/24/25	97	10.1	0.24	2.00E-03	1.00E-03	3.80E-02	5.90E-02	4.80E-02	2.56E+00	4.33E-01	2.81E+00	1.14E+00	3.39E-23	2.78E-05	1.04E-04	1.00E-03	7.00E-03	1.77E-08
BATCH-522	7/2/25	121	12.6	0.24	2.00E-03	2.00E-03	5.40E-02	6.80E-02	5.90E-02	3.16E+00	5.24E-01	3.81E+00	1.30E+00	7.38E-23	3.15E-05	1.35E-04	2.00E-03	1.40E-02	2.09E-07
BATCH-523	7/5/25	108	11.3	0.24	2.00E-03	1.00E-03	5.50E-02	5.50E-02	5.30E-02	2.80E+00	4.50E-01	3.77E+00	1.03E+00	1.02E-22	2.45E-05	1.26E-04	3.00E-03	2.00E-02	4.00E-07
BATCH-524	7/15/25	52	5.4	0.24	4.16E-04	3.14E-04	1.10E-02	1.40E-02	1.10E-02	6.02E-01	1.01E-01	7.15E-01	2.63E-01	7.25E-24	6.40E-06	2.58E-05	2.24E-04	2.00E-03	8.26E-07
BATCH-525	7/16/25	131	13.7	0.24	3.00E-03	2.00E-03	6.60E-02	6.70E-02	6.40E-02	3.39E+00	5.45E-01	4.56E+00	1.25E+00	1.23E-22	2.97E-05	1.52E-04	4.00E-03	2.40E-02	4.84E-07
BATCH-526	7/20/25	104	10.9	0.24	2.00E-03	1.00E-03	5.30E-02	5.10E-02	5.30E-02	2.69E+00	4.33E-01	3.62E+00	9.95E-01	9.81E-23	2.36E-05	1.21E-04	3.00E-03	1.90E-02	3.85E-07
BATCH-527	7/30/25	83	8.6	0.24	7.25E-04	5.47E-04	1.90E-02	2.40E-02	2.00E-02	1.07E+00	1.80E-01	1.23E+00	4.71E-01	1.22E-23	1.15E-05	4.51E-05	3.83E-04	3.00E-03	8.22E-07
BATCH-528	8/1/25	97	10.2	0.24	2.00E-03	1.00E-03	4.90E-02	4.90E-02	4.80E-02	2.51E+00	4.05E-01	3.38E+00	9.28E-01	9.16E-23	2.20E-05	1.13E-04	3.00E-03	1.80E-02	3.59E-07
BATCH-529	8/8/25	88	9.2	0.24	2.00E-03	1.00E-03	4.40E-02	4.50E-02	4.30E-02	2.27E+00	3.65E-01	3.05E+00	8.37E-01	8.26E-23	1.99E-05	1.02E-04	2.00E-03	1.60E-02	3.24E-07
BATCH-530	8/11/25	18	1.9	0.24	1.06E-04	8.02E-05	3.00E-03	3.00E-03	3.00E-03	1.54E-01	2.60E-02	1.83E-01	6.70E-02	1.85E-24	1.63E-06	6.60E-06	5.71E-05	4.14E-04	2.11E-07
BATCH-531	8/13/25	106	11.1	0.24	2.00E-03	1.00E-03	5.40E-02	5.40E-02	5.20E-02	2.74E+00	4.41E-01	3.69E+00	1.01E+00	1.00E-22	2.40E-05	1.23E-04	3.00E-03	1.90E-02	3.92E-07
BATCH-532	8/17/25	84	8.8	0.24	2.00E-03	1.00E-03	4.20E-02	4.60E-02	4.50E-02	2.16E+00	3.57E-01	2.73E+00	8.79E-01	4.75E-23	2.12E-05	9.56E-05	1.00E-03	1.00E-02	2.30E-07
BATCH-533	8/24/25	52	5.5	0.24	4.16E-04	3.14E-04	1.10E-02	1.40E-02	1.20E-02	6.12E-01	1.03E-01	7.06E-01	2.70E-01	6.97E-24	6.58E-06	2.58E-05	2.19E-04	2.00E-03	4.71E-07
BATCH-534	8/26/25	91	9.5	0.24	2.00E-03	1.00E-03	4.40E-02	5.30E-02	5.40E-02	2.32E+00	3.94E-01	2.71E+00	1.04E+00	1.44E-23	2.54E-05	1.01E-04	4.52E-04	4.00E-03	1.54E-07
BATCH-535	8/30/25	151	15.8	0.24	3.00E-03	2.00E-03	7.30E-02	8.80E-02	8.90E-02	3.83E+00	6.52E-01	4.48E+00	1.72E+00	2.36E-23	4.20E-05	1.67E-04	7.45E-04	6.00E-03	2.54E-07
BATCH-536	9/5/25	107	11.1	0.24	8.23E-04	5.92E-04	2.10E-02	2.40E-02	2.20E-02	1.16E+00	1.91E-01	1.44E+00	4.67E-01	2.86E-23	1.12E-05	5.01E-05	8.37E-04	6.00E-03	9.28E-08
BATCH-537	9/15/25	100	10.4	0.24	2.00E-03	2.00E-03	4.80E-02	5.80E-02	5.90E-02	2.53E+00	4.31E-01	2.96E+00	1.14E+00	1.57E-23	2.78E-05	1.10E-04	4.94E-04	4.00E-03	1.68E-07
BATCH-538	9/16/25	114	11.9	0.24	9.59E-04	6.95E-04	2.40E-02	2.90E-02	2.60E-02	1.35E+00	2.24E-01	1.66E+00	5.54E-01	3.04E-23	1.34E-05	5.84E-05	8.96E-04	6.00E-03	9.66E-08

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-490	1/30/25	111	11.6	0.24	2.05E-06	2.76E+02	8.92E-07	2.00E-03	9.52E-07	2.13E-37	1.40E-02	5.99E-01	1.08E-05	7.00E-03	1.79E+01	0.00E+00	1.26E-07	1.07E+01	2.43E-04
BATCH-491	2/1/25	18	1.8	0.24	3.33E+01	0.00E+00	6.84E-06	3.71E-04	2.74E-06	4.30E-30	4.00E-03	1.62E-01	4.98E-06	3.62E-04	6.17E-01	0.00E+00	2.73E+00	0.00E+00	5.39E-05
BATCH-492	2/3/25	85	8.8	0.24	1.16E-12	2.10E+02	6.78E-07	1.00E-03	7.24E-07	1.27E-37	1.10E-02	4.55E-01	8.19E-06	6.00E-03	1.36E+01	0.00E+00	6.03E-14	8.11E+00	1.89E-04
BATCH-493	2/11/25	127	13.3	0.24	3.83E+02	0.00E+00	2.16E-05	3.00E-03	1.02E-05	3.66E-28	2.10E-02	1.35E+00	7.43E-06	3.00E-03	8.64E+00	0.00E+00	2.98E+01	0.00E+00	1.89E-04
BATCH-494	2/12/25	118	12.3	0.24	2.26E-06	2.93E+02	9.44E-07	2.00E-03	1.01E-06	7.21E-37	1.50E-02	6.34E-01	1.14E-05	8.00E-03	1.90E+01	0.00E+00	1.33E-07	1.13E+01	2.70E-04
BATCH-495	2/24/25	117	12.2	0.24	4.28E+02	0.00E+00	2.19E-07	3.09E-04	1.70E-07	8.18E-30	1.00E-02	4.98E-01	1.78E-06	2.00E-03	7.18E+00	0.00E+00	2.14E+01	0.00E+00	8.09E-05
BATCH-496	2/24/25	136	14.2	0.24	5.00E-03	3.37E+02	1.09E-06	2.00E-03	1.16E-06	6.26E-34	1.70E-02	7.30E-01	1.32E-05	9.00E-03	2.19E+01	0.00E+00	3.97E-04	1.30E+01	2.97E-04
BATCH-497	3/9/25	90	9.4	0.24	1.17E-09	2.16E+02	5.81E-07	1.00E-03	6.21E-07	1.22E-40	1.20E-02	5.20E-01	7.05E-06	6.00E-03	1.50E+01	0.00E+00	7.20E-11	8.83E+00	1.89E-04
BATCH-498	3/11/25	118	12.3	0.24	4.38E+02	0.00E+00	2.22E-07	3.10E-04	1.73E-07	3.07E-29	1.00E-02	4.88E-01	1.83E-06	2.00E-03	7.18E+00	0.00E+00	2.17E+01	0.00E+00	8.09E-05
BATCH-499	3/19/25	56	5.9	0.24	1.54E+02	0.00E+00	8.74E-06	1.00E-03	4.12E-06	1.48E-28	9.00E-03	5.44E-01	3.00E-06	1.00E-03	3.49E+00	0.00E+00	1.21E+01	0.00E+00	8.09E-05
BATCH-500	3/23/25	99	10.3	0.24	1.41E-09	2.02E+02	5.96E-10	4.51E-04	6.59E-10	4.48E-40	1.50E-02	7.41E-01	1.56E-07	9.00E-03	1.90E+01	0.00E+00	8.25E-11	1.07E+01	1.62E-04
BATCH-501	3/25/25	53	5.5	0.24	1.73E+02	0.00E+00	8.85E-08	1.25E-04	6.87E-08	3.31E-30	4.00E-03	2.01E-01	7.20E-07	7.40E-04	2.91E+00	0.00E+00	8.66E+00	0.00E+00	2.70E-05
BATCH-502	3/30/25	114	11.9	0.24	2.61E-06	2.33E+02	5.97E-10	5.20E-04	6.64E-10	3.37E-37	1.70E-02	8.55E-01	1.79E-07	1.00E-02	2.19E+01	0.00E+00	2.14E-07	1.24E+01	1.89E-04
BATCH-503	4/3/25	77	8.1	0.24	9.33E-13	1.58E+02	4.70E-10	3.52E-04	5.20E-10	9.67E-44	1.20E-02	5.78E-01	1.22E-07	7.00E-03	1.48E+01	0.00E+00	5.73E-14	8.36E+00	1.08E-04
BATCH-504	4/11/25	53	5.5	0.24	1.76E+02	0.00E+00	8.95E-08	1.25E-04	6.98E-08	1.24E-29	4.00E-03	1.96E-01	7.37E-07	7.20E-04	2.89E+00	0.00E+00	8.74E+00	0.00E+00	2.70E-05
BATCH-505	4/11/25	21	2.1	0.24	4.44E+01	0.00E+00	2.51E-06	3.67E-04	1.19E-06	4.25E-29	2.00E-03	1.56E-01	8.63E-07	3.32E-04	1.00E+00	0.00E+00	3.47E+00	0.00E+00	2.33E-05
BATCH-506	4/14/25	18	1.9	0.24	4.27E+01	0.00E+00	2.18E-08	3.08E-05	1.69E-08	8.15E-31	1.00E-03	5.00E-02	1.77E-07	1.82E-04	7.15E-01	0.00E+00	2.13E+00	0.00E+00	7.72E-06
BATCH-507	4/16/25	91	9.5	0.24	9.46E-13	1.86E+02	9.76E-12	4.15E-04	3.11E-11	3.01E-43	1.40E-02	6.83E-01	1.38E-07	8.00E-03	1.75E+01	0.00E+00	5.55E-14	9.88E+00	1.35E-04
BATCH-508	4/17/25	116	12.0	0.24	4.14E+02	0.00E+00	2.60E-07	4.12E-04	2.46E-07	5.17E-35	6.00E-03	7.42E-01	2.75E-06	2.00E-03	7.09E+00	0.00E+00	2.56E+01	0.00E+00	8.09E-05
BATCH-509	4/25/25	105	11.0	0.24	1.52E-09	2.15E+02	1.11E-11	4.79E-04	3.57E-11	1.96E-40	1.60E-02	7.88E-01	1.59E-07	1.00E-02	2.02E+01	0.00E+00	1.24E-10	1.14E+01	1.62E-04
BATCH-510	4/29/25	131	13.7	0.24	9.00E-03	2.68E+02	5.23E-10	5.97E-04	2.85E-10	8.61E-33	2.00E-02	9.83E-01	1.98E-07	1.20E-02	2.52E+01	0.00E+00	7.03E-04	1.42E+01	1.89E-04
BATCH-511	5/7/25	18	1.9	0.24	4.35E+01	0.00E+00	2.21E-08	3.08E-05	1.73E-08	3.06E-30	9.48E-04	4.90E-02	1.82E-07	1.78E-04	7.14E-01	0.00E+00	2.16E+00	0.00E+00	7.96E-06
BATCH-512	5/9/25	131	13.7	0.24	6.00E-03	2.43E+02	1.04E-07	4.41E-04	1.82E-07	1.43E-06	1.80E-02	1.02E+00	1.30E-06	1.10E-02	2.46E+01	0.00E+00	3.24E-04	1.21E+01	1.62E-04
BATCH-513	5/13/25	95	9.9	0.24	6.68E-16	1.26E+02	2.82E-07	1.14E-05	4.92E-07	3.86E-06	9.00E-03	8.13E-01	3.11E-06	6.00E-03	1.67E+01	0.00E+00	3.92E-17	4.65E+00	8.09E-05
BATCH-514	5/22/25	48	5.1	0.24	1.54E+02	0.00E+00	9.68E-08	1.54E-04	9.19E-08	1.93E-35	2.00E-03	2.77E-01	1.03E-06	8.70E-04	2.65E+00	0.00E+00	9.57E+00	0.00E+00	2.70E-05
BATCH-515	5/23/25	109	11.4	0.24	9.29E-13	1.46E+02	3.26E-07	1.31E-05	5.68E-07	4.45E-06	1.10E-02	9.39E-01	3.59E-06	7.00E-03	1.93E+01	0.00E+00	7.61E-14	5.37E+00	8.09E-05
BATCH-516	5/28/25	147	15.4	0.24	7.00E-03	1.96E+02	4.40E-07	1.73E-05	7.67E-07	6.01E-06	1.50E-02	1.27E+00	4.86E-06	1.00E-02	2.60E+01	0.00E+00	3.41E-04	7.25E+00	1.08E-04
BATCH-517	6/4/25	136	14.2	0.24	4.41E-06	1.82E+02	4.06E-07	1.63E-05	7.09E-07	5.55E-06	1.40E-02	1.17E+00	4.48E-06	9.00E-03	2.40E+01	0.00E+00	3.44E-07	6.70E+00	1.08E-04
BATCH-518	6/12/25	92	9.6	0.24	2.89E+02	0.00E+00	1.80E-07	3.13E-04	2.04E-07	2.41E-07	6.00E-03	1.05E+00	2.17E-06	2.00E-03	5.87E+00	0.00E+00	2.54E+01	0.00E+00	5.39E-05
BATCH-519	6/18/25	131	13.7	0.24	3.30E-06	1.75E+02	3.91E-07	1.56E-05	6.82E-07	5.35E-06	1.30E-02	1.13E+00	4.32E-06	9.00E-03	2.31E+01	0.00E+00	1.65E-07	6.44E+00	1.08E-04
BATCH-520	6/22/25	17	1.7	0.24	3.65E+01	0.00E+00	2.29E-08	3.63E-05	2.17E-08	4.56E-36	5.37E-04	6.50E-02	2.42E-07	2.06E-04	6.24E-01	0.00E+00	2.26E+00	0.00E+00	7.90E-06
BATCH-521	6/24/25	97	10.1	0.24	6.37E-16	1.29E+02	2.90E-07	1.14E-05	5.06E-07	3.96E-06	1.00E-02	8.35E-01	3.20E-06	6.00E-03	1.71E+01	0.00E+00	5.22E-17	4.77E+00	8.09E-05
BATCH-522	7/2/25	121	12.6	0.24	3.06E-06	2.61E+02	2.02E-07	1.66E-05	3.54E-07	2.76E-06	1.10E-02	8.49E-01	2.25E-06	5.00E-03	2.22E+01	0.00E+00	1.52E-07	8.38E+00	8.09E-05
BATCH-523	7/5/25	108	11.3	0.24	2.23E-09	3.48E+02	1.09E-09	1.76E-05	2.74E-09	2.80E-09	9.00E-03	5.42E-01	4.95E-08	2.00E-03	2.08E+01	0.00E+00	1.74E-10	1.03E+01	8.09E-05
BATCH-524	7/15/25	52	5.4	0.24	1.47E+02	0.00E+00	9.19E-08	1.59E-04	1.04E-07	1.23E-07	3.00E-03	5.37E-01	1.11E-06	1.00E-03	3.00E+00	0.00E+00	1.29E+01	0.00E+00	2.70E-05
BATCH-525	7/16/25	131	13.7	0.24	5.00E-03	4.21E+02	1.07E-09	2.13E-05	2.89E-09	5.87E-40	1.10E-02	6.56E-01	5.73E-08	2.00E-03	2.51E+01	0.00E+00	2.91E-04	1.24E+01	1.08E-04
BATCH-526	7/20/25	104	10.9	0.24	1.73E-09	3.35E+02	1.06E-09	1.69E-05	2.65E-09	2.80E-09	9.00E-03	5.22E-01	4.78E-08	2.00E-03	2.00E+01	0.00E+00	8.64E-11	9.87E+00	8.09E-05
BATCH-527	7/30/25	83	8.6	0.24	2.29E+02	0.00E+00	1.19E-07	1.81E-04	1.51E-07	4.95E-07	5.00E-03	1.04E+00	1.41E-06	2.00E-03	5.51E+00	0.00E+00	2.27E+01	0.00E+00	5.39E-05
BATCH-528	8/1/25	97	10.2	0.24	1.71E-09	3.12E+02	9.07E-10	1.58E-05	2.34E-09	1.55E-09	8.00E-03	4.87E-01	4.37E-08	2.00E-03	1.87E+01	0.00E+00	8.50E-11	9.22E+00	8.09E-05
BATCH-529	8/8/25	88	9.2	0.24	1.38E-12	2.82E+02	7.16E-10	1.43E-05	1.93E-09	1.74E-12	7.00E-03	4.39E-01	3.83E-08	2.00E-03	1.68E+01	0.00E+00	1.08E-13	8.31E+00	8.09E-05
BATCH-530	8/11/25	18	1.9	0.24	3.76E+01	0.00E+00	2.35E-08	4.07E-05	2.66E-08	3.14E-08	7.29E-04	1.37E-01	2.83E-07	3.24E-04	7.65E-01	0.00E+00	3.30E+00	0.00E+00	8.02E-06
BATCH-531	8/13/25	106	11.1	0.24	2.41E-06	3.41E+02	8.67E-10	1.73E-05	2.34E-09	3.01E-43	9.00E-03	5.31E-01	4.64E-08	2.00E-03	2.04E+01	0.00E+00	1.49E-07	1.01E+01	8.09E-05
BATCH-532	8/17/25	84	8.8	0.24	9.58E-13	2.17E+02	1.05E-07	2.37E-05	6.18E-08	1.55E-12	7.00E-03	8.06E-01	1.10E-07	6.00E-03	1.49E+01	0.00E+00	4.79E-14	8.39E+00	1.08E-04
BATCH-533	8/24/25	52	5.5	0.24	1.31E+02	0.00E+00	6.80E-08	1.04E-04	8.67E-08	2.84E-07	3.00E-03	5.94E-01	8.08E-07	1.00E-03	3.16E+00	0.00E+00	1.30E+01	0.00E+00	2.60E-05
BATCH-534	8/26/25	91	9.5	0.24	1.29E-12	1.72E+02	2.36E-07	3.72E-05	1.37E-07	1.16E-12	8.00E-03	1.32E+00	2.03E-07	1.20E-02	1.46E+01	0.00E+00	6.39E-14	9.53E+00	1.35E-04
BATCH-535	8/30/25	151	15.8	0.24	6.00E-03	2.84E+02	3.90E-07	6.15E-05	2.26E-07	5.18E-12	1.30E-02	2.18E+00	3.36E-07	2.00E-02	2.42E+01	0.00E+00	5.46E-04	1.58E+01	2.16E-04
BATCH-536	9/5/25	107	11.1	0.24	4.06E+02	0.00E+00	2.68E-08	3.20E-05	4.69E-08	3.63E-07	5.00E-03	8.02E-01	3.13E-07	2.00E-03	7.45E+00	0.00E+00	2.59E+01	0.00E+00	2.70E-05
BATCH-537	9/15/25	100	10.4	0.24	1.66E-09	1.88E+02	2.58E-07	4.06E-05	1.49E-07	2.07E-46	9.00E-03	1.44E+00	2.22E-07	1.30E-02	1.60E+01	0.00E+00	1.03E-10	1.04E+01	1.62E-04
BATCH-538	9/16/25	114	11.9	0.24	3.86E+02	0.00E+00	3.17E-08	4.57E-05	5.19E-08	3.88E-07	5.00E-03	9.24E-01	3.40E-07	2.00E-03	8.38E+00	0.00E+00	2.62E+01	0.00E+00	5.39E-05

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-490	1/30/25	111	11.6	0.24	2.12E-07	1.61E+02	4.20E-02	0.00E+00	0.00E+00	4.00E-04	8.39E+00	8.51E-05	3.43E-05	5.36E-04	2.52E-01	1.93E-04	1.90E+03	0.00E+00	2.20E-02
BATCH-491	2/1/25	18	1.8	0.24	1.91E-08	1.48E+00	4.60E-02	0.00E+00	0.00E+00	1.72E-05	2.75E-01	2.50E-06	2.40E-06	1.14E-04	8.00E-03	9.84E-07	3.01E+02	0.00E+00	3.00E-03
BATCH-492	2/3/25	85	8.8	0.24	1.61E-07	1.22E+02	3.20E-02	0.00E+00	0.00E+00	4.00E-04	6.37E+00	6.47E-05	2.61E-05	4.08E-04	1.92E-01	1.46E-04	1.45E+03	0.00E+00	1.60E-02
BATCH-493	2/11/25	127	13.3	0.24	9.01E-08	4.37E+01	3.70E-01	0.00E+00	0.00E+00	2.00E-04	3.19E+00	2.42E-05	8.52E-06	6.90E-04	8.40E-02	3.50E-05	2.17E+03	0.00E+00	1.70E-02
BATCH-494	2/12/25	118	12.3	0.24	2.24E-07	1.71E+02	4.40E-02	0.00E+00	0.00E+00	4.00E-04	8.88E+00	9.01E-05	3.63E-05	5.68E-04	2.67E-01	2.04E-04	2.01E+03	0.00E+00	2.30E-02
BATCH-495	2/24/25	117	12.2	0.24	1.77E-08	4.78E+01	1.97E-01	0.00E+00	0.00E+00	2.00E-04	2.87E+00	2.65E-05	3.76E-06	1.58E-04	4.90E-02	4.66E-05	2.00E+03	0.00E+00	1.30E-02
BATCH-496	2/24/25	136	14.2	0.24	2.58E-07	1.96E+02	5.10E-02	0.00E+00	0.00E+00	6.00E-04	1.02E+01	1.04E-04	4.18E-05	6.54E-04	3.08E-01	2.35E-04	2.32E+03	0.00E+00	2.60E-02
BATCH-497	3/9/25	90	9.4	0.24	1.38E-07	1.24E+02	3.50E-02	0.00E+00	0.00E+00	2.00E-04	6.58E+00	5.56E-05	2.23E-05	3.50E-04	2.31E-01	1.26E-04	1.54E+03	0.00E+00	1.80E-02
BATCH-498	3/11/25	118	12.3	0.24	1.78E-08	4.95E+01	1.94E-01	0.00E+00	0.00E+00	2.00E-04	2.92E+00	2.77E-05	3.81E-06	1.65E-04	4.80E-02	4.86E-05	2.02E+03	0.00E+00	1.30E-02
BATCH-499	3/19/25	56	5.9	0.24	3.64E-08	1.76E+01	1.50E-01	0.00E+00	0.00E+00	8.55E-05	1.29E+00	9.76E-06	3.44E-06	2.79E-04	3.40E-02	1.41E-05	9.59E+02	0.00E+00	7.00E-03
BATCH-500	3/23/25	99	10.3	0.24	1.66E-10	1.07E+02	4.60E-02	0.00E+00	0.00E+00	5.89E-05	6.37E+00	1.15E-06	2.35E-08	7.77E-07	3.76E-01	1.27E-07	1.69E+03	0.00E+00	2.10E-02
BATCH-501	3/25/25	53	5.5	0.24	7.16E-09	1.93E+01	8.00E-02	0.00E+00	0.00E+00	9.58E-05	1.16E+00	1.07E-05	1.52E-06	6.38E-05	2.00E-02	1.89E-05	9.01E+02	0.00E+00	5.00E-03
BATCH-502	3/30/25	114	11.9	0.24	1.69E-10	1.23E+02	5.30E-02	0.00E+00	0.00E+00	6.80E-05	7.35E+00	1.32E-06	2.36E-08	8.41E-07	4.34E-01	1.27E-07	1.95E+03	0.00E+00	2.40E-02
BATCH-503	4/3/25	77	8.1	0.24	1.30E-10	8.33E+01	3.60E-02	0.00E+00	0.00E+00	4.60E-05	4.97E+00	9.00E-07	1.85E-08	6.09E-07	2.93E-01	9.99E-08	1.32E+03	0.00E+00	1.60E-02
BATCH-504	4/11/25	53	5.5	0.24	7.17E-09	1.99E+01	7.80E-02	0.00E+00	0.00E+00	9.99E-05	1.18E+00	1.12E-05	1.53E-06	6.63E-05	1.90E-02	1.96E-05	9.04E+02	0.00E+00	5.00E-03
BATCH-505	4/11/25	21	2.1	0.24	1.05E-08	5.07E+00	4.30E-02	0.00E+00	0.00E+00	2.46E-05	3.71E-01	2.81E-06	9.89E-07	8.01E-05	1.00E-02	4.07E-06	3.51E+02	0.00E+00	2.00E-03
BATCH-506	4/14/25	18	1.9	0.24	1.76E-09	4.76E+00	2.00E-02	0.00E+00	0.00E+00	2.36E-05	2.85E-01	2.64E-06	3.75E-07	1.57E-05	5.00E-03	4.64E-06	3.08E+02	0.00E+00	1.00E-03
BATCH-507	4/16/25	91	9.5	0.24	2.45E-11	9.84E+01	4.30E-02	0.00E+00	0.00E+00	5.41E-05	5.87E+00	1.01E-06	9.03E-10	3.92E-07	3.47E-01	1.93E-10	1.56E+03	0.00E+00	1.90E-02
BATCH-508	4/17/25	116	12.0	0.24	4.31E-08	5.79E+01	1.78E-01	0.00E+00	0.00E+00	2.00E-04	3.13E+00	2.99E-05	7.49E-06	1.82E-04	7.70E-02	5.90E-05	1.97E+03	0.00E+00	1.00E-02
BATCH-509	4/25/25	105	11.0	0.24	2.82E-11	1.14E+02	4.90E-02	0.00E+00	0.00E+00	6.24E-05	6.77E+00	1.17E-06	1.04E-09	4.52E-07	4.00E-01	1.98E-10	1.80E+03	0.00E+00	2.20E-02
BATCH-510	4/29/25	131	13.7	0.24	3.72E-11	1.42E+02	6.10E-02	0.00E+00	0.00E+00	7.78E-05	8.44E+00	1.46E-06	1.48E-09	5.79E-07	4.99E-01	9.79E-10	2.25E+03	0.00E+00	2.80E-02
BATCH-511	5/7/25	18	1.9	0.24	1.77E-09	4.92E+00	1.90E-02	0.00E+00	0.00E+00	2.47E-05	2.90E-01	2.76E-06	3.79E-07	1.64E-05	5.00E-03	4.83E-06	3.09E+02	0.00E+00	1.00E-03
BATCH-512	5/9/25	131	13.7	0.24	4.86E-11	1.28E+02	1.63E-01	0.00E+00	0.00E+00	9.51E-05	9.13E+00	2.38E-06	1.46E-09	4.15E-07	4.14E-01	3.97E-08	2.24E+03	0.00E+00	5.90E-02
BATCH-513	5/13/25	95	9.9	0.24	6.12E-11	6.72E+01	3.20E-01	0.00E+00	0.00E+00	1.03E-04	7.97E+00	3.55E-06	1.27E-09	1.03E-09	1.33E-01	1.05E-07	1.62E+03	0.00E+00	1.03E-01
BATCH-514	5/22/25	48	5.1	0.24	1.61E-08	2.16E+01	6.60E-02	0.00E+00	0.00E+00	8.05E-05	1.17E+00	1.12E-05	2.79E-06	6.78E-05	2.90E-02	2.20E-05	8.28E+02	0.00E+00	4.00E-03
BATCH-515	5/23/25	109	11.4	0.24	7.07E-11	7.75E+01	3.69E-01	0.00E+00	0.00E+00	1.19E-04	9.19E+00	4.10E-06	1.46E-09	1.15E-09	1.54E-01	1.21E-07	1.87E+03	0.00E+00	1.19E-01
BATCH-516	5/28/25	147	15.4	0.24	9.57E-11	1.05E+02	4.99E-01	0.00E+00	0.00E+00	1.61E-04	1.24E+01	5.54E-06	2.03E-09	3.76E-09	2.08E-01	1.65E-07	2.52E+03	0.00E+00	1.61E-01
BATCH-517	6/4/25	136	14.2	0.24	8.82E-11	9.67E+01	4.61E-01	0.00E+00	0.00E+00	1.48E-04	1.15E+01	5.11E-06	1.82E-09	1.37E-09	1.92E-01	1.51E-07	2.33E+03	0.00E+00	1.48E-01
BATCH-518	6/12/25	92	9.6	0.24	3.86E-08	4.23E+01	2.42E-01	0.00E+00	0.00E+00	8.81E-05	2.55E+00	1.58E-05	6.25E-06	9.78E-05	8.50E-02	3.51E-05	1.57E+03	0.00E+00	1.20E-02
BATCH-519	6/18/25	131	13.7	0.24	8.49E-11	9.30E+01	4.43E-01	0.00E+00	0.00E+00	1.43E-04	1.10E+01	4.92E-06	1.75E-09	1.26E-09	1.85E-01	1.46E-07	2.24E+03	0.00E+00	1.43E-01
BATCH-520	6/22/25	17	1.7	0.24	3.80E-09	5.10E+00	1.60E-02	0.00E+00	0.00E+00	1.90E-05	2.76E-01	2.64E-06	6.60E-07	1.60E-05	7.00E-03	5.20E-06	2.86E+02	0.00E+00	8.61E-04
BATCH-521	6/24/25	97	10.1	0.24	6.29E-11	6.89E+01	3.29E-01	0.00E+00	0.00E+00	1.06E-04	8.18E+00	3.65E-06	1.30E-09	7.75E-10	1.37E-01	1.08E-07	1.66E+03	0.00E+00	1.06E-01
BATCH-522	7/2/25	121	12.6	0.24	5.97E-11	6.35E+01	3.25E-01	0.00E+00	0.00E+00	6.00E-04	8.68E+00	3.54E-05	1.05E-08	3.07E-09	1.38E-01	1.28E-06	2.07E+03	0.00E+00	1.04E-01
BATCH-523	7/5/25	108	11.3	0.24	3.23E-11	3.15E+01	1.96E-01	0.00E+00	0.00E+00	1.20E-03	6.06E+00	6.68E-05	1.95E-08	5.14E-09	8.70E-02	2.44E-06	1.85E+03	0.00E+00	6.20E-02
BATCH-524	7/15/25	52	5.4	0.24	1.97E-08	2.16E+01	1.24E-01	0.00E+00	0.00E+00	4.49E-05	1.30E+00	8.07E-06	3.19E-06	4.99E-05	4.30E-02	1.79E-05	8.90E+02	0.00E+00	6.00E-03
BATCH-525	7/16/25	131	13.7	0.24	3.95E-11	3.81E+01	2.37E-01	0.00E+00	0.00E+00	1.40E-03	7.33E+00	8.09E-05	2.37E-08	8.28E-09	1.06E-01	2.95E-06	2.24E+03	0.00E+00	7.50E-02
BATCH-526	7/20/25	104	10.9	0.24	3.11E-11	3.03E+01	1.88E-01	0.00E+00	0.00E+00	1.20E-03	5.83E+00	6.43E-05	1.88E-08	4.94E-09	8.40E-02	2.35E-06	1.78E+03	0.00E+00	5.90E-02
BATCH-527	7/30/25	83	8.6	0.24	1.96E-08	3.31E+01	2.78E-01	0.00E+00	0.00E+00	5.74E-05	2.37E+00	8.41E-06	3.17E-06	4.95E-05	7.40E-02	1.78E-05	1.41E+03	0.00E+00	1.70E-02
BATCH-528	8/1/25	97	10.2	0.24	2.90E-11	2.83E+01	1.76E-01	0.00E+00	0.00E+00	1.00E-03	5.45E+00	6.00E-05	1.76E-08	4.62E-09	7.80E-02	2.19E-06	1.66E+03	0.00E+00	5.60E-02
BATCH-529	8/8/25	88	9.2	0.24	2.61E-11	2.55E+01	1.58E-01	0.00E+00	0.00E+00	1.00E-03	4.91E+00	5.42E-05	1.58E-08	4.16E-09	7.10E-02	1.98E-06	1.50E+03	0.00E+00	5.00E-02
BATCH-530	8/11/25	18	1.9	0.24	5.03E-09	5.51E+00	3.20E-02	0.00E+00	0.00E+00	1.15E-05	3.32E-01	2.06E-06	8.14E-07	1.27E-05	1.10E-02	4.57E-06	3.11E+02	0.00E+00	2.00E-03
BATCH-531	8/13/25	106	11.1	0.24	3.16E-11	3.08E+01	1.92E-01	0.00E+00	0.00E+00	1.20E-03	5.94E+00	6.55E-05	1.92E-08	5.04E-09	8.60E-02	2.39E-06	1.82E+03	0.00E+00	6.10E-02
BATCH-532	8/17/25	84	8.8	0.24	7.33E-10	3.20E+01	2.55E-01	0.00E+00	0.00E+00	4.00E-04	6.54E+00	2.77E-05	4.15E-08	2.58E-06	1.37E-01	1.13E-06	1.44E+03	0.00E+00	8.00E-02
BATCH-533	8/24/25	52	5.5	0.24	1.12E-08	1.90E+01	1.59E-01	0.00E+00	0.00E+00	3.29E-05	1.36E+00	4.82E-06	1.82E-06	2.84E-05	4.30E-02	1.02E-05	8.95E+02	0.00E+00	1.00E-02
BATCH-534	8/26/25	91	9.5	0.24	1.62E-09	4.34E+01	3.95E-01	0.00E+00	0.00E+00	7.64E-05	9.20E+00	1.61E-06	7.55E-08	5.79E-06	2.29E-01	3.22E-07	1.56E+03	0.00E+00	1.23E-01
BATCH-535	8/30/25	151	15.8	0.24	2.68E-09	7.18E+01	6.53E-01	0.00E+00	0.00E+00	1.25E-04	1.52E+01	2.58E-06	1.25E-07	9.59E-06	3.80E-01	5.32E-07	2.58E+03	0.00E+00	2.04E-01
BATCH-536	9/5/25	107	11.1	0.24	1.48E-11	1.99E+01	2.72E-01	0.00E+00	0.00E+00	2.00E-04	2.51E+00	1.57E-05	4.64E-09	2.74E-08	5.50E-02	5.67E-07	1.82E+03	0.00E+00	2.50E-02
BATCH-537	9/15/25	100	10.4	0.24	1.77E-09	4.75E+01	4.31E-01	0.00E+00	0.00E+00	8.35E-05	1.01E+01	1.75E-06	8.26E-08	6.33E-06	2.51E-01	3.52E-07	1.71E+03	0.00E+00	1.34E-01
BATCH-538	9/16/25	114	11.9	0.24	3.77E-11	2.41E+01	3.06E-01	0.00E+00	0.00E+00	2.00E-04	2.90E+00	1.60E-05	5.77E-09	1.17E-07	7.00E-02	5.81E-07	1.95E+03	0.00E+00	2.80E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-490	1/30/25	111	11.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	1.01E+02	1.87E-07	1.14E+01	8.17E+01	4.10E-02	2.36E-05	0.00E+00	8.20E-02	1.00E-03	1.60E-02
BATCH-491	2/1/25	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.01E+00	2.95E-08	1.76E+00	1.75E+00	1.00E-03	1.04E-08	0.00E+00	5.00E-03	2.53E-04	6.97E-04
BATCH-492	2/3/25	85	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	7.71E+01	1.42E-07	8.64E+00	6.21E+01	3.10E-02	1.80E-05	0.00E+00	6.20E-02	9.75E-04	1.20E-02
BATCH-493	2/11/25	127	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.58E+01	1.09E-07	2.29E+01	3.03E+01	2.10E-02	5.31E-06	0.00E+00	5.70E-02	5.38E-04	6.00E-03
BATCH-494	2/12/25	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	1.07E+02	1.98E-07	1.20E+01	8.64E+01	4.40E-02	2.50E-05	0.00E+00	8.70E-02	1.00E-03	1.60E-02
BATCH-495	2/24/25	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.94E+01	4.02E-08	1.77E+01	3.01E+01	1.80E-02	6.98E-06	0.00E+00	3.60E-02	3.62E-04	3.00E-03
BATCH-496	2/24/25	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	1.24E+02	2.28E-07	1.39E+01	9.96E+01	5.00E-02	2.88E-05	0.00E+00	1.00E-01	2.00E-03	1.90E-02
BATCH-497	3/9/25	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	8.09E+01	1.22E-07	9.03E+00	6.39E+01	3.40E-02	1.54E-05	0.00E+00	8.90E-02	8.37E-04	1.50E-02
BATCH-498	3/11/25	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.01E+01	4.18E-08	1.79E+01	3.09E+01	1.80E-02	7.30E-06	0.00E+00	3.40E-02	3.78E-04	3.00E-03
BATCH-499	3/19/25	56	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	2.25E+01	4.41E-08	9.25E+00	1.22E+01	8.00E-03	2.14E-06	0.00E+00	2.30E-02	2.17E-04	2.00E-03
BATCH-500	3/23/25	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	8.44E+01	1.23E-10	9.24E+00	6.09E+01	4.20E-02	1.55E-08	0.00E+00	2.03E-01	7.86E-06	2.60E-02
BATCH-501	3/25/25	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.00E+01	1.63E-08	7.18E+00	1.22E+01	7.00E-03	2.82E-06	0.00E+00	1.50E-02	1.46E-04	1.00E-03
BATCH-502	3/30/25	114	11.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.90E-02	9.74E+01	1.23E-10	1.07E+01	7.03E+01	4.90E-02	1.55E-08	0.00E+00	2.34E-01	8.94E-06	3.00E-02
BATCH-503	4/3/25	77	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	6.59E+01	9.70E-11	7.21E+00	4.75E+01	3.30E-02	1.23E-08	0.00E+00	1.58E-01	6.14E-06	2.10E-02
BATCH-504	4/11/25	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.02E+01	1.68E-08	7.20E+00	1.24E+01	7.00E-03	2.94E-06	0.00E+00	1.30E-02	1.52E-04	1.00E-03
BATCH-505	4/11/25	21	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	6.48E+00	1.27E-08	2.66E+00	3.52E+00	2.00E-03	6.17E-07	0.00E+00	7.00E-03	6.25E-05	6.70E-04
BATCH-506	4/14/25	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.53E-04	4.92E+00	4.01E-09	1.77E+00	3.00E+00	2.00E-03	6.95E-07	0.00E+00	4.00E-03	3.60E-05	3.37E-04
BATCH-507	4/16/25	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-02	7.79E+01	3.39E-13	8.52E+00	5.62E+01	3.90E-02	2.18E-11	0.00E+00	1.87E-01	6.47E-06	2.40E-02
BATCH-508	4/17/25	116	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.48E+01	5.40E-08	2.03E+01	3.36E+01	1.70E-02	8.06E-06	0.00E+00	3.60E-02	4.26E-04	5.00E-03
BATCH-509	4/25/25	105	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-02	8.98E+01	3.67E-13	9.83E+00	6.48E+01	4.50E-02	2.21E-11	0.00E+00	2.16E-01	7.47E-06	2.80E-02
BATCH-510	4/29/25	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-02	1.12E+02	2.94E-12	1.23E+01	8.08E+01	5.60E-02	1.41E-10	0.00E+00	2.69E-01	9.32E-06	3.50E-02
BATCH-511	5/7/25	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.52E-04	4.99E+00	4.16E-09	1.78E+00	3.07E+00	2.00E-03	7.26E-07	0.00E+00	3.00E-03	3.76E-05	3.23E-04
BATCH-512	5/9/25	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-02	9.99E+01	3.71E-10	1.00E+01	7.62E+01	6.60E-02	1.37E-10	0.00E+00	2.71E-01	7.04E-06	3.10E-02
BATCH-513	5/13/25	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	4.84E+01	1.00E-09	2.91E+00	4.59E+01	6.70E-02	5.18E-11	0.00E+00	2.01E-01	5.86E-07	1.50E-02
BATCH-514	5/22/25	48	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.04E+01	2.02E-08	7.58E+00	1.25E+01	6.00E-03	3.01E-06	0.00E+00	1.30E-02	1.59E-04	2.00E-03
BATCH-515	5/23/25	109	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	5.58E+01	1.15E-09	3.36E+00	5.30E+01	7.70E-02	5.98E-11	0.00E+00	2.32E-01	6.76E-07	1.70E-02
BATCH-516	5/28/25	147	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	7.53E+01	1.56E-09	4.52E+00	7.15E+01	1.04E-01	1.95E-10	0.00E+00	3.13E-01	9.13E-07	2.30E-02
BATCH-517	6/4/25	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	6.96E+01	1.44E-09	4.18E+00	6.61E+01	9.60E-02	7.47E-11	0.00E+00	2.89E-01	8.42E-07	2.10E-02
BATCH-518	6/12/25	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.83E+01	3.41E-08	2.13E+01	2.57E+01	1.50E-02	4.31E-06	0.00E+00	5.20E-02	2.34E-04	6.00E-03
BATCH-519	6/18/25	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-02	6.70E+01	1.39E-09	4.03E+00	6.36E+01	9.30E-02	7.19E-11	0.00E+00	2.78E-01	8.09E-07	2.00E-02
BATCH-520	6/22/25	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.83E+00	4.76E-09	1.79E+00	2.96E+00	1.00E-03	7.10E-07	0.00E+00	3.00E-03	3.75E-05	4.23E-04
BATCH-521	6/24/25	97	10.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	4.95E+01	1.03E-09	2.98E+00	4.71E+01	6.90E-02	5.32E-11	0.00E+00	2.06E-01	5.98E-07	1.50E-02
BATCH-522	7/2/25	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	5.66E+01	7.17E-10	4.54E+00	5.54E+01	8.80E-02	4.83E-11	0.00E+00	1.63E-01	6.84E-06	1.30E-02
BATCH-523	7/5/25	108	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.47E+01	1.61E-12	5.01E+00	4.59E+01	8.10E-02	2.28E-11	0.00E+00	3.90E-02	1.31E-05	5.00E-03
BATCH-524	7/15/25	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.47E+01	1.74E-08	1.09E+01	1.31E+01	8.00E-03	2.20E-06	0.00E+00	2.70E-02	1.20E-04	3.00E-03
BATCH-525	7/16/25	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	5.41E+01	1.68E-12	6.06E+00	5.56E+01	9.80E-02	1.19E-10	0.00E+00	4.70E-02	1.58E-05	6.00E-03
BATCH-526	7/20/25	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	4.30E+01	1.58E-12	4.82E+00	4.42E+01	7.80E-02	2.19E-11	0.00E+00	3.80E-02	1.26E-05	4.00E-03
BATCH-527	7/30/25	83	8.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.23E+01	1.74E-08	1.92E+01	2.17E+01	1.60E-02	2.18E-06	0.00E+00	5.90E-02	1.19E-04	6.00E-03
BATCH-528	8/1/25	97	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	4.02E+01	1.20E-12	4.50E+00	4.13E+01	7.30E-02	2.04E-11	0.00E+00	3.50E-02	1.17E-05	4.00E-03
BATCH-529	8/8/25	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.62E+01	7.17E-13	4.06E+00	3.72E+01	6.60E-02	1.84E-11	0.00E+00	3.20E-02	1.06E-05	4.00E-03
BATCH-530	8/11/25	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.29E+00	4.44E-09	2.77E+00	3.35E+00	2.00E-03	5.61E-07	0.00E+00	7.00E-03	3.05E-05	7.70E-04
BATCH-531	8/13/25	106	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.38E+01	8.68E-13	4.91E+00	4.50E+01	7.90E-02	2.23E-11	0.00E+00	3.80E-02	1.28E-05	4.00E-03
BATCH-532	8/17/25	84	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.78E+01	5.90E-09	4.47E+00	3.38E+01	6.80E-02	9.38E-12	0.00E+00	4.40E-02	1.10E-05	8.00E-03
BATCH-533	8/24/25	52	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.42E+01	9.95E-09	1.10E+01	1.24E+01	9.00E-03	1.25E-06	0.00E+00	3.40E-02	6.83E-05	3.00E-03
BATCH-534	8/26/25	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-02	4.43E+01	1.32E-08	5.49E+00	3.42E+01	7.80E-02	4.63E-13	0.00E+00	6.40E-02	1.29E-05	1.30E-02
BATCH-535	8/30/25	151	15.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.90E-02	7.33E+01	2.19E-08	9.09E+00	5.66E+01	1.30E-01	9.34E-11	0.00E+00	1.06E-01	2.13E-05	2.20E-02
BATCH-536	9/5/25	107	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.45E+01	9.46E-11	1.33E+01	2.04E+01	2.70E-02	1.64E-11	0.00E+00	4.50E-02	3.45E-06	4.00E-03
BATCH-537	9/15/25	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.50E-02	4.84E+01	1.45E-08	6.01E+00	3.74E+01	8.60E-02	5.05E-13	0.00E+00	7.00E-02	1.41E-05	1.40E-02
BATCH-538	9/16/25	114	11.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	3.86E+01	2.79E-10	1.39E+01	2.31E+01	3.00E-02	2.13E-11	0.00E+00	5.30E-02	3.89E-06	5.00E-03

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-539	9/25/25	18	1.9	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.27E-01	1.62E-02	2.13E+02	5.30E-02	8.00E-03	8.73E-01	3.36E-14	6.00E-02	2.25E-04	1.50E-02	5.00E-04
BATCH-540	9/27/25	103	10.8	0.24	0.00E+00	0.00E+00	4.30E-02	1.20E-02	3.31E+00	1.13E-01	1.56E+03	3.35E-01	5.20E-02	6.79E+00	8.97E-14	3.75E-01	1.00E-03	9.70E-02	4.00E-03
BATCH-541	9/28/25	135	14.1	0.24	0.00E+00	0.00E+00	1.68E-01	4.70E-02	1.30E+01	4.44E-01	2.70E+03	1.28E+00	2.02E-01	1.35E+01	7.98E-13	1.48E+00	5.00E-03	3.82E-01	1.25E-02
BATCH-542	10/8/25	52	5.4	0.24	0.00E+00	0.00E+00	2.10E-02	6.00E-03	1.59E+00	5.67E-02	8.09E+02	1.71E-01	2.60E-02	3.77E+00	3.23E-14	1.81E-01	7.04E-04	4.70E-02	2.00E-03
BATCH-543	10/13/25	100	10.4	0.24	0.00E+00	0.00E+00	3.90E-02	1.10E-02	3.04E+00	1.23E-01	1.70E+03	3.42E-01	5.30E-02	8.50E+00	8.45E-14	3.45E-01	1.00E-03	9.00E-02	4.50E-03
BATCH-544	10/14/25	50	5.2	0.24	0.00E+00	0.00E+00	2.20E-02	6.00E-03	1.68E+00	5.76E-02	8.25E+02	1.78E-01	2.80E-02	3.78E+00	3.63E-14	1.92E-01	7.37E-04	4.90E-02	2.00E-03
BATCH-545	10/19/25	151	15.7	0.24	0.00E+00	0.00E+00	1.87E-01	5.30E-02	1.45E+01	4.95E-01	3.01E+03	1.42E+00	2.25E-01	1.50E+01	8.89E-13	1.65E+00	6.00E-03	4.25E-01	1.40E-02
BATCH-546	10/23/25	53	5.5	0.24	0.00E+00	0.00E+00	2.00E-02	5.00E-03	1.54E+00	5.22E-02	7.30E+02	1.56E-01	2.40E-02	3.17E+00	4.19E-14	1.75E-01	6.64E-04	4.50E-02	1.75E-03
BATCH-547	10/29/25	121	12.6	0.24	0.00E+00	0.00E+00	1.50E-01	4.20E-02	1.16E+01	3.97E-01	2.42E+03	1.14E+00	1.81E-01	1.20E+01	7.13E-13	1.33E+00	5.00E-03	3.41E-01	1.13E-02
BATCH-548	11/4/25	18	1.9	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	4.10E-01	1.44E-02	2.09E+02	4.40E-02	7.00E-03	9.72E-01	8.32E-15	4.70E-02	1.82E-04	1.20E-02	5.00E-04
BATCH-549	11/6/25	17	1.8	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	4.16E-01	1.44E-02	2.05E+02	4.40E-02	7.00E-03	9.37E-01	8.99E-15	4.80E-02	1.83E-04	1.20E-02	5.00E-04
BATCH-550	11/8/25	47	4.9	0.24	0.00E+00	0.00E+00	1.70E-02	4.00E-03	1.27E+00	5.22E-02	7.13E+02	1.43E-01	2.20E-02	3.57E+00	3.54E-14	1.45E-01	5.79E-04	3.80E-02	2.00E-03
BATCH-551	11/11/25	19	2.0	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	4.10E-01	1.35E-02	1.94E+02	4.10E-02	6.00E-03	8.42E-01	1.11E-14	4.60E-02	1.76E-04	1.20E-02	5.00E-04
BATCH-552	11/13/25	115	12.0	0.24	0.00E+00	0.00E+00	1.91E-01	6.80E-02	1.48E+01	3.74E-01	2.30E+03	1.43E+00	2.21E-01	1.15E+01	7.07E-13	1.72E+00	6.00E-03	4.42E-01	1.23E-02
BATCH-553	11/13/25	119	12.5	0.24	0.00E+00	0.00E+00	2.38E-01	1.30E-01	1.85E+01	3.85E-01	2.39E+03	1.77E+00	2.69E-01	1.19E+01	7.55E-13	2.16E+00	8.00E-03	5.53E-01	1.43E-02
BATCH-554	11/25/25	119	12.5	0.24	0.00E+00	0.00E+00	2.38E-01	1.30E-01	1.84E+01	3.84E-01	2.39E+03	1.77E+00	2.69E-01	1.19E+01	7.55E-13	2.16E+00	8.00E-03	5.53E-01	1.43E-02
BATCH-555	11/26/25	86	9.0	0.24	0.00E+00	0.00E+00	1.71E-01	9.40E-02	1.33E+01	2.77E-01	1.72E+03	1.27E+00	1.93E-01	8.56E+00	5.43E-13	1.56E+00	6.00E-03	3.98E-01	1.03E-02
BATCH-556	12/5/25	17	1.7	0.24	0.00E+00	0.00E+00	4.00E-03	1.00E-03	3.03E-01	1.26E-02	1.69E+02	3.40E-02	5.00E-03	8.48E-01	8.42E-15	3.40E-02	1.38E-04	9.00E-03	5.00E-04
BATCH-557	12/7/25	119	12.4	0.24	0.00E+00	0.00E+00	2.37E-01	1.30E-01	1.84E+01	3.84E-01	2.38E+03	1.76E+00	2.69E-01	1.19E+01	7.53E-13	2.16E+00	8.00E-03	5.52E-01	1.43E-02
BATCH-558	12/8/25	92	9.6	0.24	0.00E+00	0.00E+00	1.83E-01	1.00E-01	1.42E+01	2.95E-01	1.84E+03	1.36E+00	2.07E-01	9.14E+00	5.80E-13	1.66E+00	6.00E-03	4.25E-01	1.10E-02
BATCH-559	12/18/25	110	11.5	0.24	0.00E+00	0.00E+00	1.61E-01	8.00E-02	1.25E+01	4.22E-01	2.20E+03	1.11E+00	1.74E-01	1.10E+01	4.58E-13	1.38E+00	5.00E-03	3.58E-01	1.03E-02
BATCH-560	12/20/25	100	10.4	0.24	0.00E+00	0.00E+00	7.50E-02	2.40E-02	5.83E+00	4.64E-01	1.70E+03	3.77E-01	6.80E-02	7.45E+00	1.29E-13	5.15E-01	2.00E-03	1.41E-01	5.75E-03
BATCH-561	12/29/25	139	14.5	0.24	0.00E+00	0.00E+00	1.05E-01	3.40E-02	8.10E+00	6.44E-01	2.36E+03	5.23E-01	9.40E-02	1.03E+01	1.79E-13	7.15E-01	3.00E-03	1.96E-01	8.25E-03
BATCH-562	12/31/25	160	16.7	0.24	0.00E+00	0.00E+00	1.21E-01	3.90E-02	9.34E+00	7.43E-01	2.72E+03	6.03E-01	1.09E-01	1.19E+01	2.06E-13	8.24E-01	3.00E-03	2.26E-01	9.50E-03
BATCH-563	1/13/26	107	11.1	0.24	0.00E+00	0.00E+00	8.10E-02	2.30E-02	6.19E+00	4.96E-01	1.77E+03	4.03E-01	6.90E-02	7.97E+00	6.93E-14	5.25E-01	2.00E-03	1.51E-01	6.25E-03
BATCH-564	1/16/26	138	14.4	0.24	0.00E+00	0.00E+00	1.05E-01	3.00E-02	8.02E+00	6.43E-01	2.30E+03	5.22E-01	8.90E-02	1.03E+01	8.98E-14	6.80E-01	2.00E-03	1.96E-01	8.25E-03
BATCH-565	1/24/26	113	11.8	0.24	0.00E+00	0.00E+00	8.50E-02	2.40E-02	6.53E+00	5.24E-01	1.87E+03	4.25E-01	7.30E-02	8.41E+00	7.31E-14	5.54E-01	2.00E-03	1.60E-01	6.50E-03
BATCH-566	1/31/26	81	8.4	0.24	0.00E+00	0.00E+00	4.20E-02	1.30E-02	3.26E+00	1.22E-01	1.13E+03	3.05E-01	4.60E-02	4.99E+00	8.31E-14	3.48E-01	1.00E-03	9.50E-02	3.00E-03
BATCH-567	2/5/26	105	11.0	0.24	0.00E+00	0.00E+00	9.80E-02	2.90E-02	7.55E+00	4.64E-01	2.10E+03	5.74E-01	9.10E-02	1.02E+01	8.89E-14	7.08E-01	2.00E-03	1.98E-01	7.00E-03
BATCH-568	2/9/26	118	12.3	0.24	0.00E+00	0.00E+00	2.10E-01	6.50E-02	1.62E+01	3.86E-01	2.35E+03	1.59E+00	2.28E-01	1.17E+01	2.10E-13	1.81E+00	5.00E-03	4.85E-01	1.25E-02
BATCH-569	2/16/26	88	9.2	0.24	0.00E+00	0.00E+00	4.60E-02	1.60E-02	3.55E+00	1.28E-01	1.20E+03	3.28E-01	4.90E-02	5.37E+00	8.35E-14	3.79E-01	1.00E-03	1.03E-01	3.25E-03
BATCH-570	2/21/26	102	10.6	0.24	0.00E+00	0.00E+00	1.82E-01	5.60E-02	1.40E+01	3.35E-01	2.04E+03	1.38E+00	1.98E-01	1.01E+01	1.82E-13	1.57E+00	5.00E-03	4.20E-01	1.10E-02
BATCH-571	2/26/26	83	8.7	0.24	0.00E+00	0.00E+00	1.48E-01	4.60E-02	1.14E+01	2.73E-01	1.66E+03	1.12E+00	1.61E-01	8.27E+00	1.49E-13	1.28E+00	4.00E-03	3.42E-01	9.00E-03
BATCH-572	3/4/26	59	6.2	0.24	0.00E+00	0.00E+00	2.90E-02	9.00E-03	2.23E+00	8.37E-02	7.74E+02	2.08E-01	3.10E-02	3.41E+00	5.68E-14	2.38E-01	7.02E-04	6.50E-02	2.00E-03
BATCH-573	3/7/26	81	8.4	0.24	0.00E+00	0.00E+00	1.44E-01	4.50E-02	1.11E+01	2.65E-01	1.61E+03	1.09E+00	1.56E-01	8.03E+00	1.44E-13	1.24E+00	4.00E-03	3.32E-01	8.75E-03
BATCH-574	3/11/26	106	11.0	0.24	0.00E+00	0.00E+00	1.89E-01	5.80E-02	1.46E+01	3.47E-01	2.11E+03	1.43E+00	2.05E-01	1.05E+01	1.89E-13	1.63E+00	5.00E-03	4.36E-01	1.13E-02
BATCH-575	3/15/26	55	5.7	0.24	0.00E+00	0.00E+00	2.60E-02	9.00E-03	2.01E+00	7.29E-02	6.78E+02	1.85E-01	2.80E-02	3.04E+00	4.73E-14	2.14E-01	6.31E-04	5.80E-02	1.75E-03
BATCH-576	3/21/26	92	9.5	0.24	0.00E+00	0.00E+00	1.64E-01	5.10E-02	1.26E+01	3.01E-01	1.83E+03	1.24E+00	1.78E-01	9.12E+00	1.64E-13	1.41E+00	4.00E-03	3.77E-01	9.75E-03
BATCH-577	3/22/26	105	10.9	0.24	0.00E+00	0.00E+00	6.00E-02	2.50E-02	4.62E+00	1.43E-01	1.47E+03	4.23E-01	6.20E-02	6.85E+00	8.35E-14	4.99E-01	1.00E-03	1.35E-01	3.75E-03
BATCH-578	3/31/26	24	2.5	0.24	0.00E+00	0.00E+00	1.00E-02	3.00E-03	7.52E-01	2.79E-02	2.61E+02	7.00E-02	1.10E-02	1.15E+00	1.92E-14	8.00E-02	2.37E-04	2.20E-02	7.50E-04
BATCH-579	4/2/26	107	11.1	0.24	0.00E+00	0.00E+00	4.90E-02	1.80E-02	3.79E+00	1.80E-01	1.17E+03	3.15E-01	4.80E-02	5.37E+00	5.77E-14	3.81E-01	1.00E-03	1.05E-01	3.25E-03
BATCH-580	4/3/26	20	2.1	0.24	0.00E+00	0.00E+00	7.00E-03	3.00E-03	5.60E-01	1.98E-02	1.89E+02	5.20E-02	8.00E-03	8.48E-01	1.32E-14	6.00E-02	1.76E-04	1.60E-02	5.00E-04
BATCH-581	4/5/26	95	9.9	0.24	0.00E+00	0.00E+00	1.70E-01	5.30E-02	1.31E+01	3.12E-01	1.90E+03	1.29E+00	1.85E-01	9.47E+00	1.70E-13	1.47E+00	4.00E-03	3.92E-01	1.03E-02
BATCH-582	4/13/26	87	9.0	0.24	0.00E+00	0.00E+00	4.70E-02	1.70E-02	3.60E+00	1.24E-01	1.14E+03	3.26E-01	4.80E-02	5.27E+00	5.63E-14	3.84E-01	1.00E-03	1.04E-01	3.00E-03
BATCH-583	4/15/26	53	5.6	0.24	0.00E+00	0.00E+00	2.80E-02	1.20E-02	2.13E+00	6.57E-02	6.77E+02	1.95E-01	2.90E-02	3.16E+00	3.86E-14	2.31E-01	6.75E-04	6.20E-02	1.75E-03
BATCH-584	4/21/26	139	14.5	0.24	0.00E+00	0.00E+00	2.11E-01	6.40E-02	1.63E+01	3.87E-01	2.79E+03	1.60E+00	2.29E-01	1.39E+01	2.06E-13	1.83E+00	5.00E-03	4.89E-01	1.30E-02
BATCH-585	4/22/26	152	15.8	0.24	0.00E+00	0.00E+00	1.72E-01	5.10E-02	1.32E+01	3.13E-01	3.03E+03	1.32E+00	1.87E-01	1.51E+01	1.58E-13	1.50E+00	4.00E-03	4.01E-01	1.13E-02
BATCH-586	5/5/26	57	5.9	0.24	0.00E+00	0.00E+00	2.40E-02	9.00E-03	1.84E+00	8.73E-02	5.66E+02	1.53E-01	2.30E-02	2.61E+00	2.80E-14	1.85E-01	5.42E-04	5.10E-02	1.50E-03
BATCH-587	5/9/26	94	9.8	0.24	0.00E+00	0.00E+00	1.06E-01	3.10E-02	8.16E+00	1.94E-01	1.87E+03	8.11E-01	1.15E-01	9.32E+00	9.72E-14	9.26E-01	3.00E-03	2.47E-01	7.00E-03

Appendix A Nominal ILAW Inventory

TWRS/O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-539	9/25/25	18	1.9	0.24	9.03E-09	5.52E+01	2.77E+01	2.00E-03	1.52E+01	9.00E-03	5.96E-05	1.00E-06	3.07E-05	1.40E-05	1.39E-05	3.53E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-540	9/27/25	103	10.8	0.24	5.95E-08	3.09E+02	1.71E+02	1.40E-02	9.17E+01	5.40E-02	4.75E-05	6.17E-06	1.77E-04	8.13E-05	8.75E-05	2.06E-04	1.30E-02	6.50E-02	1.90E-02
BATCH-541	9/28/25	135	14.1	0.24	2.22E-07	4.05E+02	6.61E+02	5.90E-02	3.68E+00	2.25E-01	1.00E-03	2.38E-05	7.19E-04	3.18E-04	3.35E-04	8.05E-04	5.70E-02	2.95E-01	7.30E-02
BATCH-542	10/8/25	52	5.4	0.24	2.95E-08	1.56E+02	8.37E+01	7.00E-03	4.41E+01	2.50E-02	1.97E-06	3.01E-06	6.68E-05	3.37E-05	4.49E-05	8.86E-05	5.00E-03	2.60E-02	9.00E-03
BATCH-543	10/13/25	100	10.4	0.24	6.18E-08	2.99E+02	1.59E+02	1.20E-02	8.22E+01	4.50E-02	5.47E-05	5.69E-06	1.06E-04	5.60E-05	9.01E-05	1.50E-04	9.00E-03	4.70E-02	1.80E-02
BATCH-544	10/14/25	50	5.2	0.24	3.04E-08	1.50E+02	8.84E+01	7.00E-03	4.69E+01	2.70E-02	5.69E-06	3.18E-06	7.23E-05	3.62E-05	4.69E-05	9.50E-05	5.00E-03	2.80E-02	9.00E-03
BATCH-545	10/19/25	151	15.7	0.24	2.48E-07	4.52E+02	7.37E+02	6.60E-02	4.10E+00	2.51E-01	1.00E-03	2.65E-05	8.01E-04	3.55E-04	3.73E-04	8.97E-04	6.40E-02	3.29E-01	8.10E-02
BATCH-546	10/23/25	53	5.5	0.24	2.78E-08	1.59E+02	7.96E+01	7.00E-03	4.28E+01	2.50E-02	2.22E-05	2.88E-06	8.27E-05	3.79E-05	4.08E-05	9.62E-05	6.00E-03	3.00E-02	9.00E-03
BATCH-547	10/29/25	121	12.6	0.24	1.99E-07	3.62E+02	5.91E+02	5.30E-02	3.29E+00	2.01E-01	9.41E-04	2.13E-05	6.43E-04	2.84E-04	2.99E-04	7.19E-04	5.10E-02	2.64E-01	6.50E-02
BATCH-548	11/4/25	18	1.9	0.24	7.61E-09	5.48E+01	2.16E+01	2.00E-03	1.14E+01	7.00E-03	5.07E-07	7.76E-07	1.72E-05	8.69E-06	1.16E-05	2.29E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-549	11/6/25	17	1.8	0.24	7.55E-09	5.22E+01	2.19E+01	2.00E-03	1.16E+01	7.00E-03	1.41E-06	7.89E-07	1.79E-05	8.98E-06	1.16E-05	2.36E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-550	11/8/25	47	4.9	0.24	2.59E-08	1.41E+02	6.69E+01	5.00E-03	3.45E+01	1.90E-02	2.30E-05	2.39E-06	4.43E-05	2.35E-05	3.78E-05	6.28E-05	4.00E-03	2.00E-02	8.00E-03
BATCH-551	11/11/25	19	2.0	0.24	7.37E-09	5.65E+01	2.11E+01	2.00E-03	1.14E+01	7.00E-03	5.88E-06	7.65E-07	2.20E-05	1.01E-05	1.09E-05	2.55E-05	2.00E-03	8.00E-03	2.00E-03
BATCH-552	11/13/25	115	12.0	0.24	2.20E-07	3.46E+02	7.83E+02	7.00E-02	4.32E+00	2.64E-01	8.86E-04	2.82E-05	7.15E-04	3.42E-04	3.65E-04	9.22E-04	5.90E-02	3.03E-01	7.70E-02
BATCH-553	11/13/25	119	12.5	0.24	2.53E-07	3.58E+02	9.90E+02	8.80E-02	5.44E+00	3.32E-01	9.09E-04	3.56E-05	8.25E-04	4.13E-04	4.43E-04	1.00E-03	6.90E-02	3.57E-01	9.30E-02
BATCH-554	11/25/25	119	12.5	0.24	2.53E-07	3.58E+02	9.89E+02	8.80E-02	5.44E+00	3.32E-01	9.09E-04	3.56E-05	8.25E-04	4.12E-04	4.43E-04	1.00E-03	6.90E-02	3.56E-01	9.20E-02
BATCH-555	11/26/25	86	9.0	0.24	1.82E-07	2.58E+02	7.12E+02	6.30E-02	3.91E+00	2.39E-01	6.54E-04	2.56E-05	5.93E-04	2.97E-04	3.19E-04	8.25E-04	5.00E-02	2.55E-01	6.70E-02
BATCH-556	12/5/25	17	1.7	0.24	6.16E-09	4.96E+01	1.59E+01	1.00E-03	8.20E-02	5.00E-03	5.46E-06	5.67E-07	1.05E-05	5.59E-06	8.99E-06	1.49E-05	9.14E-04	5.00E-03	2.00E-03
BATCH-557	12/7/25	119	12.4	0.24	2.53E-07	3.58E+02	9.88E+02	8.80E-02	5.43E+00	3.32E-01	9.07E-04	3.55E-05	8.23E-04	4.12E-04	4.42E-04	1.00E-03	6.90E-02	3.56E-01	9.20E-02
BATCH-558	12/8/25	92	9.6	0.24	1.95E-07	2.75E+02	7.61E+02	6.80E-02	4.18E+00	2.55E-01	6.98E-04	2.73E-05	6.34E-04	3.17E-04	3.40E-04	8.82E-04	5.30E-02	2.74E-01	7.10E-02
BATCH-559	12/18/25	110	11.5	0.24	1.90E-07	3.30E+02	6.16E+02	5.50E-02	3.41E+00	2.09E-01	5.25E-04	2.21E-05	6.85E-04	3.02E-04	2.77E-04	7.88E-04	5.30E-02	1.83E-01	6.50E-02
BATCH-560	12/20/25	100	10.4	0.24	1.21E-07	2.99E+02	2.02E+02	1.90E-02	1.17E+00	7.30E-02	1.00E-04	7.25E-06	5.32E-04	1.80E-04	9.39E-05	3.91E-04	3.50E-02	1.83E-01	3.50E-02
BATCH-561	12/29/25	139	14.5	0.24	1.68E-07	4.16E+02	2.80E+02	2.70E-02	1.62E+00	1.02E-01	1.39E-04	1.01E-05	7.39E-04	2.50E-04	1.30E-04	5.43E-04	4.90E-02	2.54E-01	4.80E-02
BATCH-562	12/31/25	160	16.7	0.24	1.93E-07	4.80E+02	3.23E+02	3.10E-02	1.87E+00	1.17E-01	1.60E-04	1.16E-05	8.53E-04	2.89E-04	1.50E-04	6.27E-04	5.70E-02	2.93E-01	5.60E-02
BATCH-563	1/13/26	107	11.1	0.24	9.23E-08	3.20E+02	2.14E+02	2.00E-02	1.15E+00	6.80E-02	1.07E-04	7.51E-06	5.13E-04	1.93E-04	1.00E-04	4.18E-04	3.80E-02	1.96E-01	3.70E-02
BATCH-564	1/16/26	138	14.4	0.24	1.20E-07	4.15E+02	2.77E+02	2.50E-02	1.49E+00	8.80E-02	1.39E-04	9.73E-06	6.65E-04	2.50E-04	1.30E-04	5.42E-04	4.90E-02	2.53E-01	4.80E-02
BATCH-565	1/24/26	113	11.8	0.24	9.74E-08	3.38E+02	2.26E+02	2.10E-02	1.22E+00	7.20E-02	1.13E-04	7.92E-06	5.42E-04	2.03E-04	1.06E-04	4.42E-04	4.00E-02	2.06E-01	3.90E-02
BATCH-566	1/31/26	81	8.4	0.24	3.93E-08	2.43E+02	1.61E+02	1.40E-02	8.32E+01	4.80E-02	2.08E-04	5.64E-06	1.71E-04	8.16E-05	7.85E-05	2.06E-04	1.50E-02	7.60E-02	1.80E-02
BATCH-567	2/5/26	105	11.0	0.24	1.02E-07	3.16E+02	3.09E+02	2.70E-02	1.64E+00	9.70E-02	1.11E-04	1.09E-05	5.07E-04	2.10E-04	1.44E-04	4.92E-04	3.90E-02	2.05E-01	4.30E-02
BATCH-568	2/9/26	118	12.3	0.24	1.74E-07	3.53E+02	8.71E+02	7.40E-02	4.52E+00	2.67E-01	1.53E-04	3.07E-05	5.77E-04	3.46E-04	4.05E-04	9.76E-04	5.70E-02	2.98E-01	8.10E-02
BATCH-569	2/16/26	88	9.2	0.24	4.15E-08	2.65E+02	1.75E+02	1.50E-02	9.05E+01	5.20E-02	2.05E-04	6.15E-06	1.82E-04	8.79E-05	8.38E-05	2.25E-04	1.60E-02	8.10E-02	1.90E-02
BATCH-570	2/21/26	102	10.6	0.24	1.51E-07	3.05E+02	7.55E+02	6.40E-02	3.91E+00	2.31E-01	1.32E-04	2.66E-05	5.00E-04	3.00E-04	3.51E-04	8.45E-04	4.90E-02	2.58E-01	7.00E-02
BATCH-571	2/26/26	83	8.7	0.24	1.23E-07	2.49E+02	6.15E+02	5.20E-02	3.19E+00	1.89E-01	1.08E-04	2.17E-05	4.08E-04	2.44E-04	2.86E-04	6.89E-04	4.00E-02	2.10E-01	5.70E-02
BATCH-572	3/4/26	59	6.2	0.24	2.68E-08	1.78E+02	1.10E+02	9.00E-03	5.68E+01	3.30E-02	1.42E-04	3.86E-06	1.17E-04	5.57E-05	5.37E-05	1.41E-04	1.00E-02	5.20E-02	1.20E-02
BATCH-573	3/7/26	81	8.4	0.24	1.19E-07	2.42E+02	5.97E+02	5.10E-02	3.10E+00	1.83E-01	1.05E-04	2.11E-05	3.96E-04	2.37E-04	2.78E-04	6.69E-04	3.90E-02	2.04E-01	5.50E-02
BATCH-574	3/11/26	106	11.0	0.24	1.56E-07	3.17E+02	7.84E+02	6.70E-02	4.06E+00	2.40E-01	1.38E-04	2.76E-05	5.19E-04	3.11E-04	3.65E-04	8.78E-04	5.10E-02	2.68E-01	7.30E-02
BATCH-575	3/15/26	55	5.7	0.24	2.35E-08	1.64E+02	9.91E+01	9.00E-03	5.12E+01	3.00E-02	1.16E-04	3.48E-06	1.03E-04	4.98E-05	4.74E-05	1.27E-04	9.00E-03	4.60E-02	1.10E-02
BATCH-576	3/21/26	92	9.5	0.24	1.35E-07	2.75E+02	6.78E+02	5.80E-02	3.52E+00	2.08E-01	1.19E-04	2.39E-05	4.49E-04	2.69E-04	3.15E-04	7.60E-04	4.40E-02	2.32E-01	6.30E-02
BATCH-577	3/22/26	105	10.9	0.24	5.00E-08	3.13E+02	2.34E+02	2.00E-02	1.20E+00	7.00E-02	1.78E-04	8.21E-06	2.16E-04	1.10E-04	1.06E-04	2.92E-04	1.90E-02	9.80E-02	2.40E-02
BATCH-578	3/31/26	24	2.5	0.24	9.05E-09	7.13E+01	3.70E+01	3.00E-03	1.92E+01	1.10E-02	4.80E-05	1.30E-06	3.94E-05	1.88E-05	1.81E-05	4.75E-05	3.00E-03	1.70E-02	4.00E-03
BATCH-579	4/2/26	107	11.1	0.24	4.64E-08	3.20E+02	1.72E+02	1.50E-02	8.97E+01	5.20E-02	1.08E-04	6.04E-06	2.21E-04	9.89E-05	7.91E-05	2.44E-04	1.80E-02	9.30E-02	2.10E-02
BATCH-580	4/3/26	20	2.1	0.24	6.56E-09	5.94E+01	2.77E+01	2.00E-03	1.43E+01	8.00E-03	3.24E-05	9.71E-07	2.88E-05	1.39E-05	1.32E-05	3.55E-05	2.00E-03	1.30E-02	3.00E-03
BATCH-581	4/5/26	95	9.9	0.24	1.41E-07	2.85E+02	7.05E+02	6.00E-02	3.66E+00	2.16E-01	1.24E-04	2.49E-05	4.67E-04	2.80E-04	3.28E-04	7.89E-04	4.60E-02	2.41E-01	6.50E-02
BATCH-582	4/13/26	87	9.0	0.24	4.06E-08	2.59E+02	1.79E+02	1.50E-02	9.27E+01	5.40E-02	9.63E-05	6.29E-06	1.71E-04	8.57E-05	8.23E-05	2.26E-04	1.50E-02	7.80E-02	1.90E-02
BATCH-583	4/15/26	53	5.6	0.24	2.31E-08	1.60E+02	1.08E+02	9.00E-03	5.56E+01	3.20E-02	8.23E-05	3.79E-06	9.96E-05	5.06E-05	4.91E-05	1.35E-04	9.00E-03	4.50E-02	1.10E-02
BATCH-584	4/21/26	139	14.5	0.24	1.70E-07	4.18E+02	8.81E+02	7.50E-02	4.55E+00	2.67E-01	1.23E-04	3.11E-05	5.54E-04	3.38E-04	4.12E-04	9.60E-04	5.50E-02	2.89E-01	8.10E-02
BATCH-585	4/22/26	152	15.8	0.24	1.30E-07	4.55E+02	7.27E+02	6.20E-02	3.73E+00	2.15E-01	4.45E-05	2.56E-05	4.05E-04	2.58E-04	3.44E-04	7.43E-04	4.20E-02	2.17E-01	6.40E-02
BATCH-586	5/5/26	57	5.9	0.24	2.25E-08	1.70E+02	8.34E+01	7.00E-03	4.35E+01	2.50E-02	5.25E-05	2.93E-06	1.07E-04	4.80E-05	3.84E-05	1.19E-04	9.00E-03	4.50E-02	1.00E-02
BATCH-587	5/9/26	94	9.8	0.24	8.04E-08	2.81E+02	4.49E+02	3.80E-02	2.30E+00	1.33E-01	2.75E-05	1.58E-05	2.50E-04	1.59E-04	2.12E-04	4.59E-04	2.60E-02	1.34E-01	4.00E-02

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-539	9/25/25	18	1.9	0.24	1.08E-04	8.12E-05	3.00E-03	4.00E-03	3.00E-03	1.58E-01	2.70E-02	1.83E-01	7.00E-02	1.80E-24	1.70E-06	6.69E-06	5.68E-05	4.00E-04	1.22E-07
BATCH-540	9/27/25	103	10.8	0.24	7.60E-04	5.46E-04	1.80E-02	2.30E-02	2.00E-02	1.05E+00	1.75E-01	1.26E+00	4.40E-01	2.16E-23	1.07E-05	4.48E-05	6.48E-04	4.00E-03	6.69E-08
BATCH-541	9/28/25	135	14.1	0.24	3.00E-03	2.00E-03	6.50E-02	7.90E-02	8.00E-02	3.43E+00	5.83E-01	4.01E+00	1.54E+00	2.12E-23	3.76E-05	1.49E-04	6.67E-04	6.00E-03	2.27E-07
BATCH-542	10/8/25	52	5.4	0.24	3.62E-04	2.60E-04	9.00E-03	1.10E-02	1.00E-02	5.08E-01	8.40E-02	6.31E-01	2.06E-01	1.26E-23	4.95E-06	2.20E-05	3.68E-04	2.00E-03	4.08E-08
BATCH-543	10/13/25	100	10.4	0.24	7.38E-04	5.17E-04	1.90E-02	1.90E-02	1.90E-02	9.59E-01	1.56E-01	1.26E+00	3.68E-01	2.99E-23	8.77E-06	4.29E-05	8.59E-04	6.00E-03	1.24E-07
BATCH-544	10/14/25	50	5.2	0.24	3.76E-04	2.72E-04	1.00E-02	1.10E-02	1.00E-02	5.29E-01	8.80E-02	6.50E-01	2.17E-01	1.19E-23	5.23E-06	2.29E-05	3.51E-04	2.00E-03	3.78E-08
BATCH-545	10/19/25	151	15.7	0.24	3.00E-03	2.00E-03	7.30E-02	8.80E-02	8.90E-02	3.83E+00	6.50E-01	4.47E+00	1.71E+00	2.36E-23	4.19E-05	1.66E-04	7.44E-04	6.00E-03	2.53E-07
BATCH-546	10/23/25	53	5.5	0.24	3.55E-04	2.55E-04	8.00E-03	1.10E-02	1.00E-02	4.91E-01	8.20E-02	5.87E-01	2.06E-01	1.01E-23	4.97E-06	2.09E-05	3.02E-04	2.00E-03	3.12E-08
BATCH-547	10/29/25	121	12.6	0.24	3.00E-03	2.00E-03	5.80E-02	7.10E-02	7.10E-02	3.07E+00	5.21E-01	3.58E+00	1.37E+00	1.89E-23	3.36E-05	1.33E-04	5.96E-04	5.00E-03	2.03E-07
BATCH-548	11/4/25	18	1.9	0.24	9.33E-05	6.71E-05	2.00E-03	3.00E-03	2.00E-03	1.31E-01	2.20E-02	1.63E-01	5.30E-02	3.24E-24	1.28E-06	5.69E-06	9.50E-05	6.38E-04	1.05E-08
BATCH-549	11/6/25	17	1.8	0.24	9.32E-05	6.76E-05	2.00E-03	3.00E-03	2.00E-03	1.31E-01	2.20E-02	1.61E-01	5.40E-02	2.96E-24	1.30E-06	5.67E-06	8.71E-05	5.88E-04	9.39E-09
BATCH-550	11/8/25	47	4.9	0.24	3.09E-04	2.17E-04	8.00E-03	8.00E-03	8.00E-03	4.02E-01	6.50E-02	5.29E-01	1.54E-01	1.26E-23	3.68E-06	1.80E-05	3.60E-04	2.00E-03	5.22E-08
BATCH-551	11/11/25	19	2.0	0.24	9.42E-05	6.77E-05	2.00E-03	3.00E-03	3.00E-03	1.30E-01	2.20E-02	1.56E-01	5.50E-02	2.68E-24	1.32E-06	5.55E-06	8.03E-05	5.33E-04	8.29E-09
BATCH-552	11/13/25	115	12.0	0.24	3.00E-03	2.00E-03	7.60E-02	1.40E-01	8.70E-02	6.11E+00	1.03E+00	5.34E+00	2.72E+00	1.39E-22	6.66E-05	2.01E-04	5.00E-03	2.90E-02	2.08E-07
BATCH-553	11/13/25	119	12.5	0.24	4.00E-03	3.00E-03	9.50E-02	2.04E-01	1.06E-01	8.94E+00	1.50E+00	7.10E+00	3.98E+00	2.43E-22	9.72E-05	2.69E-04	8.00E-03	5.10E-02	2.27E-07
BATCH-554	11/25/25	119	12.5	0.24	4.00E-03	3.00E-03	9.50E-02	2.04E-01	1.06E-01	8.94E+00	1.50E+00	7.10E+00	3.97E+00	2.43E-22	9.71E-05	2.68E-04	8.00E-03	5.10E-02	2.27E-07
BATCH-555	11/26/25	86	9.0	0.24	3.00E-03	2.00E-03	6.80E-02	1.46E-01	7.60E-02	6.43E+00	1.08E+00	5.10E+00	2.86E+00	1.75E-22	6.99E-05	1.93E-04	6.00E-03	3.60E-02	1.63E-07
BATCH-556	12/5/25	17	1.7	0.24	7.36E-05	5.15E-05	2.00E-03	2.00E-03	2.00E-03	9.60E-02	1.60E-02	1.26E-01	3.70E-02	2.99E-24	8.75E-07	4.28E-06	8.57E-05	5.79E-04	1.24E-08
BATCH-557	12/7/25	119	12.4	0.24	4.00E-03	3.00E-03	9.50E-02	2.03E-01	1.06E-01	8.92E+00	1.50E+00	7.08E+00	3.97E+00	2.42E-22	9.70E-05	2.68E-04	8.00E-03	5.10E-02	2.27E-07
BATCH-558	12/8/25	92	9.6	0.24	3.00E-03	2.00E-03	7.30E-02	1.57E-01	8.10E-02	6.87E+00	1.15E+00	5.45E+00	3.05E+00	1.87E-22	7.47E-05	2.06E-04	6.00E-03	3.90E-02	1.74E-07
BATCH-559	12/18/25	110	11.5	0.24	3.00E-03	2.00E-03	6.00E-02	1.37E-01	7.30E-02	5.91E+00	1.00E+00	4.42E+00	2.69E+00	1.57E-22	6.62E-05	1.67E-04	5.00E-03	3.60E-02	1.23E-07
BATCH-560	12/20/25	100	10.4	0.24	1.00E-03	9.15E-04	2.10E-02	6.40E-02	3.60E-02	2.57E+00	4.48E-01	1.45E+00	1.28E+00	6.29E-23	3.20E-05	5.46E-05	2.00E-03	2.10E-02	7.42E-09
BATCH-561	12/29/25	139	14.5	0.24	2.00E-03	1.00E-03	2.90E-02	8.90E-02	5.00E-02	3.56E+00	6.23E-01	2.01E+00	1.77E+00	8.74E-23	4.44E-05	7.57E-05	3.00E-03	2.90E-02	1.03E-08
BATCH-562	12/31/25	160	16.7	0.24	2.00E-03	1.00E-03	3.40E-02	1.03E-01	5.80E-02	4.11E+00	7.18E-01	2.32E+00	2.05E+00	1.01E-22	5.12E-05	8.73E-05	3.00E-03	3.30E-02	1.17E-08
BATCH-563	1/13/26	107	11.1	0.24	2.00E-03	9.78E-04	2.20E-02	6.80E-02	3.90E-02	2.74E+00	4.79E-01	1.55E+00	1.30E+00	1.43E-23	3.42E-05	5.83E-05	2.00E-03	2.10E-02	7.92E-09
BATCH-564	1/16/26	138	14.4	0.24	2.00E-03	1.00E-03	2.90E-02	8.80E-02	5.00E-02	3.56E+00	6.21E-01	2.00E+00	1.69E+00	1.85E-23	4.43E-05	7.56E-05	3.00E-03	2.80E-02	1.02E-08
BATCH-565	1/24/26	113	11.8	0.24	2.00E-03	1.00E-03	2.40E-02	7.20E-02	4.10E-02	2.89E+00	5.06E-01	1.63E+00	1.37E+00	1.51E-23	3.61E-05	6.15E-05	2.00E-03	2.30E-02	8.32E-09
BATCH-566	1/31/26	81	8.4	0.24	7.31E-04	5.29E-04	1.60E-02	2.60E-02	2.00E-02	1.14E+00	1.94E-01	1.05E+00	4.97E-01	4.21E-24	1.28E-05	3.94E-05	6.24E-04	5.00E-03	4.53E-08
BATCH-567	2/5/26	105	11.0	0.24	2.00E-03	1.00E-03	3.10E-02	7.60E-02	4.60E-02	3.15E+00	5.45E-01	2.12E+00	1.45E+00	1.46E-23	3.78E-05	7.95E-05	2.00E-03	2.00E-02	9.71E-09
BATCH-568	2/9/26	118	12.3	0.24	3.00E-03	2.00E-03	8.40E-02	1.35E-01	9.20E-02	5.92E+00	1.00E+00	5.56E+00	2.52E+00	1.94E-23	6.44E-05	2.07E-04	3.00E-03	1.90E-02	2.16E-08
BATCH-569	2/16/26	88	9.2	0.24	7.83E-04	5.67E-04	1.70E-02	3.20E-02	2.10E-02	1.37E+00	2.33E-01	1.18E+00	5.96E-01	6.02E-24	1.54E-05	4.44E-05	8.95E-04	7.00E-03	4.54E-08
BATCH-570	2/21/26	102	10.6	0.24	3.00E-03	2.00E-03	7.30E-02	1.17E-01	8.00E-02	5.13E+00	8.68E-01	4.81E+00	2.18E+00	1.68E-23	5.58E-05	1.79E-04	2.00E-03	1.60E-02	1.87E-08
BATCH-571	2/26/26	83	8.7	0.24	2.00E-03	2.00E-03	5.90E-02	9.50E-02	6.50E-02	4.18E+00	7.07E-01	3.92E+00	1.78E+00	1.37E-23	4.55E-05	1.46E-04	2.00E-03	1.30E-02	1.52E-08
BATCH-572	3/4/26	59	6.2	0.24	5.00E-04	3.62E-04	1.10E-02	1.80E-02	1.40E-02	7.82E-01	1.33E-01	7.18E-01	3.40E-01	2.87E-24	8.76E-06	2.69E-05	4.26E-04	3.00E-03	3.09E-08
BATCH-573	3/7/26	81	8.4	0.24	2.00E-03	2.00E-03	5.80E-02	9.20E-02	6.30E-02	4.06E+00	6.87E-01	3.81E+00	1.73E+00	1.33E-23	4.42E-05	1.42E-04	2.00E-03	1.30E-02	1.48E-08
BATCH-574	3/11/26	106	11.0	0.24	3.00E-03	2.00E-03	7.60E-02	1.21E-01	8.30E-02	5.32E+00	9.01E-01	5.00E+00	2.27E+00	1.74E-23	5.79E-05	1.86E-04	3.00E-03	1.70E-02	1.94E-08
BATCH-575	3/15/26	55	5.7	0.24	4.43E-04	3.21E-04	1.00E-02	1.80E-02	1.20E-02	7.78E-01	1.32E-01	6.67E-01	3.38E-01	3.41E-24	8.70E-06	2.51E-05	5.07E-04	4.00E-03	2.57E-08
BATCH-576	3/21/26	92	9.5	0.24	3.00E-03	2.00E-03	6.50E-02	1.05E-01	7.20E-02	4.61E+00	7.80E-01	4.33E+00	1.96E+00	1.51E-23	5.01E-05	1.61E-04	2.00E-03	1.50E-02	1.68E-08
BATCH-577	3/22/26	105	10.9	0.24	9.74E-04	7.12E-04	2.30E-02	4.90E-02	2.70E-02	2.14E+00	3.62E-01	1.66E+00	9.24E-01	1.15E-23	2.38E-05	6.26E-05	2.00E-03	1.20E-02	4.15E-08
BATCH-578	3/31/26	24	2.5	0.24	1.69E-04	1.22E-04	4.00E-03	6.00E-03	5.00E-03	2.64E-01	4.50E-02	2.42E-01	1.15E-01	9.69E-25	2.95E-06	9.08E-06	1.44E-04	1.00E-03	1.04E-08
BATCH-579	4/2/26	107	11.1	0.24	8.40E-04	5.90E-04	1.70E-02	4.00E-02	2.30E-02	1.70E+00	2.90E-01	1.21E+00	7.57E-01	8.77E-24	1.96E-05	4.57E-05	1.00E-03	1.00E-02	2.13E-08
BATCH-580	4/3/26	20	2.1	0.24	1.24E-04	8.95E-05	3.00E-03	5.00E-03	3.00E-03	2.17E-01	3.70E-02	1.86E-01	9.40E-02	9.51E-25	2.43E-06	7.01E-06	1.41E-04	1.00E-03	7.17E-09
BATCH-581	4/5/26	95	9.9	0.24	3.00E-03	2.00E-03	6.80E-02	1.09E-01	7.50E-02	4.79E+00	8.11E-01	4.50E+00	2.04E+00	1.57E-23	5.21E-05	1.68E-04	2.00E-03	1.50E-02	1.75E-08
BATCH-582	4/13/26	87	9.0	0.24	7.63E-04	5.57E-04	1.70E-02	2.10E-02	1.55E+00	2.62E-01	1.23E+00	6.72E-01	7.41E-24	1.73E-05	4.61E-05	1.00E-03	8.00E-03	2.03E-08
BATCH-583	4/15/26	53	5.6	0.24	4.50E-04	3.29E-04	1.10E-02	2.30E-02	1.20E-02	9.88E-01	1.67E-01	7.65E-01	4.27E-01	5.33E-24	1.10E-05	2.89E-05	7.95E-04	5.00E-03	1.92E-08
BATCH-584	4/21/26	139	14.5	0.24	3.00E-03	2.00E-03	8.50E-02	1.33E-01	9.20E-02	5.86E+00	9.90E-01	5.54E+00	2.48E+00	1.80E-23	6.33E-05	2.06E-04	3.00E-03	1.70E-02	1.65E-08
BATCH-585	4/22/26	152	15.8	0.24	3.00E-03	2.00E-03	7.00E-02	1.03E-01	7.40E-02	4.61E+00	7.76E-01	4.43E+00	1.92E+00	1.20E-23	4.88E-05	1.65E-04	2.00E-03	1.10E-02	3.95E-09
BATCH-586	5/5/26	57	5.9	0.24	4.08E-04	2.86E-04	8.00E-03	1.90E-02	1.10E-02	8.23E-01	1.41E-01	5.88E-01	3.67E-01	1.46E-24	9.52E-06	2.22E-05	6.33E-04	5.00E-03	1.03E-08
BATCH-587	5/9/26	94	9.8	0.24	2.00E-03	1.00E-03	4.30E-02	6.40E-02	4.60E-02	2.85E+00	4.79E-01	2.74E+00	1.18E+00	7.39E-24	3.01E-05	1.02E-04	1.00E-03	7.00E-03	2.45E-09

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	BH3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-539	9/25/25	18	1.9	0.24	3.40E+01	0.00E+00	1.76E-08	2.69E-05	2.24E-08	7.35E-08	7.44E-04	1.54E-01	2.09E-07	3.40E-04	8.17E-01	0.00E+00	3.36E+00	0.00E+00	6.73E-06
BATCH-540	9/27/25	103	10.8	0.24	3.27E+02	0.00E+00	7.50E-08	7.04E-06	1.14E-07	8.23E-07	5.00E-03	9.09E-01	6.83E-07	2.00E-03	7.25E+00	0.00E+00	2.31E+01	0.00E+00	2.70E-05
BATCH-541	9/28/25	135	14.1	0.24	3.15E-06	2.54E+02	3.49E-07	5.51E-05	2.03E-07	2.63E-15	1.20E-02	1.95E+00	3.01E-07	1.80E-02	2.16E+01	0.00E+00	2.77E-07	1.41E+01	2.16E-04
BATCH-542	10/8/25	52	5.4	0.24	1.79E+02	0.00E+00	1.18E-08	1.41E-05	2.06E-08	1.60E-07	2.00E-03	3.53E-01	1.38E-07	7.00E-04	3.28E+00	0.00E+00	1.14E+01	0.00E+00	1.58E-05
BATCH-543	10/13/25	100	10.4	0.24	4.21E+02	0.00E+00	1.72E-08	7.66E-06	1.05E-08	7.62E-41	4.00E-03	6.68E-01	2.80E-08	1.00E-03	6.94E+00	0.00E+00	2.42E+01	0.00E+00	2.70E-05
BATCH-544	10/14/25	50	5.2	0.24	1.51E+02	0.00E+00	1.24E-08	1.79E-05	2.03E-08	1.52E-07	2.00E-03	3.62E-01	1.33E-07	8.09E-04	3.28E+00	0.00E+00	1.03E+01	0.00E+00	1.69E-05
BATCH-545	10/19/25	151	15.7	0.24	6.00E-03	2.83E+02	3.89E-07	6.14E-05	2.26E-07	1.24E-11	1.30E-02	2.18E+00	3.35E-07	2.00E-02	2.41E+01	0.00E+00	5.66E-04	1.57E+01	2.16E-04
BATCH-546	10/23/25	53	5.5	0.24	1.53E+02	0.00E+00	3.50E-08	3.29E-06	5.31E-08	3.84E-07	2.00E-03	4.24E-01	3.19E-07	1.00E-03	3.38E+00	0.00E+00	1.08E+01	0.00E+00	1.66E-05
BATCH-547	10/29/25	121	12.6	0.24	1.78E-09	2.27E+02	3.12E-07	4.92E-05	1.81E-07	1.49E-18	1.10E-02	1.75E+00	2.69E-07	1.60E-02	1.93E+01	0.00E+00	1.57E-10	1.26E+01	1.89E-04
BATCH-548	11/4/25	18	1.9	0.24	4.61E+01	0.00E+00	3.04E-09	3.63E-06	5.32E-09	4.12E-08	5.42E-04	9.10E-02	3.55E-08	1.81E-04	8.45E-01	0.00E+00	2.93E+00	0.00E+00	4.08E-06
BATCH-549	11/6/25	17	1.8	0.24	3.75E+01	0.00E+00	3.09E-09	4.44E-06	5.05E-09	3.77E-08	5.27E-04	9.00E-02	3.31E-08	2.01E-04	8.15E-01	0.00E+00	2.54E+00	0.00E+00	4.19E-06
BATCH-550	11/8/25	47	4.9	0.24	1.77E+02	0.00E+00	7.22E-09	3.21E-06	4.41E-09	3.20E-41	2.00E-03	2.80E-01	1.18E-08	6.09E-04	2.91E+00	0.00E+00	1.01E+01	0.00E+00	1.47E-05
BATCH-551	11/11/25	19	2.0	0.24	4.06E+01	0.00E+00	9.29E-09	8.73E-07	1.02E-07	5.60E-04	1.13E-01	8.46E-08	2.90E-04	8.99E-01	0.00E+00	2.86E+00	0.00E+00	4.41E-06
BATCH-552	11/13/25	115	12.0	0.24	2.56E-06	1.62E+02	2.19E-07	3.06E-05	1.44E-07	5.53E-15	8.00E-03	1.79E+00	5.45E-07	1.20E-02	1.81E+01	0.00E+00	2.53E-07	7.80E+00	1.89E-04
BATCH-553	11/13/25	119	12.5	0.24	8.00E-03	1.24E+02	1.62E-07	1.85E-05	1.27E-07	6.74E-12	7.00E-03	1.95E+00	8.01E-07	1.10E-02	1.85E+01	0.00E+00	4.79E-04	4.63E+00	2.16E-04
BATCH-554	11/25/25	119	12.5	0.24	6.00E-03	1.24E+02	1.62E-07	1.85E-05	1.27E-07	5.82E-12	7.00E-03	1.95E+00	8.01E-07	1.10E-02	1.85E+01	0.00E+00	3.93E-04	4.63E+00	2.16E-04
BATCH-555	11/26/25	86	9.0	0.24	1.09E-12	8.92E+01	1.17E-07	1.33E-05	9.11E-08	9.09E-22	5.00E-03	1.41E+00	5.76E-07	8.00E-03	1.33E+01	0.00E+00	9.58E-14	3.34E+00	1.62E-04
BATCH-556	12/5/25	17	1.7	0.24	4.20E+01	0.00E+00	1.72E-09	7.64E-07	1.05E-09	7.60E-42	3.67E-04	6.70E-02	2.79E-09	1.45E-04	6.92E-01	0.00E+00	2.41E+00	0.00E+00	3.49E-06
BATCH-557	12/7/25	119	12.4	0.24	7.00E-03	1.24E+02	1.62E-07	1.84E-05	1.26E-07	1.74E-11	7.00E-03	1.95E+00	7.99E-07	1.10E-02	1.84E+01	0.00E+00	4.88E-04	4.62E+00	2.16E-04
BATCH-558	12/8/25	92	9.6	0.24	1.46E-09	9.53E+01	1.25E-07	1.42E-05	9.73E-08	3.16E-18	5.00E-03	1.50E+00	6.15E-07	8.00E-03	1.42E+01	0.00E+00	1.45E-10	3.55E+00	1.62E-04
BATCH-559	12/18/25	110	11.5	0.24	3.39E-06	1.24E+02	9.63E-08	1.15E-05	7.56E-08	3.03E-15	6.00E-03	1.95E+00	4.96E-07	1.40E-02	1.78E+01	0.00E+00	2.15E-07	4.98E+00	1.35E-04
BATCH-560	12/20/25	100	10.4	0.24	7.52E-16	1.25E+02	2.34E-08	3.89E-06	1.92E-08	6.27E-25	6.00E-03	1.94E+00	1.59E-07	1.90E-02	1.70E+01	0.00E+00	6.60E-17	5.38E+00	2.70E-05
BATCH-561	12/29/25	139	14.5	0.24	2.87E-06	1.73E+02	3.24E-08	5.39E-06	2.66E-08	2.89E-15	8.00E-03	2.70E+00	2.21E-07	2.60E-02	2.36E+01	0.00E+00	1.95E-07	7.47E+00	5.39E-05
BATCH-562	12/31/25	160	16.7	0.24	6.00E-03	2.00E+02	3.73E-08	6.22E-06	3.06E-08	9.99E-46	9.00E-03	3.11E+00	2.54E-07	3.00E-02	2.72E+01	0.00E+00	3.17E-04	8.62E+00	5.39E-05
BATCH-563	1/13/26	107	11.1	0.24	9.41E-13	1.34E+02	2.50E-08	4.15E-06	2.05E-08	2.03E-21	6.00E-03	2.08E+00	1.70E-07	2.00E-02	2.36E+01	0.00E+00	9.30E-14	5.75E+00	2.70E-05
BATCH-564	1/16/26	138	14.4	0.24	3.43E-06	1.73E+02	3.23E-08	5.38E-06	2.65E-08	8.62E-15	8.00E-03	2.69E+00	2.20E-07	2.60E-02	2.36E+01	0.00E+00	2.42E-07	7.46E+00	5.39E-05
BATCH-565	1/24/26	113	11.8	0.24	2.06E-09	1.41E+02	2.63E-08	4.38E-06	2.16E-08	1.84E-18	6.00E-03	2.19E+00	1.79E-07	2.10E-02	1.92E+01	0.00E+00	1.31E-10	6.07E+00	5.39E-05
BATCH-566	1/31/26	81	8.4	0.24	1.68E+02	0.00E+00	6.17E-08	9.39E-06	3.77E-08	2.57E-13	3.00E-03	1.70E+00	9.58E-08	5.00E-03	5.47E+00	0.00E+00	2.77E+01	6.02E+00	5.39E-05
BATCH-567	2/5/26	105	11.0	0.24	1.53E-09	1.39E+02	2.14E-08	3.72E-06	2.34E-08	1.53E-18	6.00E-03	1.87E+00	1.90E-07	1.80E-02	1.74E+01	0.00E+00	1.04E-10	6.02E+00	5.39E-05
BATCH-568	2/9/26	118	12.3	0.24	2.99E-06	1.97E+02	7.26E-09	2.20E-06	4.34E-08	5.42E-49	7.00E-03	1.13E+00	3.32E-07	1.30E-02	1.69E+01	0.00E+00	1.72E-07	8.63E+00	5.39E-05
BATCH-569	2/16/26	88	9.2	0.24	2.01E+02	0.00E+00	5.58E-08	8.23E-06	3.55E-08	7.00E-13	3.00E-03	1.58E+00	1.15E-07	5.00E-03	5.67E+00	0.00E+00	2.83E+01	0.00E+00	5.39E-05
BATCH-570	2/21/26	102	10.6	0.24	2.15E-09	1.71E+02	6.29E-09	1.90E-06	3.76E-08	5.40E-18	6.00E-03	9.78E-01	2.87E-07	1.10E-02	1.46E+01	0.00E+00	1.52E-10	7.48E+00	1.35E-04
BATCH-571	2/26/26	83	8.7	0.24	1.58E-12	1.39E+02	5.13E-09	1.55E-06	3.06E-08	1.41E-21	5.00E-03	7.98E-01	2.34E-07	9.00E-03	1.19E+01	0.00E+00	6.10E-13	6.10E+00	1.08E-04
BATCH-572	3/4/26	59	6.2	0.24	1.15E+02	0.00E+00	4.21E-08	6.42E-06	2.58E-08	1.76E-13	2.00E-03	1.16E+00	6.54E-08	3.00E-03	1.16E+01	0.00E+00	1.89E+01	0.00E+00	2.70E-05
BATCH-573	3/7/26	81	8.4	0.24	1.21E-12	1.35E+02	4.98E-09	1.51E-06	2.98E-08	1.21E-21	5.00E-03	7.74E-01	2.27E-07	9.00E-03	1.16E+01	0.00E+00	8.18E-14	5.92E+00	1.08E-04
BATCH-574	3/11/26	106	11.0	0.24	1.80E-09	1.77E+02	6.52E-09	1.97E-06	3.90E-08	3.26E-52	7.00E-03	1.02E+00	2.98E-07	1.10E-02	1.52E+01	0.00E+00	1.04E-10	7.76E+00	1.35E-04
BATCH-575	3/15/26	55	5.7	0.24	1.14E+02	0.00E+00	3.16E-08	4.66E-06	2.01E-08	3.96E-13	2.00E-03	8.94E-01	6.53E-08	3.00E-03	3.21E+00	0.00E+00	1.60E+01	0.00E+00	2.53E-05
BATCH-576	3/21/26	92	9.5	0.24	1.49E-12	1.53E+02	5.64E-09	1.71E-06	3.38E-08	3.75E-21	6.00E-03	8.78E-01	2.58E-07	1.00E-02	1.31E+01	0.00E+00	1.05E-13	6.72E+00	1.35E-04
BATCH-577	3/22/26	105	10.9	0.24	2.52E+02	0.00E+00	3.17E-08	3.82E-06	2.64E-08	5.60E-13	3.00E-03	1.52E+00	1.74E-07	5.00E-03	6.12E+00	0.00E+00	6.38E+00	0.00E+00	5.39E-05
BATCH-578	3/31/26	24	2.5	0.24	3.87E+01	0.00E+00	1.42E-08	2.17E-06	8.70E-09	5.92E-14	7.83E-04	3.92E-01	2.21E-08	1.00E-03	1.26E+00	0.00E+00	2.93E+01	0.00E+00	1.00E-05
BATCH-579	4/2/26	107	11.1	0.24	2.36E+02	0.00E+00	2.00E-08	2.69E-06	1.75E-08	4.69E-13	4.00E-03	1.67E+00	1.24E-07	7.00E-03	7.05E+00	0.00E+00	4.47E+00	0.00E+00	2.70E-05
BATCH-580	4/3/26	20	2.1	0.24	3.18E+01	0.00E+00	8.81E-09	1.30E-06	5.61E-09	1.11E-13	5.44E-04	2.49E-01	1.82E-08	7.54E-04	8.95E-01	0.00E+00	6.91E-14	6.98E+00	1.35E-04
BATCH-581	4/5/26	95	9.9	0.24	1.20E-12	1.59E+02	5.86E-09	1.78E-06	3.51E-08	2.18E-55	6.00E-03	9.12E-01	2.68E-07	1.00E-02	1.36E+01	0.00E+00	2.79E+01	0.00E+00	2.70E-05
BATCH-582	4/13/26	87	9.0	0.24	2.19E+02	0.00E+00	1.61E-08	2.11E-06	1.61E-08	1.34E-12	3.00E-03	1.30E+00	1.12E-07	4.00E-03	5.12E+00	0.00E+00	1.43E+01	0.00E+00	2.27E-05
BATCH-583	4/15/26	53	5.6	0.24	1.16E+02	0.00E+00	1.46E-08	1.76E-06	1.22E-08	2.59E-13	2.00E-03	7.03E-01	8.05E-08	2.00E-03	2.83E+00	0.00E+00	1.00E-03	8.50E+00	1.62E-04
BATCH-584	4/21/26	139	14.5	0.24	9.00E-03	2.07E+02	5.54E-09	1.72E-06	3.31E-08	1.39E-17	7.00E-03	1.24E+00	2.52E-07	1.20E-02	1.78E+01	0.00E+00	8.40E-04	6.60E+00	1.35E-04
BATCH-585	4/22/26	152	15.8	0.24	6.00E-03	1.84E+02	1.32E-09	5.26E-07	7.86E-09	2.08E-17	6.00E-03	1.20E+00	5.65E-08	9.00E-03	1.60E+01	0.00E+00	1.42E+01	0.00E+00	1.67E-05
BATCH-586	5/5/26	57	5.9	0.24	1.15E+02	0.00E+00	9.73E-09	1.31E-06	8.47E-09	2.28E-13	2.00E-03	8.10E-01	6.00E-08	3.00E-03	3.42E+00	0.00E+00	5.07E-17	4.07E+00	8.09E-05
BATCH-587	5/9/26	94	9.8	0.24	8.83E-16	1.14E+02	8.18E-10	3.25E-07	4.87E-09	1.60E-58	4.00E-03	7.41E-01	3.50E-08	6.00E-03	9.90E+00	0.00E+00	5.07E-17	4.07E+00	

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Please view the native document

for the original page.

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-539	9/25/25	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.27E+00	2.57E-09	2.85E+00	3.21E+00	2.00E-03	3.23E-07	0.00E+00	9.00E-03	1.77E-05	8.43E-04
BATCH-540	9/27/25	103	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	3.30E+01	1.04E-09	1.08E+01	1.98E+01	3.00E-02	2.15E-11	0.00E+00	5.60E-02	2.68E-06	5.00E-03
BATCH-541	9/28/25	135	14.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.90E-02	6.56E+01	1.96E-08	8.14E+00	5.07E+01	1.16E-01	7.10E-13	0.00E+00	9.50E-02	1.91E-05	2.00E-02
BATCH-542	10/8/25	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.52E+01	4.16E-11	5.85E+00	8.98E+00	1.20E-02	7.23E-12	0.00E+00	2.00E-02	1.52E-06	2.00E-03
BATCH-543	10/13/25	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	2.45E+01	9.53E-10	6.90E+00	1.65E+01	2.90E-02	1.84E-11	0.00E+00	1.80E-02	4.63E-06	2.00E-03
BATCH-544	10/14/25	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.51E+01	1.09E-10	5.43E+00	9.07E+00	1.20E-02	8.33E-12	0.00E+00	2.10E-02	1.52E-06	2.00E-03
BATCH-545	10/19/25	151	15.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.90E-02	7.31E+01	2.19E-08	9.07E+00	5.65E+01	1.29E-01	5.52E-11	0.00E+00	1.06E-01	2.13E-05	2.20E-02
BATCH-546	10/23/25	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.54E+01	4.85E-10	5.06E+00	9.23E+00	1.40E-02	1.00E-11	0.00E+00	2.60E-02	1.25E-06	2.00E-03
BATCH-547	10/29/25	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	5.86E+01	1.76E-08	7.27E+00	4.53E+01	1.04E-01	5.93E-13	0.00E+00	8.50E-02	1.70E-05	1.70E-02
BATCH-548	11/4/25	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-04	3.92E+00	1.07E-11	1.51E+00	2.32E+00	3.00E-03	1.87E-12	0.00E+00	5.00E-03	3.92E-07	4.54E-04
BATCH-549	11/6/25	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.76E+00	2.71E-11	1.35E+00	2.25E+00	3.00E-03	2.07E-12	0.00E+00	5.00E-03	3.78E-07	4.91E-04
BATCH-550	11/8/25	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.03E+01	4.00E-10	2.89E+00	6.93E+00	1.20E-02	7.70E-12	0.00E+00	7.00E-03	1.94E-06	9.43E-04
BATCH-551	11/11/25	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.09E+00	1.29E-10	1.34E+00	2.45E+00	4.00E-03	2.66E-12	0.00E+00	7.00E-03	3.32E-07	5.64E-04
BATCH-552	11/13/25	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	4.94E+01	1.21E-08	5.12E+00	4.47E+01	7.70E-02	5.44E-09	0.00E+00	5.40E-02	1.26E-05	1.50E-02
BATCH-553	11/13/25	119	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-01	4.58E+01	8.69E-09	3.82E+00	4.77E+01	6.30E-02	1.01E-08	0.00E+00	3.40E-02	1.01E-05	1.40E-02
BATCH-554	11/25/25	119	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-01	4.58E+01	8.69E-09	3.82E+00	4.76E+01	6.30E-02	1.01E-08	0.00E+00	3.40E-02	1.01E-05	1.40E-02
BATCH-555	11/26/25	86	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-01	3.30E+01	6.26E-09	2.75E+00	3.43E+01	4.50E-02	7.25E-09	0.00E+00	2.40E-02	7.29E-06	1.00E-02
BATCH-556	12/5/25	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.66E-04	2.45E+00	9.50E-11	6.88E-01	1.65E+00	3.00E-03	1.83E-12	0.00E+00	2.00E-03	4.62E-07	2.24E-04
BATCH-557	12/7/25	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E-01	4.58E+01	8.68E-09	3.81E+00	4.76E+01	6.30E-02	1.01E-08	0.00E+00	3.40E-02	1.01E-05	1.40E-02
BATCH-558	12/8/25	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	3.52E+01	6.68E-09	2.94E+00	3.66E+01	4.80E-02	7.75E-09	0.00E+00	2.60E-02	7.78E-06	1.10E-02
BATCH-559	12/18/25	110	11.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-01	3.68E+01	5.80E-09	3.06E+00	4.01E+01	8.60E-02	5.30E-09	0.00E+00	2.10E-02	1.98E-05	9.00E-03
BATCH-560	12/20/25	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-02	2.68E+01	2.59E-09	2.23E+00	3.19E+01	1.13E-01	5.07E-12	0.00E+00	7.00E-03	3.05E-05	3.00E-03
BATCH-561	12/29/25	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-01	3.72E+01	3.60E-09	3.10E+00	4.43E+01	1.56E-01	5.10E-12	0.00E+00	1.00E-02	4.24E-05	4.00E-03
BATCH-562	12/31/25	160	16.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-01	4.29E+01	4.15E-09	3.57E+00	5.11E+01	1.80E-01	1.13E-13	0.00E+00	1.20E-02	4.89E-05	4.00E-03
BATCH-563	1/13/26	107	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-02	2.87E+01	2.77E-09	2.38E+00	3.41E+01	1.20E-01	5.06E-12	0.00E+00	8.00E-03	3.26E-05	3.00E-03
BATCH-564	1/16/26	138	14.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-01	3.71E+01	3.59E-09	3.09E+00	4.42E+01	1.56E-01	5.09E-12	0.00E+00	1.00E-02	4.23E-05	4.00E-03
BATCH-565	1/24/26	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.70E-02	3.02E+01	2.92E-09	2.52E+00	3.60E+01	1.27E-01	3.31E-12	0.00E+00	8.00E-03	3.44E-05	3.00E-03
BATCH-566	1/31/26	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	3.14E+01	3.55E-09	1.80E+01	1.36E+01	2.90E-02	4.85E-10	0.00E+00	2.20E-02	5.79E-06	4.00E-03
BATCH-567	2/5/26	105	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	3.11E+01	2.33E-09	2.65E+00	3.45E+01	1.03E-01	3.43E-09	0.00E+00	1.60E-02	3.49E-05	5.00E-03
BATCH-568	2/9/26	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.60E-02	4.99E+01	5.05E-10	4.55E+00	4.32E+01	3.20E-02	2.22E-08	0.00E+00	6.60E-02	5.35E-05	1.50E-02
BATCH-569	2/16/26	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.54E+01	3.23E-09	2.62E+01	1.39E+01	3.00E-02	8.22E-10	0.00E+00	2.00E-02	6.02E-06	4.00E-03
BATCH-570	2/21/26	102	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	4.32E+01	4.37E-10	3.94E+00	3.74E+01	2.80E-02	1.92E-08	0.00E+00	5.70E-02	4.64E-05	1.30E-02
BATCH-571	2/26/26	83	8.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.40E-02	3.52E+01	3.57E-10	3.21E+00	3.05E+01	2.30E-02	1.56E-08	0.00E+00	4.60E-02	3.78E-05	1.10E-02
BATCH-572	3/4/26	59	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	2.14E+01	2.42E-09	1.23E+01	9.27E+00	2.00E-02	3.32E-10	0.00E+00	1.50E-02	3.95E-06	3.00E-03
BATCH-573	3/7/26	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-02	3.42E+01	3.46E-10	3.12E+00	2.96E+01	2.20E-02	1.52E-08	0.00E+00	4.50E-02	3.67E-05	1.00E-02
BATCH-574	3/11/26	106	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-02	4.48E+01	4.52E-10	4.09E+00	3.88E+01	2.90E-02	1.99E-08	0.00E+00	5.90E-02	4.81E-05	1.40E-02
BATCH-575	3/15/26	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	2.00E+01	1.83E-09	1.48E+01	7.84E+00	1.70E-02	4.65E-10	0.00E+00	1.10E-02	3.41E-06	2.00E-03
BATCH-576	3/21/26	92	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.90E-02	3.88E+01	3.91E-10	3.54E+00	3.36E+01	2.50E-02	1.73E-08	0.00E+00	5.10E-02	4.17E-05	1.20E-02
BATCH-577	3/22/26	105	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-02	3.90E+01	1.87E-09	3.28E+01	1.51E+01	2.70E-02	2.69E-09	0.00E+00	1.50E-02	7.92E-06	3.00E-03
BATCH-578	3/31/26	24	2.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	7.23E+00	8.17E-10	4.14E+00	3.13E+00	7.00E-03	1.12E-10	0.00E+00	5.00E-03	1.33E-06	8.75E-04
BATCH-579	4/2/26	107	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.42E+01	1.46E-09	2.40E+01	1.56E+01	3.90E-02	1.72E-09	0.00E+00	1.30E-02	1.17E-05	3.00E-03
BATCH-580	4/3/26	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	5.59E+00	5.09E-10	4.14E+00	2.19E+00	5.00E-03	1.30E-10	0.00E+00	3.00E-03	9.51E-07	5.77E-04
BATCH-581	4/5/26	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-02	4.03E+01	4.06E-10	3.68E+00	3.49E+01	2.60E-02	1.79E-08	0.00E+00	5.30E-02	4.33E-05	1.20E-02
BATCH-582	4/13/26	87	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	3.01E+01	1.05E-09	2.24E+01	1.25E+01	2.20E-02	2.75E-09	0.00E+00	1.50E-02	9.48E-06	3.00E-03
BATCH-583	4/15/26	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	1.80E+01	8.66E-10	1.52E+01	6.99E+00	1.20E-02	1.24E-09	0.00E+00	7.00E-03	3.66E-06	2.00E-03
BATCH-584	4/21/26	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.20E-02	5.90E+01	3.82E-10	4.38E+00	6.53E+01	2.50E-02	1.68E-08	0.00E+00	5.60E-02	3.77E-05	1.30E-02
BATCH-585	4/22/26	152	15.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	6.41E+01	8.55E-11	3.22E+00	9.30E+01	6.00E-03	3.77E-09	0.00E+00	2.70E-02	1.43E-06	8.00E-03
BATCH-586	5/5/26	57	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	1.66E+01	7.10E-10	1.17E+01	7.58E+00	1.90E-02	8.33E-10	0.00E+00	6.00E-03	5.70E-06	1.00E-03
BATCH-587	5/9/26	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.95E+01	5.29E-11	1.99E+00	5.73E+01	4.00E-03	2.34E-09	0.00E+00	1.70E-02	9.11E-07	5.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-588	5/11/26	19	2.0	0.24	0.00E+00	0.00E+00	7.00E-03	3.00E-03	5.67E-01	1.71E-02	1.80E+02	5.20E-02	8.00E-03	8.41E-01	1.03E-14	6.10E-02	1.79E-04	1.70E-02	5.00E-04
BATCH-589	5/14/26	53	5.6	0.24	0.00E+00	0.00E+00	2.60E-02	1.00E-02	2.01E+00	6.93E-02	6.37E+02	1.82E-01	2.70E-02	2.95E+00	3.15E-14	2.14E-01	6.27E-04	5.80E-02	1.75E-03
BATCH-590	5/19/26	132	13.8	0.24	0.00E+00	0.00E+00	1.49E-01	4.40E-02	1.15E+01	2.73E-01	2.64E+03	1.14E+00	1.62E-01	1.31E+01	1.37E-13	1.31E+00	4.00E-03	3.48E-01	9.75E-03
BATCH-591	5/19/26	135	14.1	0.24	0.00E+00	0.00E+00	1.53E-01	4.50E-02	1.18E+01	2.79E-01	2.70E+03	1.17E+00	1.66E-01	1.35E+01	1.40E-13	1.34E+00	4.00E-03	3.57E-01	1.00E-02
BATCH-592	6/2/26	21	2.1	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.24E-01	2.52E-02	1.61E+02	4.30E-02	7.00E-03	7.42E-01	7.97E-15	5.30E-02	1.54E-04	1.40E-02	5.00E-04
BATCH-593	6/3/26	151	15.8	0.24	0.00E+00	0.00E+00	1.71E-01	5.10E-02	1.32E+01	3.12E-01	3.03E+03	1.31E+00	1.86E-01	1.51E+01	1.57E-13	1.50E+00	4.00E-03	4.00E-01	1.10E-02
BATCH-594	6/4/26	92	9.6	0.24	0.00E+00	0.00E+00	4.60E-02	1.40E-02	3.57E+00	1.31E-01	1.13E+03	3.24E-01	4.80E-02	5.21E+00	4.44E-14	3.78E-01	1.00E-03	1.03E-01	3.00E-03
BATCH-595	6/14/26	19	2.0	0.24	0.00E+00	0.00E+00	7.00E-03	3.00E-03	5.23E-01	1.80E-02	1.66E+02	4.70E-02	7.00E-03	7.67E-01	8.19E-15	5.60E-02	1.63E-04	1.50E-02	5.00E-04
BATCH-596	6/16/26	117	12.2	0.24	0.00E+00	0.00E+00	1.32E-01	3.90E-02	1.02E+01	2.42E-01	2.34E+03	1.02E+00	1.44E-01	1.17E+01	1.22E-13	1.16E+00	3.00E-03	3.09E-01	8.50E-03
BATCH-597	6/19/26	102	10.6	0.24	0.00E+00	0.00E+00	1.92E-01	5.30E-02	1.48E+01	2.91E-01	2.04E+03	1.45E+00	2.06E-01	1.02E+01	1.68E-13	1.66E+00	5.00E-03	4.42E-01	1.08E-02
BATCH-598	6/28/26	127	13.2	0.24	0.00E+00	0.00E+00	2.51E-01	7.00E-02	1.93E+01	3.75E-01	2.53E+03	1.89E+00	2.70E-01	1.26E+01	2.20E-13	2.18E+00	6.00E-03	5.79E-01	1.38E-02
BATCH-599	6/30/26	58	6.0	0.24	0.00E+00	0.00E+00	2.51E-01	7.00E-02	1.93E+01	3.74E-01	2.53E+03	1.89E+00	2.69E-01	1.26E+01	2.20E-13	2.17E+00	6.00E-03	5.79E-01	1.38E-02
BATCH-600	7/6/26	127	13.2	0.24	0.00E+00	0.00E+00	2.24E-01	6.20E-02	1.72E+01	3.34E-01	2.26E+03	1.69E+00	2.40E-01	1.12E+01	1.96E-13	1.94E+00	6.00E-03	5.16E-01	1.23E-02
BATCH-601	7/12/26	113	11.8	0.24	0.00E+00	0.00E+00	1.73E-01	4.80E-02	1.33E+01	2.59E-01	1.75E+03	1.31E+00	1.86E-01	8.71E+00	1.52E-13	1.50E+00	4.00E-03	4.00E-01	9.50E-03
BATCH-602	7/19/26	87	9.1	0.24	0.00E+00	0.00E+00	1.81E-01	5.00E-02	1.39E+01	2.70E-01	1.83E+03	1.36E+00	1.94E-01	9.09E+00	1.59E-13	1.57E+00	5.00E-03	4.18E-01	1.00E-02
BATCH-603	7/24/26	91	9.5	0.24	0.00E+00	0.00E+00	1.81E-01	5.00E-02	1.39E+01	2.70E-01	1.83E+03	1.36E+00	1.94E-01	9.09E+00	1.59E-13	1.57E+00	5.00E-03	4.18E-01	1.00E-02
BATCH-604	7/29/26	22	2.2	0.24	0.00E+00	0.00E+00	8.00E-03	2.00E-03	6.20E-01	2.25E-02	1.96E+02	5.60E-02	8.00E-03	9.05E-01	7.71E-15	6.60E-02	1.92E-04	1.80E-02	5.00E-04
BATCH-605	7/31/26	114	11.9	0.24	0.00E+00	0.00E+00	2.19E-01	6.00E-02	1.69E+01	3.23E-01	2.29E+03	1.66E+00	2.36E-01	1.14E+01	2.08E-13	1.91E+00	6.00E-03	5.07E-01	1.20E-02
BATCH-606	8/3/26	120	12.5	0.24	0.00E+00	0.00E+00	2.18E-01	5.80E-02	1.68E+01	3.13E-01	2.40E+03	1.66E+00	2.35E-01	1.20E+01	2.34E-13	1.91E+00	6.00E-03	5.07E-01	1.23E-02
BATCH-607	8/13/26	107	11.2	0.24	0.00E+00	0.00E+00	1.94E-01	5.20E-02	1.50E+01	2.79E-01	2.14E+03	1.48E+00	2.10E-01	1.07E+01	2.08E-13	1.70E+00	5.00E-03	4.52E-01	1.08E-02
BATCH-608	8/15/26	83	8.6	0.24	0.00E+00	0.00E+00	1.51E-01	4.00E-02	1.16E+01	2.16E-01	1.66E+03	1.15E+00	1.62E-01	8.26E+00	1.61E-13	1.32E+00	4.00E-03	3.50E-01	8.50E-03
BATCH-609	8/24/26	130	13.6	0.24	0.00E+00	0.00E+00	2.37E-01	6.30E-02	1.83E+01	3.40E-01	2.61E+03	1.80E+00	2.55E-01	1.30E+01	2.54E-13	2.07E+00	6.00E-03	5.50E-01	1.33E-02
BATCH-610	8/24/26	87	9.0	0.24	0.00E+00	0.00E+00	1.57E-01	4.20E-02	1.21E+01	2.26E-01	1.73E+03	1.20E+00	1.70E-01	8.62E+00	1.68E-13	1.38E+00	4.00E-03	3.66E-01	8.75E-03
BATCH-611	9/2/26	107	11.2	0.24	0.00E+00	0.00E+00	1.95E-01	5.20E-02	1.50E+01	2.80E-01	2.14E+03	1.48E+00	2.10E-01	1.07E+01	2.09E-13	1.70E+00	5.00E-03	4.53E-01	1.08E-02
BATCH-612	9/7/26	105	10.9	0.24	0.00E+00	0.00E+00	1.98E-01	5.30E-02	1.53E+01	2.83E-01	2.09E+03	1.50E+00	2.13E-01	1.04E+01	1.96E-13	1.73E+00	5.00E-03	4.20E-01	1.00E-02
BATCH-613	9/14/26	92	9.6	0.24	0.00E+00	0.00E+00	1.82E-01	4.80E-02	1.40E+01	2.58E-01	1.84E+03	1.37E+00	1.94E-01	9.18E+00	1.66E-13	1.58E+00	5.00E-03	3.26E-01	7.75E-03
BATCH-614	9/18/26	71	7.5	0.24	0.00E+00	0.00E+00	1.41E-01	3.70E-02	1.08E+01	2.00E-01	1.43E+03	1.06E+00	1.51E-01	7.11E+00	1.29E-13	1.23E+00	4.00E-03	3.40E-01	8.00E-03
BATCH-615	9/24/26	75	7.8	0.24	0.00E+00	0.00E+00	1.47E-01	3.90E-02	1.13E+01	2.09E-01	1.49E+03	1.11E+00	1.58E-01	7.44E+00	1.35E-13	1.28E+00	4.00E-03	3.12E-01	8.00E-03
BATCH-616	9/25/26	112	11.7	0.24	0.00E+00	0.00E+00	2.21E-01	5.90E-02	1.71E+01	3.14E-01	2.25E+03	1.67E+00	2.37E-01	1.12E+01	2.03E-13	1.93E+00	6.00E-03	5.12E-01	1.23E-02
BATCH-617	10/2/26	93	9.6	0.24	0.00E+00	0.00E+00	1.82E-01	4.80E-02	1.41E+01	2.59E-01	1.85E+03	1.38E+00	1.95E-01	9.21E+00	1.67E-13	1.59E+00	5.00E-03	4.22E-01	1.00E-02
BATCH-618	10/7/26	93	9.7	0.24	0.00E+00	0.00E+00	1.84E-01	4.90E-02	1.42E+01	2.61E-01	1.86E+03	1.39E+00	1.97E-01	9.28E+00	1.68E-13	1.60E+00	5.00E-03	4.25E-01	1.00E-02
BATCH-619	10/11/26	84	8.8	0.24	0.00E+00	0.00E+00	1.66E-01	4.40E-02	1.28E+01	2.36E-01	1.69E+03	1.25E+00	1.78E-01	8.39E+00	1.52E-13	1.45E+00	4.00E-03	3.84E-01	9.25E-03
BATCH-620	10/17/26	110	11.5	0.24	0.00E+00	0.00E+00	6.00E-02	1.80E-02	4.65E+00	1.03E-01	1.50E+03	4.59E-01	6.50E-02	7.08E+00	5.76E-14	5.25E-01	2.00E-03	1.40E-01	3.50E-03
BATCH-621	10/20/26	105	10.9	0.24	0.00E+00	0.00E+00	5.40E-02	1.50E-02	4.13E+00	8.73E-02	1.32E+03	4.07E-01	5.80E-02	6.33E+00	4.96E-14	4.67E-01	1.00E-03	1.24E-01	3.25E-03
BATCH-622	10/29/26	92	9.6	0.24	0.00E+00	0.00E+00	1.55E-01	4.00E-02	1.19E+01	2.37E-01	1.84E+03	1.17E+00	1.66E-01	9.15E+00	9.12E-12	1.33E+00	4.00E-03	3.54E-01	8.50E-03
BATCH-623	10/31/26	75	7.9	0.24	0.00E+00	0.00E+00	1.25E-01	3.20E-02	9.65E+00	1.93E-01	1.51E+03	9.47E-01	1.35E-01	7.51E+00	8.07E-12	1.07E+00	3.00E-03	2.86E-01	7.00E-03
BATCH-624	11/8/26	76	7.9	0.24	0.00E+00	0.00E+00	1.26E-01	3.30E-02	9.73E+00	1.94E-01	1.52E+03	9.55E-01	1.36E-01	7.57E+00	8.13E-12	1.08E+00	3.00E-03	2.89E-01	7.00E-03
BATCH-625	11/9/26	69	7.2	0.24	0.00E+00	0.00E+00	1.15E-01	3.00E-02	8.81E+00	1.76E-01	1.38E+03	8.65E-01	1.23E-01	6.86E+00	7.37E-12	9.81E-01	3.00E-03	2.61E-01	6.25E-03
BATCH-626	11/16/26	53	5.5	0.24	0.00E+00	0.00E+00	2.60E-02	8.00E-03	2.03E+00	4.50E-02	6.53E+02	2.00E-01	2.90E-02	3.09E+00	2.52E-14	2.29E-01	6.69E-04	6.10E-02	1.50E-03
BATCH-627	11/16/26	53	5.6	0.24	0.00E+00	0.00E+00	2.50E-02	7.00E-03	1.90E+00	3.96E-02	6.06E+02	1.87E-01	2.70E-02	2.91E+00	2.28E-14	2.15E-01	6.27E-04	5.70E-02	1.50E-03
BATCH-628	11/22/26	81	8.4	0.24	0.00E+00	0.00E+00	1.34E-01	3.50E-02	1.03E+01	2.06E-01	1.61E+03	1.01E+00	1.44E-01	8.04E+00	8.64E-12	1.15E+00	3.00E-03	3.06E-01	7.50E-03
BATCH-629	11/22/26	67	6.9	0.24	0.00E+00	0.00E+00	1.11E-01	2.80E-02	8.51E+00	1.70E-01	1.33E+03	8.35E-01	1.19E-01	6.62E+00	7.12E-12	9.47E-01	3.00E-03	2.52E-01	6.00E-03
BATCH-630	11/29/26	96	10.0	0.24	0.00E+00	0.00E+00	5.30E-02	1.50E-02	4.11E+00	8.19E-02	1.33E+03	4.04E-01	5.70E-02	6.20E+00	5.52E-13	4.64E-01	1.00E-03	1.23E-01	3.00E-03
BATCH-631	11/30/26	67	7.0	0.24	0.00E+00	0.00E+00	1.11E-01	2.90E-02	8.57E+00	1.71E-01	1.34E+03	8.41E-01	1.20E-01	6.67E+00	7.17E-12	9.54E-01	3.00E-03	2.54E-01	6.25E-03
BATCH-632	12/7/26	18	1.9	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.14E-01	1.17E-02	1.65E+02	5.10E-02	7.00E-03	7.82E-01	6.37E-15	5.80E-02	1.69E-04	1.50E-02	5.00E-04
BATCH-633	12/9/26	18	1.9	0.24	0.00E+00	0.00E+00	6.00E-03	2.00E-03	4.71E-01	9.90E-03	1.50E+02	4.60E-02	7.00E-03	7.21E-01	5.65E-15	5.30E-02	1.56E-04	1.40E-02	2.50E-04
BATCH-634	12/9/26	97	10.1	0.24	0.00E+00	0.00E+00	6.00E-02	1.60E-02	4.59E+00	8.82E-02	1.51E+03	4.50E-01	6.40E-02	6.90E+00	1.11E-12	5.16E-01	2.00E-03	1.37E-01	3.25E-03
BATCH-635	12/11/26	71	7.4	0.24	0.00E+00	0.00E+00	1.18E-01	3.00E-02	9.09E+00	1.82E-01	1.42E+03	8.92E-01	1.27E-01	7.08E+00	7.61E-12	1.01E+00	3.00E-03	2.70E-01	6.50E-03
BATCH-636	12/19/26	94	9.8	0.24	0.00E+00	0.00E+00	5.70E-02	1.50E-02	4.39E+00	8.37E-02	1.44E+03	4.31E-01	6.10E-02	6.55E+00	1.10E-12	4.94E-01	1.00E-03	1.31E-01	3.25E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-588	5/11/26	19	2.0	0.24	6.14E-09	5.67E+01	2.87E+01	2.00E-03	1.48E-01	9.00E-03	2.19E-05	1.01E-06	2.65E-05	1.35E-05	1.31E-05	3.58E-05	2.00E-03	1.20E-02	3.00E-03
BATCH-589	5/14/26	53	5.6	0.24	2.27E-08	1.60E+02	1.00E+02	9.00E-03	5.18E-01	3.00E-02	5.38E-05	3.52E-06	9.53E-05	4.79E-05	4.60E-05	1.26E-04	8.00E-03	4.30E-02	1.10E-02
BATCH-590	5/19/26	132	13.8	0.24	1.13E-07	3.96E+02	6.32E+02	5.40E-02	3.24E+00	1.87E-01	3.87E-05	2.22E-05	3.52E-04	2.24E-04	2.99E-04	6.46E-04	3.60E-02	1.89E-01	5.60E-02
BATCH-591	5/19/26	135	14.1	0.24	1.16E-07	4.05E+02	6.47E+02	5.50E-02	3.32E+00	1.91E-01	3.96E-05	2.28E-05	3.60E-04	2.29E-04	3.06E-04	6.61E-04	3.70E-02	1.93E-01	5.70E-02
BATCH-592	6/2/26	21	2.1	0.24	6.41E-09	6.16E+01	2.37E+01	2.00E-03	1.24E-01	7.00E-03	1.49E-05	8.34E-07	3.05E-05	1.37E-05	1.09E-05	3.37E-05	2.00E-03	1.30E-02	3.00E-03
BATCH-593	6/3/26	151	15.8	0.24	1.30E-07	4.54E+02	7.25E+02	6.20E-02	3.72E+00	2.14E-01	4.43E-05	2.55E-05	4.03E-04	2.57E-04	3.43E-04	7.41E-04	4.20E-02	2.16E-01	6.40E-02
BATCH-594	6/4/26	92	9.6	0.24	4.14E-08	2.75E+02	1.77E+02	1.50E-02	9.21E-01	5.40E-02	3.73E-05	1.64E-04	8.35E-05	1.25E-05	8.25E-05	2.19E-04	1.50E-02	7.60E-02	1.90E-02
BATCH-595	6/14/26	19	2.0	0.24	5.90E-09	5.62E+01	2.60E+01	2.00E-03	1.35E-01	8.00E-03	1.40E-05	9.16E-07	2.48E-05	1.25E-05	1.20E-05	3.28E-05	2.00E-03	1.10E-02	3.00E-03
BATCH-596	6/16/26	117	12.2	0.24	1.01E-07	3.51E+02	5.61E+02	4.80E-02	2.88E+00	1.66E-01	3.43E-05	1.97E-05	3.12E-04	1.99E-04	2.65E-04	5.73E-04	3.20E-02	1.68E-01	4.90E-02
BATCH-597	6/19/26	102	10.6	0.24	1.36E-07	3.06E+02	8.02E+02	6.70E-02	4.09E+00	2.32E-01	1.83E-05	2.81E-05	4.59E-04	2.93E-04	3.68E-04	8.58E-04	4.80E-02	2.50E-01	7.20E-02
BATCH-598	6/28/26	127	13.2	0.24	1.77E-07	3.80E+02	1.05E+03	8.80E-02	5.36E+00	3.04E-01	2.08E-05	3.63E-06	6.03E-04	3.84E-04	4.81E-04	1.00E-03	6.30E-02	3.28E-01	9.40E-02
BATCH-599	6/30/26	58	6.0	0.24	2.41E-08	1.74E+02	1.03E+02	9.00E-03	5.37E+01	3.20E-02	2.18E-05	9.56E-05	4.87E-05	3.84E-04	4.81E-04	1.28E-04	8.00E-03	4.40E-02	1.10E-02
BATCH-600	7/6/26	127	13.2	0.24	1.77E-07	3.80E+02	1.05E+03	8.80E-02	5.35E+00	3.04E-01	2.08E-05	3.68E-05	6.03E-04	3.42E-04	4.29E-04	1.00E-03	6.30E-02	3.28E-01	9.40E-02
BATCH-601	7/12/26	113	11.8	0.24	1.58E-07	3.38E+02	9.36E+02	7.80E-02	4.77E+00	2.71E-01	1.85E-05	3.28E-05	5.37E-04	3.42E-04	4.29E-04	1.00E-03	5.60E-02	2.92E-01	8.40E-02
BATCH-602	7/19/26	87	9.1	0.24	1.22E-07	2.62E+02	7.25E+02	6.10E-02	3.70E+00	2.10E-01	1.43E-05	2.54E-05	4.16E-04	2.65E-04	3.32E-04	7.78E-04	4.30E-02	2.26E-01	6.50E-02
BATCH-603	7/24/26	91	9.5	0.24	1.28E-07	2.74E+02	7.57E+02	6.30E-02	3.86E+00	2.19E-01	1.50E-05	2.66E-05	4.35E-04	2.77E-04	3.47E-04	8.12E-04	4.50E-02	2.36E-01	6.80E-02
BATCH-604	7/29/26	22	2.2	0.24	7.19E-09	6.46E+01	3.07E+01	3.00E-03	1.60E-01	9.00E-03	6.48E-06	1.08E-06	2.85E-05	1.45E-05	1.43E-05	3.81E-05	3.00E-03	1.30E-02	3.00E-03
BATCH-605	7/31/26	114	11.9	0.24	1.53E-07	3.43E+02	9.21E+02	7.70E-02	4.71E+00	2.68E-01	2.04E-05	3.22E-05	5.17E-04	3.30E-04	4.19E-04	9.67E-04	5.40E-02	2.82E-01	8.10E-02
BATCH-606	8/3/26	120	12.5	0.24	1.50E-07	3.60E+02	9.24E+02	7.70E-02	4.74E+00	2.70E-01	2.42E-05	3.22E-05	4.99E-04	3.19E-04	4.16E-04	9.32E-04	5.30E-02	2.74E-01	8.00E-02
BATCH-607	8/13/26	107	11.2	0.24	1.34E-07	3.21E+02	8.24E+02	6.90E-02	4.23E+00	2.40E-01	2.15E-05	2.87E-05	4.45E-04	2.85E-04	3.71E-04	8.31E-04	4.70E-02	2.44E-01	7.10E-02
BATCH-608	8/15/26	83	8.6	0.24	1.04E-07	2.49E+02	6.38E+02	5.30E-02	3.27E+00	1.86E-01	1.67E-05	2.22E-05	3.45E-04	2.21E-04	2.87E-04	6.44E-04	3.60E-02	1.89E-01	5.50E-02
BATCH-609	8/24/26	130	13.6	0.24	1.63E-07	3.91E+02	1.00E+03	8.40E-02	5.15E+00	2.93E-01	2.62E-05	3.49E-05	5.42E-04	3.47E-04	4.52E-04	1.00E-03	5.70E-02	2.98E-01	8.70E-02
BATCH-610	8/24/26	87	9.0	0.24	1.08E-07	2.60E+02	6.66E+02	5.60E-02	3.42E+00	1.95E-01	1.74E-05	2.32E-05	3.60E-04	2.30E-04	3.00E-04	6.72E-04	3.80E-02	1.98E-01	5.80E-02
BATCH-611	9/2/26	107	11.2	0.24	1.34E-07	3.22E+02	8.25E+02	6.90E-02	4.23E+00	2.41E-01	2.16E-05	2.87E-05	4.46E-04	2.85E-04	3.71E-04	8.33E-04	4.70E-02	2.45E-01	7.20E-02
BATCH-612	9/7/26	105	10.9	0.24	1.39E-07	3.13E+02	8.38E+02	7.00E-02	4.32E+00	2.47E-01	3.50E-05	2.92E-05	4.67E-04	2.97E-04	3.77E-04	8.69E-04	4.90E-02	2.55E-01	7.40E-02
BATCH-613	9/14/26	92	9.6	0.24	1.29E-07	2.76E+02	7.66E+02	6.40E-02	3.96E+00	2.28E-01	4.21E-05	2.67E-05	4.39E-04	2.78E-04	3.44E-04	8.13E-04	4.60E-02	2.38E-01	6.80E-02
BATCH-614	9/18/26	71	7.5	0.24	1.00E-07	2.14E+02	5.94E+02	5.00E-02	3.07E+00	1.77E-01	3.26E-05	2.07E-05	3.40E-04	2.15E-04	2.67E-04	6.30E-04	3.50E-02	1.84E-01	5.30E-02
BATCH-615	9/24/26	75	7.8	0.24	1.05E-07	2.24E+02	6.21E+02	5.20E-02	3.21E+00	1.85E-01	3.41E-05	2.17E-05	3.55E-04	2.25E-04	2.79E-04	6.59E-04	3.70E-02	1.93E-01	5.50E-02
BATCH-616	9/25/26	112	11.7	0.24	1.57E-07	3.37E+02	9.33E+02	7.80E-02	4.82E+00	2.78E-01	5.12E-05	3.26E-05	5.34E-04	3.38E-04	4.20E-04	9.91E-04	5.60E-02	2.90E-01	8.30E-02
BATCH-617	10/2/26	93	9.6	0.24	1.30E-07	2.77E+02	7.69E+02	6.40E-02	3.97E+00	2.29E-01	4.22E-05	2.68E-05	4.40E-04	2.79E-04	3.46E-04	8.17E-04	4.60E-02	2.39E-01	6.80E-02
BATCH-618	10/7/26	93	9.7	0.24	1.30E-07	2.80E+02	7.75E+02	6.50E-02	4.00E+00	2.31E-01	4.25E-05	2.70E-05	4.44E-04	2.81E-04	3.48E-04	8.23E-04	4.60E-02	2.40E-01	6.90E-02
BATCH-619	10/11/26	84	8.8	0.24	1.18E-07	2.53E+02	7.00E+02	5.90E-02	3.62E+00	2.09E-01	3.85E-05	2.44E-05	4.01E-04	2.54E-04	3.15E-04	7.44E-04	4.20E-02	2.17E-01	6.20E-02
BATCH-620	10/17/26	110	11.5	0.24	4.58E-08	3.29E+02	2.54E+02	2.10E-02	1.31E+00	7.60E-02	2.14E-05	8.91E-06	1.50E-04	9.34E-05	1.18E-04	2.69E-04	1.50E-02	8.00E-02	2.30E-02
BATCH-621	10/20/26	105	10.9	0.24	3.90E-08	3.13E+02	2.26E+02	1.90E-02	1.16E+00	6.60E-02	9.80E-06	7.92E-06	1.27E-04	8.09E-05	1.05E-04	2.35E-04	1.30E-02	6.90E-02	2.00E-02
BATCH-622	10/29/26	92	9.6	0.24	1.25E-07	2.76E+02	6.45E+02	5.40E-02	3.29E+00	1.87E-01	4.70E-02	2.24E-05	3.48E-04	2.20E-04	2.96E-04	6.38E-04	3.60E-02	1.88E-01	5.60E-02
BATCH-623	10/31/26	75	7.9	0.24	1.03E-07	2.26E+02	5.21E+02	4.40E-02	2.66E+00	1.51E-01	4.20E-02	1.81E-05	2.80E-04	1.77E-04	2.40E-04	5.12E-04	2.90E-02	1.51E-01	4.50E-02
BATCH-624	11/8/26	76	7.9	0.24	1.03E-07	2.28E+02	5.26E+02	4.40E-02	2.68E+00	1.52E-01	4.20E-02	1.83E-05	2.82E-04	1.78E-04	2.42E-04	5.16E-04	2.90E-02	1.52E-01	4.60E-02
BATCH-625	11/9/26	69	7.2	0.24	9.37E-08	2.07E+02	4.76E+02	4.00E-02	2.43E+00	1.38E-01	3.80E-02	1.66E-05	2.55E-04	1.62E-04	2.19E-04	4.68E-04	2.60E-02	1.38E-01	4.10E-02
BATCH-626	11/16/26	53	5.5	0.24	2.00E-08	1.59E+02	1.11E+02	9.00E-03	5.70E-01	3.30E-02	9.35E-06	3.89E-06	6.53E-05	4.08E-05	5.13E-05	1.18E-04	7.00E-03	3.50E-02	1.00E-02
BATCH-627	11/16/26	53	5.6	0.24	1.79E-08	1.60E+02	1.04E+02	9.00E-03	5.33E-01	3.00E-02	4.51E-06	3.64E-06	5.83E-05	3.72E-05	4.81E-05	1.08E-04	6.00E-03	3.20E-02	9.00E-03
BATCH-628	11/22/26	81	8.4	0.24	1.10E-07	2.42E+02	5.58E+02	4.70E-02	2.85E+00	1.62E-01	4.50E-02	1.94E-05	2.99E-04	1.89E-04	2.56E-04	5.48E-04	3.10E-02	1.61E-01	4.80E-02
BATCH-629	11/22/26	67	6.9	0.24	9.04E-08	1.99E+02	4.60E+02	3.80E-02	2.34E+00	1.33E-01	3.70E-02	1.60E-05	2.46E-04	1.56E-04	2.11E-04	4.51E-04	2.50E-02	1.33E-01	4.00E-02
BATCH-630	11/29/26	96	10.0	0.24	3.90E-08	2.87E+02	2.25E+02	1.90E-02	1.15E+00	6.60E-02	3.00E-03	7.85E-06	1.26E-04	7.98E-05	1.03E-04	2.33E-04	1.30E-02	6.80E-02	2.00E-02
BATCH-631	11/30/26	67	7.0	0.24	9.11E-08	2.01E+02	4.63E+02	3.90E-02	2.36E+00	1.34E-01	3.70E-02	1.61E-05	2.48E-04	1.57E-04	2.13E-04	4.55E-04	2.60E-02	1.34E-01	4.00E-02
BATCH-632	12/7/26	18	1.9	0.24	5.06E-09	5.51E+01	2.80E+01	2.00E-03	1.44E-01	8.00E-03	2.37E-06	9.84E-07	1.65E-05	1.03E-05	1.30E-05	2.97E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-633	12/9/26	18	1.9	0.24	4.44E-09	5.46E+01	2.58E+01	2.00E-03	1.32E-01	8.00E-03	1.12E-06	9.04E-07	1.45E-05	9.22E-06	1.19E-05	2.68E-05	2.00E-03	8.00E-03	2.00E-03
BATCH-634	12/9/26	97	10.1	0.24	4.38E-08	2.90E+02	2.50E+02	2.10E-02	1.28E+00	7.30E-02	6.00E-03	8.72E-06	1.39E-04	8.86E-05	1.14E-04	2.59E-04	1.50E-02	7.60E-02	2.20E-02
BATCH-635	12/11/26	71	7.4	0.24	9.67E-08	2.13E+02	4.91E+02	4.10E-02	2.51E+00	1.42E-01	4.00E-02	1.71E-05	2.63E-04	1.67E-04	2.26E-04	4.82E-04	2.70E-02	1.42E-01	4.30E-02
BATCH-636	12/19/26	94	9.8	0.24	4.17E-08	2.81E+02	2.39E+02	2.00E-02	1.23E+00	7.00E-02	5.00E-03	8.34E-06	1.32E-04	8.40E-05	1.09E-04	2.45E-04	1.40E-02	7.20E-02	2.10E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-588	5/11/26	19	2.0	0.24	1.20E-04	8.74E-05	3.00E-03	6.00E-03	3.00E-03	2.62E-01	4.40E-02	2.03E-01	1.13E-01	1.42E-24	2.92E-06	7.68E-06	2.11E-04	1.00E-03	5.10E-09
BATCH-589	5/14/26	53	5.6	0.24	4.26E-04	3.11E-04	1.00E-02	2.00E-02	1.20E-02	8.63E-01	1.47E-01	6.85E-01	3.76E-01	4.14E-24	9.69E-06	2.58E-05	6.17E-04	4.00E-03	1.14E-08
BATCH-590	5/19/26	132	13.8	0.24	2.00E-03	2.00E-03	6.10E-02	9.00E-02	6.40E-02	4.01E+00	6.74E-01	3.85E+00	1.67E+00	1.04E-23	4.24E-05	1.43E-04	2.00E-03	1.00E-02	3.44E-09
BATCH-591	5/19/26	135	14.1	0.24	2.00E-03	2.00E-03	6.20E-02	9.20E-02	6.60E-02	4.10E+00	6.91E-01	3.95E+00	1.71E+00	1.07E-23	4.35E-05	1.47E-04	2.00E-03	1.00E-02	3.51E-09
BATCH-592	6/2/26	21	2.1	0.24	1.16E-04	8.14E-05	2.00E-03	6.00E-03	3.00E-03	2.34E-01	4.00E-02	1.67E-01	1.04E-01	1.21E-24	2.71E-06	6.31E-06	1.80E-04	1.00E-03	2.93E-09
BATCH-593	6/3/26	151	15.8	0.24	3.00E-03	2.00E-03	7.00E-02	1.03E-01	7.40E-02	4.60E+00	7.74E-01	4.42E+00	1.91E+00	1.19E-23	4.87E-05	1.64E-04	2.00E-03	1.10E-02	3.94E-09
BATCH-594	6/4/26	92	9.6	0.24	7.55E-04	5.54E-04	1.70E-02	3.20E-02	2.10E-02	1.36E+00	2.32E-01	1.15E+00	5.96E-01	5.06E-24	1.54E-05	4.27E-05	7.51E-04	6.00E-03	4.21E-09
BATCH-595	6/14/26	19	2.0	0.24	1.11E-04	8.10E-05	3.00E-03	5.00E-03	3.00E-03	2.25E-01	3.80E-02	1.78E-01	9.80E-02	1.08E-24	2.52E-06	6.71E-06	1.61E-04	1.00E-03	2.95E-09
BATCH-596	6/16/26	117	12.2	0.24	2.00E-03	2.00E-03	5.40E-02	8.00E-02	5.70E-02	3.56E+00	5.99E-01	3.42E+00	1.48E+00	9.23E-24	3.77E-05	1.27E-04	1.00E-03	9.00E-03	3.05E-09
BATCH-597	6/19/26	102	10.6	0.24	3.00E-03	2.00E-03	7.80E-02	1.08E-01	8.20E-02	4.76E+00	8.02E-01	4.83E+00	1.99E+00	9.06E-24	5.09E-05	1.79E-04	1.00E-03	8.00E-03	6.03E-10
BATCH-598	6/28/26	127	13.2	0.24	4.00E-03	3.00E-03	1.02E-01	1.41E-01	1.08E-01	6.19E+00	1.05E+00	6.32E+00	2.60E+00	1.14E-23	6.63E-05	2.35E-04	2.00E-03	1.00E-02	3.93E-10
BATCH-599	6/30/26	58	6.0	0.24	4.40E-04	3.23E-04	1.00E-02	1.80E-02	1.20E-02	7.94E-01	1.35E-01	6.67E-01	3.47E-01	2.95E-24	8.95E-06	2.49E-05	4.37E-04	3.00E-03	2.45E-09
BATCH-600	7/6/26	127	13.2	0.24	4.00E-03	3.00E-03	1.02E-01	1.41E-01	1.07E-01	6.19E+00	1.04E+00	6.32E+00	2.59E+00	1.14E-23	6.62E-05	2.34E-04	2.00E-03	1.00E-02	3.93E-10
BATCH-601	7/12/26	113	11.8	0.24	3.00E-03	3.00E-03	9.10E-02	1.26E-01	9.60E-02	5.52E+00	9.31E-01	5.63E+00	2.31E+00	1.02E-23	5.90E-05	2.09E-04	1.00E-03	9.00E-03	3.52E-10
BATCH-602	7/19/26	87	9.1	0.24	3.00E-03	2.00E-03	7.00E-02	9.70E-02	7.40E-02	4.27E+00	7.21E-01	4.36E+00	1.79E+00	7.89E-24	4.57E-05	1.62E-04	1.00E-03	7.00E-03	2.73E-10
BATCH-603	7/24/26	91	9.5	0.24	3.00E-03	2.00E-03	7.30E-02	1.02E-01	7.80E-02	4.48E+00	7.53E-01	4.56E+00	1.87E+00	8.24E-24	4.78E-05	1.69E-04	1.00E-03	8.00E-03	2.83E-10
BATCH-604	7/29/26	22	2.2	0.24	1.31E-04	9.61E-05	3.00E-03	6.00E-03	4.00E-03	2.37E-01	4.00E-02	1.99E-01	1.03E-01	8.78E-25	2.67E-06	7.42E-06	1.30E-04	1.00E-03	7.32E-10
BATCH-605	7/31/26	114	11.9	0.24	3.00E-03	3.00E-03	8.90E-02	1.20E-01	9.30E-02	5.28E+00	8.91E-01	5.50E+00	2.22E+00	8.59E-24	5.68E-05	2.05E-04	1.00E-03	8.00E-03	8.86E-10
BATCH-606	8/3/26	120	12.5	0.24	3.00E-03	3.00E-03	9.00E-02	1.15E-01	9.20E-02	5.02E+00	8.51E-01	5.45E+00	2.14E+00	6.18E-24	5.48E-05	2.03E-04	8.98E-04	6.00E-03	1.81E-09
BATCH-607	8/13/26	107	11.2	0.24	3.00E-03	2.00E-03	8.00E-02	1.03E-01	8.20E-02	4.48E+00	7.59E-01	4.85E+00	1.91E+00	5.51E-24	4.88E-05	1.81E-04	8.01E-04	5.00E-03	1.62E-09
BATCH-608	8/15/26	83	8.6	0.24	2.00E-03	2.00E-03	6.20E-02	8.00E-02	6.40E-02	3.47E+00	5.88E-01	3.76E+00	1.48E+00	4.27E-24	3.78E-05	1.40E-04	6.21E-04	4.00E-03	1.25E-09
BATCH-609	8/24/26	130	13.6	0.24	4.00E-03	3.00E-03	9.70E-02	1.25E-01	1.00E-01	5.45E+00	9.24E-01	5.91E+00	2.32E+00	6.70E-24	5.95E-05	2.21E-04	9.75E-04	6.00E-03	1.97E-09
BATCH-610	8/24/26	87	9.0	0.24	2.00E-03	2.00E-03	6.50E-02	8.30E-02	6.60E-02	3.62E+00	6.14E-01	3.93E+00	1.54E+00	4.46E-24	3.95E-05	1.47E-04	6.48E-04	4.00E-03	1.31E-09
BATCH-611	9/2/26	107	11.2	0.24	3.00E-03	2.00E-03	8.00E-02	1.03E-01	8.20E-02	4.49E+00	7.60E-01	4.86E+00	1.91E+00	5.52E-24	4.89E-05	1.81E-04	8.02E-04	5.00E-03	1.62E-09
BATCH-612	9/7/26	105	10.9	0.24	3.00E-03	2.00E-03	8.10E-02	1.05E-01	8.40E-02	4.60E+00	7.80E-01	4.96E+00	1.96E+00	5.95E-24	5.02E-05	1.85E-04	8.58E-04	5.00E-03	3.27E-09
BATCH-613	9/14/26	92	9.6	0.24	3.00E-03	2.00E-03	7.40E-02	9.70E-02	7.80E-02	4.24E+00	7.19E-01	4.56E+00	1.81E+00	5.72E-24	4.63E-05	1.69E-04	8.17E-04	5.00E-03	4.25E-09
BATCH-614	9/18/26	71	7.5	0.24	2.00E-03	2.00E-03	5.80E-02	7.50E-02	6.00E-02	3.29E+00	5.57E-01	3.53E+00	1.40E+00	4.43E-24	3.59E-05	1.31E-04	6.34E-04	4.00E-03	3.29E-09
BATCH-615	9/24/26	75	7.8	0.24	2.00E-03	2.00E-03	6.00E-02	7.90E-02	6.30E-02	3.44E+00	5.83E-01	3.69E+00	1.47E+00	4.63E-24	3.75E-05	1.37E-04	6.63E-04	4.00E-03	3.44E-09
BATCH-616	9/25/26	112	11.7	0.24	3.00E-03	3.00E-03	9.00E-02	1.18E-01	9.50E-02	5.17E+00	8.76E-01	5.55E+00	2.20E+00	6.97E-24	5.64E-05	2.06E-04	9.96E-04	6.00E-03	5.18E-09
BATCH-617	10/2/26	93	9.6	0.24	3.00E-03	2.00E-03	7.50E-02	9.70E-02	7.80E-02	4.26E+00	7.22E-01	4.57E+00	1.81E+00	5.74E-24	4.65E-05	1.70E-04	8.21E-04	5.00E-03	4.27E-09
BATCH-618	10/7/26	93	9.7	0.24	3.00E-03	2.00E-03	7.50E-02	9.80E-02	7.80E-02	4.29E+00	7.27E-01	4.61E+00	1.83E+00	5.78E-24	4.68E-05	1.71E-04	8.27E-04	5.00E-03	4.30E-09
BATCH-619	10/11/26	84	8.8	0.24	3.00E-03	2.00E-03	6.80E-02	8.90E-02	7.10E-02	3.88E+00	6.57E-01	4.16E+00	1.65E+00	5.23E-24	4.23E-05	1.55E-04	7.47E-04	5.00E-03	3.89E-09
BATCH-620	10/17/26	110	11.5	0.24	9.22E-04	7.07E-04	2.40E-02	3.60E-02	2.60E-02	1.58E+00	2.66E-01	1.56E+00	6.64E-01	3.87E-24	1.70E-05	5.78E-05	5.74E-04	4.00E-03	2.55E-09
BATCH-621	10/20/26	105	10.9	0.24	8.10E-04	6.23E-04	2.20E-02	3.10E-02	2.30E-02	1.35E+00	2.28E-01	1.36E+00	5.67E-01	2.79E-24	1.45E-05	5.06E-05	4.12E-04	3.00E-03	7.87E-10
BATCH-622	10/29/26	92	9.6	0.24	2.00E-03	2.00E-03	6.20E-02	8.00E-02	6.40E-02	3.52E+00	5.93E-01	3.86E+00	1.49E+00	4.76E-24	3.82E-05	1.44E-04	6.96E-04	4.00E-03	8.57E-06
BATCH-623	10/31/26	75	7.9	0.24	2.00E-03	1.00E-03	5.00E-02	6.50E-02	5.20E-02	2.84E+00	4.78E-01	3.13E+00	1.20E+00	3.84E-24	3.08E-05	1.17E-04	5.63E-04	3.00E-03	7.59E-06
BATCH-624	11/8/26	76	7.9	0.24	2.00E-03	1.00E-03	5.10E-02	6.50E-02	5.20E-02	2.87E+00	4.83E-01	3.15E+00	1.21E+00	3.87E-24	3.10E-05	1.18E-04	5.68E-04	3.00E-03	7.65E-06
BATCH-625	11/9/26	69	7.2	0.24	2.00E-03	1.00E-03	4.60E-02	5.90E-02	4.70E-02	2.60E+00	4.37E-01	2.86E+00	1.10E+00	3.51E-24	2.81E-05	1.06E-04	5.15E-04	3.00E-03	6.93E-06
BATCH-626	11/16/26	53	5.5	0.24	4.02E-04	3.09E-04	1.10E-02	1.60E-02	1.10E-02	6.89E-01	1.16E-01	6.79E-01	2.90E-01	1.69E-24	7.41E-06	2.52E-05	2.50E-04	2.00E-03	1.11E-09
BATCH-627	11/16/26	53	5.6	0.24	3.72E-04	2.86E-04	1.00E-02	1.40E-02	1.10E-02	6.22E-01	1.05E-01	6.26E-01	2.61E-01	1.28E-24	6.65E-06	2.33E-05	1.89E-04	1.00E-03	3.62E-10
BATCH-628	11/22/26	81	8.4	0.24	2.00E-03	2.00E-03	5.40E-02	6.90E-02	5.50E-02	3.04E+00	5.12E-01	3.35E+00	1.29E+00	4.11E-24	3.29E-05	1.25E-04	6.03E-04	4.00E-03	8.13E-06
BATCH-629	11/22/26	67	6.9	0.24	2.00E-03	1.00E-03	4.40E-02	5.70E-02	4.60E-02	2.51E+00	4.22E-01	2.76E+00	1.06E+00	3.39E-24	2.71E-05	1.03E-04	4.97E-04	3.00E-03	6.70E-06
BATCH-630	11/29/26	96	10.0	0.24	8.02E-04	6.18E-04	2.20E-02	2.90E-02	2.30E-02	1.29E+00	2.18E-01	1.35E+00	5.44E-01	2.21E-24	1.39E-05	5.00E-05	3.23E-04	2.00E-03	4.80E-07
BATCH-631	11/30/26	67	7.0	0.24	2.00E-03	1.00E-03	4.50E-02	5.70E-02	4.60E-02	2.53E+00	4.25E-01	2.78E+00	1.07E+00	3.41E-24	2.73E-05	1.04E-04	5.00E-04	3.00E-03	6.75E-06
BATCH-632	12/7/26	18	1.9	0.24	1.02E-04	7.81E-05	3.00E-03	4.00E-03	3.00E-03	1.74E-01	2.90E-02	1.72E-01	7.30E-02	4.28E-25	1.88E-06	6.39E-06	6.34E-05	4.05E-04	2.82E-10
BATCH-633	12/9/26	18	1.9	0.24	9.24E-05	7.10E-05	2.00E-03	3.00E-03	3.00E-03	1.54E-01	2.60E-02	1.55E-01	6.50E-02	3.18E-25	1.65E-06	5.77E-06	4.70E-05	2.95E-04	8.97E-11
BATCH-634	12/9/26	97	10.1	0.24	8.93E-04	6.89E-04	2.40E-02	3.20E-02	2.50E-02	1.41E+00	2.38E-01	1.49E+00	5.95E-01	2.18E-24	1.52E-05	5.56E-05	3.18E-04	2.00E-03	1.01E-06
BATCH-635	12/11/26	71	7.4	0.24	2.00E-03	1.00E-03	4.70E-02	6.10E-02	4.90E-02	2.68E+00	4.51E-01	2.95E+00	1.13E+00	3.62E-24	2.90E-05	1.10E-04	5.31E-04	3.00E-03	7.16E-06
BATCH-636	12/19/26	94	9.8	0.24	8.50E-04	6.56E-04	2.30E-02	3.00E-02	2.40E-02	1.33E+00	2.24E-01	1.42E+00	5.62E-01	1.89E-24	1.44E-05	5.30E-05	2.74E-04	2.00E-03	9.93E-07

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-588	5/11/26	19	2.0	0.24	3.09E+01	0.00E+00	3.89E-09	4.69E-07	3.24E-09	6.88E-14	4.25E-04	1.87E-01	2.14E-08	5.86E-04	7.51E-01	0.00E+00	3.80E+00	0.00E+00	6.03E-06
BATCH-589	5/14/26	53	5.6	0.24	1.22E+02	0.00E+00	9.00E-09	1.18E-06	8.98E-09	7.47E-13	2.00E-03	7.25E-01	6.24E-08	2.00E-03	2.86E+00	0.00E+00	1.56E+01	0.00E+00	1.99E-05
BATCH-590	5/19/26	132	13.8	0.24	4.71E-06	1.60E+02	1.15E-09	4.58E-07	6.84E-09	7.21E-21	5.00E-03	1.04E+00	4.92E-08	8.00E-03	1.39E+01	0.00E+00	7.77E-07	5.74E+00	1.08E-04
BATCH-591	5/19/26	135	14.1	0.24	3.03E-06	1.64E+02	1.18E-09	4.68E-07	6.99E-09	1.05E-20	5.00E-03	1.07E+00	5.02E-08	8.00E-03	1.43E+01	0.00E+00	4.26E-07	5.88E+00	1.08E-04
BATCH-592	6/2/26	21	2.1	0.24	3.26E+01	0.00E+00	2.77E-09	3.71E-07	2.41E-09	6.48E-14	5.10E-04	2.30E-01	1.71E-08	9.31E-04	9.73E-01	0.00E+00	4.04E+00	0.00E+00	4.75E-06
BATCH-593	6/3/26	151	15.8	0.24	5.00E-03	1.84E+02	1.32E-09	5.24E-07	7.83E-09	1.20E-17	6.00E-03	1.20E+00	5.63E-08	9.00E-03	1.60E+01	0.00E+00	6.64E-04	6.58E+00	1.35E-04
BATCH-594	6/4/26	92	9.6	0.24	2.23E+02	0.00E+00	4.40E-09	8.82E-07	9.10E-09	8.93E-47	4.00E-03	1.29E+00	7.12E-08	5.00E-03	5.37E+00	0.00E+00	2.93E+01	0.00E+00	2.70E-05
BATCH-595	6/14/26	19	2.0	0.24	3.19E+01	0.00E+00	2.34E-09	3.08E-07	2.34E-09	1.95E-13	4.41E-04	1.89E-01	1.62E-08	6.33E-04	7.44E-01	0.00E+00	4.06E+00	0.00E+00	5.18E-06
BATCH-596	6/15/26	117	12.2	0.24	2.75E-09	1.42E+02	1.02E-09	4.06E-07	6.06E-09	4.21E-24	5.00E-03	9.26E-01	4.36E-08	7.00E-03	1.24E+01	0.00E+00	4.53E-10	5.09E+00	1.08E-04
BATCH-597	6/19/26	102	10.6	0.24	1.53E-09	1.86E+02	8.02E-10	1.40E-02	1.29E-09	5.32E-24	6.00E-03	5.15E-01	1.13E-08	3.00E-03	2.16E+01	0.00E+00	2.15E-10	8.32E+00	1.35E-04
BATCH-598	6/28/26	127	13.2	0.24	6.00E-03	2.42E+02	9.82E-10	2.00E-02	9.06E-10	1.29E-17	7.00E-03	5.88E-01	9.39E-09	3.00E-03	2.87E+01	0.00E+00	8.05E-04	1.10E+01	1.89E-04
BATCH-599	6/30/26	58	6.0	0.24	1.30E+02	0.00E+00	2.56E-09	5.14E-07	5.30E-09	5.20E-47	2.00E-03	7.54E-01	4.15E-08	3.00E-03	3.13E+00	0.00E+00	1.71E+01	0.00E+00	1.88E-05
BATCH-600	7/6/26	127	13.2	0.24	6.00E-03	2.42E+02	9.81E-10	2.00E-02	9.06E-10	3.40E-17	7.00E-03	5.88E-01	9.38E-09	3.00E-03	2.87E+01	0.00E+00	7.09E-04	1.10E+01	1.89E-04
BATCH-601	7/12/26	113	11.8	0.24	2.81E-06	2.15E+02	8.74E-10	1.80E-02	8.11E-10	6.26E-21	6.00E-03	5.24E-01	8.39E-09	2.00E-03	2.56E+01	0.00E+00	3.46E-07	9.81E+00	1.62E-04
BATCH-602	7/19/26	87	9.1	0.24	1.85E-12	1.67E+02	6.77E-10	1.40E-02	6.29E-10	2.83E-27	5.00E-03	4.06E-01	6.50E-09	2.00E-03	1.98E+01	0.00E+00	1.38E-13	7.60E+00	1.35E-04
BATCH-603	7/24/26	91	9.5	0.24	9.83E-13	1.74E+02	7.07E-10	1.40E-02	6.53E-10	3.42E-27	5.00E-03	4.24E-01	6.77E-09	2.00E-03	2.07E+01	0.00E+00	1.38E-13	7.93E+00	1.35E-04
BATCH-604	7/29/26	22	2.2	0.24	3.87E+01	0.00E+00	7.64E-10	1.53E-07	1.58E-09	1.55E-47	6.61E-04	2.25E-01	1.24E-08	8.29E-04	9.33E-01	0.00E+00	5.10E+00	0.00E+00	5.62E-06
BATCH-605	7/31/26	114	11.9	0.24	3.07E-06	2.10E+02	8.56E-10	1.10E-02	1.59E-09	6.10E-21	6.00E-03	5.35E-01	1.61E-08	2.00E-03	2.42E+01	0.00E+00	3.81E-07	9.56E+00	1.62E-04
BATCH-606	8/3/26	120	12.5	0.24	2.83E-06	2.07E+02	8.51E-10	6.98E-04	2.96E-09	1.72E-20	5.00E-03	5.69E-01	2.95E-08	2.00E-03	2.27E+01	0.00E+00	3.60E-07	9.42E+00	1.62E-04
BATCH-607	8/13/26	107	11.2	0.24	1.60E-09	1.84E+02	7.59E-10	6.23E-04	2.64E-09	3.56E-24	5.00E-03	5.07E-01	2.63E-08	1.00E-03	2.02E+01	0.00E+00	1.97E-10	8.39E+00	1.35E-04
BATCH-608	8/15/26	83	8.6	0.24	1.36E-15	1.43E+02	5.88E-10	4.85E-04	2.04E-09	2.07E-30	4.00E-03	3.93E-01	2.04E-08	1.00E-03	1.57E+01	0.00E+00	2.23E-16	6.50E+00	1.08E-04
BATCH-609	8/24/26	130	13.6	0.24	8.00E-03	2.25E+02	9.24E-10	7.47E-04	3.21E-09	3.34E-51	6.00E-03	6.18E-01	3.20E-08	2.00E-03	2.46E+01	0.00E+00	1.00E-03	1.02E+01	1.62E-04
BATCH-610	8/24/26	87	9.0	0.24	6.89E-16	1.49E+02	6.14E-10	5.06E-04	2.13E-09	2.40E-30	4.00E-03	4.10E-01	2.13E-08	1.00E-03	1.63E+01	0.00E+00	9.70E-17	6.79E+00	1.08E-04
BATCH-611	9/2/26	107	11.2	0.24	1.74E-09	1.85E+02	7.60E-10	6.20E-04	2.64E-09	3.45E-24	5.00E-03	5.08E-01	2.63E-08	1.00E-03	2.02E+01	0.00E+00	2.16E-10	8.41E+00	1.35E-04
BATCH-612	9/7/26	105	10.9	0.24	1.44E-09	2.00E+02	1.37E-09	2.96E-04	5.86E-09	8.79E-24	7.00E-03	4.52E-01	4.55E-08	2.00E-03	2.29E+01	0.00E+00	1.83E-10	9.35E+00	1.35E-04
BATCH-613	9/14/26	92	9.6	0.24	9.83E-13	1.92E+02	1.71E-09	1.60E-05	7.82E-09	2.19E-27	8.00E-03	3.63E-01	5.62E-08	2.00E-03	2.27E+01	0.00E+00	1.21E-13	9.18E+00	1.35E-04
BATCH-614	9/18/26	71	7.5	0.24	1.07E-18	1.49E+02	1.32E-09	1.25E-05	6.06E-09	1.64E-33	6.00E-03	2.82E-01	4.35E-08	1.00E-03	1.76E+01	0.00E+00	1.77E-19	7.12E+00	1.08E-04
BATCH-615	9/24/26	75	7.8	0.24	5.22E-19	1.55E+02	1.38E-09	1.30E-05	6.34E-09	1.81E-33	6.00E-03	2.94E-01	4.55E-08	1.00E-03	1.84E+01	0.00E+00	7.34E-20	7.44E+00	1.08E-04
BATCH-616	9/25/26	112	11.7	0.24	4.19E-06	2.34E+02	2.08E-09	1.94E-05	9.53E-09	1.68E-54	1.00E-02	4.43E-01	6.84E-08	2.00E-03	2.76E+01	0.00E+00	5.52E-07	1.12E+01	1.62E-04
BATCH-617	10/2/26	93	9.6	0.24	1.06E-12	1.93E+02	1.71E-09	1.60E-05	7.85E-09	2.11E-27	8.00E-03	3.65E-01	5.64E-08	2.00E-03	2.28E+01	0.00E+00	1.32E-13	9.22E+00	1.35E-04
BATCH-618	10/7/26	93	9.7	0.24	8.71E-13	1.94E+02	1.73E-09	1.59E-05	7.91E-09	5.32E-27	8.00E-03	3.67E-01	5.68E-08	2.00E-03	2.30E+01	0.00E+00	1.11E-13	9.29E+00	1.35E-04
BATCH-619	10/11/26	84	8.8	0.24	6.56E-16	1.75E+02	1.56E-09	1.43E-05	7.15E-09	1.46E-30	7.00E-03	3.32E-01	5.14E-08	1.00E-03	2.07E+01	0.00E+00	8.07E-17	8.39E+00	1.35E-04
BATCH-620	10/17/26	110	11.5	0.24	2.87E+02	0.00E+00	9.02E-10	6.85E-04	5.07E-09	1.71E-18	5.00E-03	7.70E-01	3.85E-08	2.00E-03	5.87E+00	0.00E+00	3.45E+01	0.00E+00	5.39E-05
BATCH-621	10/20/26	105	10.9	0.24	2.86E+02	0.00E+00	3.37E-10	1.00E-03	1.53E-09	1.37E-18	5.00E-03	6.13E-01	1.14E-08	2.00E-03	5.64E+00	0.00E+00	3.32E+01	0.00E+00	2.70E-05
BATCH-622	10/29/26	92	9.6	0.24	2.00E-09	1.57E+02	6.71E-06	1.49E-04	2.52E-06	8.01E-58	1.20E-01	6.30E-01	5.97E-06	9.00E-03	1.99E+01	0.00E+00	2.63E-10	8.45E+00	1.89E-04
BATCH-623	10/31/26	75	7.9	0.24	6.79E-16	1.27E+02	5.94E-06	1.31E-04	2.23E-06	1.35E-30	1.06E-01	5.34E-01	5.29E-06	8.00E-03	1.61E+01	0.00E+00	8.42E-17	6.88E+00	1.62E-04
BATCH-624	11/8/26	76	7.9	0.24	5.53E-16	1.28E+02	5.99E-06	1.32E-04	2.25E-06	3.37E-30	1.06E-01	5.38E-01	5.33E-06	8.00E-03	1.62E+01	0.00E+00	7.04E-17	6.94E+00	1.62E-04
BATCH-625	11/9/26	69	7.2	0.24	4.59E-19	1.16E+02	5.43E-06	1.19E-04	2.04E-06	1.02E-33	9.60E-02	4.88E-01	4.83E-06	7.00E-03	1.47E+01	0.00E+00	5.65E-20	6.29E+00	1.35E-04
BATCH-626	11/16/26	53	5.5	0.24	1.25E+02	0.00E+00	3.94E-10	2.99E-04	2.21E-09	7.48E-19	2.00E-03	3.36E-01	1.68E-08	1.00E-03	2.56E+00	0.00E+00	1.51E+01	0.00E+00	1.99E-05
BATCH-627	11/16/26	53	5.6	0.24	1.31E+02	0.00E+00	1.55E-10	5.97E-04	7.02E-10	6.29E-19	2.00E-03	2.82E-01	5.25E-09	7.06E-04	2.59E+00	0.00E+00	1.53E+01	0.00E+00	1.85E-05
BATCH-628	11/22/26	81	8.4	0.24	1.19E-12	1.36E+02	6.37E-06	1.40E-04	2.39E-06	4.78E-61	1.13E-01	5.72E-01	5.66E-06	9.00E-03	1.72E+01	0.00E+00	1.57E-13	7.37E+00	1.62E-04
BATCH-629	11/22/26	67	6.9	0.24	4.91E-19	1.12E+02	5.25E-06	1.15E-04	1.97E-06	9.76E-34	9.30E-02	4.71E-01	4.67E-06	7.00E-03	1.42E+01	0.00E+00	6.09E-20	6.07E+00	1.35E-04
BATCH-630	11/29/26	96	10.0	0.24	2.66E+02	0.00E+00	3.76E-07	8.54E-04	1.42E-07	7.66E-19	2.80E-02	4.83E-01	3.44E-07	1.00E-03	6.06E+00	0.00E+00	3.13E+01	0.00E+00	5.39E-05
BATCH-631	11/30/26	67	7.0	0.24	3.96E-19	1.13E+02	5.29E-06	1.16E-04	1.98E-06	2.42E-33	9.40E-02	4.75E-01	4.70E-06	7.00E-03	1.43E+01	0.00E+00	5.05E-20	6.12E+00	1.35E-04
BATCH-632	12/7/26	18	1.9	0.24	3.17E+01	0.00E+00	9.97E-11	7.57E-05	5.60E-10	1.89E-19	6.03E-04	8.50E-02	4.25E-09	2.60E-04	6.48E-01	0.00E+00	3.81E+00	0.00E+00	5.03E-06
BATCH-633	12/9/26	18	1.9	0.24	3.26E+01	0.00E+00	3.84E-11	1.48E-04	1.74E-10	1.56E-19	5.79E-04	7.00E-02	1.30E-09	1.75E-04	6.43E-01	0.00E+00	3.79E+00	0.00E+00	4.60E-06
BATCH-634	12/9/26	97	10.1	0.24	2.67E+02	0.00E+00	7.87E-07	2.00E-03	2.96E-07	6.12E-19	5.40E-02	4.15E-01	7.05E-07	1.00E-03	7.04E+00	0.00E+00	3.15E+01	0.00E+00	5.39E-05
BATCH-635	12/11/26	71	7.4	0.24	8.04E-16	1.19E+02	5.61E-06	1.23E-04	2.10E-06	3.22E-64	1.00E-01	5.03E-01	4.99E-06	8.00E-03	1.52E+01	0.00E+00	1.06E-16	6.49E+00	1.35E-04
BATCH-636	12/19/26	94	9.8	0.24	2.56E+02	0.00E+00	7.78E-07	9.97E-04	2.92E-07	1.58E-18	5.40E-02	3.97E-01	6.98E-07	1.00E-03	6.67E+00	0.00E+00	3.09E+01	0.00E+00	5.39E-05

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization			Losses		1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-588	5/11/26	19		0.24	4.19E-10	1.47E+00	7.80E-02	0.00E+00	0.00E+00	1.17E-05	4.34E-01	2.04E-07	3.93E-08	1.01E-07	9.00E-03	1.74E-08	3.23E+02	0.00E+00	1.20E-02
BATCH-589	5/14/26	53		0.24	1.86E-09	5.83E+00	3.00E-01	0.00E+00	0.00E+00	5.77E-05	1.71E+00	5.31E-07	1.01E-07	2.36E-07	2.90E-02	4.32E-08	9.14E+02	0.00E+00	3.80E-02
BATCH-590	5/19/26	132		0.24	3.66E-09	7.17E+01	2.26E-01	0.00E+00	0.00E+00	1.20E-03	1.06E+01	6.10E-08	6.71E-08	2.96E-08	1.13E-01	3.12E-08	2.25E+03	0.00E+00	4.40E-02
BATCH-591	5/19/26	135		0.24	3.74E-09	7.34E+01	2.32E-01	0.00E+00	0.00E+00	1.20E-03	1.09E+01	6.23E-08	6.86E-08	3.03E-08	1.16E-01	3.19E-08	2.31E+03	0.00E+00	4.50E-02
BATCH-592	6/2/26	21		0.24	3.55E-10	1.90E+00	9.90E-02	0.00E+00	0.00E+00	1.21E-05	6.17E-01	1.85E-07	2.68E-08	7.42E-08	9.00E-03	9.65E-09	3.51E+02	0.00E+00	1.50E-02
BATCH-593	6/3/26	151		0.24	4.19E-09	8.22E+01	2.59E-01	0.00E+00	0.00E+00	1.20E-03	1.22E+01	6.98E-08	7.69E-08	3.39E-08	1.30E-01	3.57E-08	2.59E+03	0.00E+00	5.10E-02
BATCH-594	6/4/26	92		0.24	3.76E-09	1.31E+01	5.27E-01	0.00E+00	0.00E+00	1.67E-04	3.41E+00	4.40E-07	8.13E-08	1.22E-07	4.40E-02	3.08E-08	1.57E+03	0.00E+00	5.60E-02
BATCH-595	6/14/26	19		0.24	4.84E-10	1.52E+00	7.80E-02	0.00E+00	0.00E+00	1.50E-05	4.45E-01	1.38E-07	2.62E-08	6.14E-08	8.00E-03	1.12E-08	3.20E+02	0.00E+00	1.00E-02
BATCH-596	6/16/26	117		0.24	3.24E-09	6.36E+01	2.01E-01	0.00E+00	0.00E+00	1.00E-03	9.43E+00	5.40E-08	5.95E-08	2.63E-08	1.01E-01	2.76E-08	2.00E+03	0.00E+00	3.90E-02
BATCH-597	6/19/26	102		0.24	4.70E-10	3.31E+01	1.67E-01	0.00E+00	0.00E+00	1.00E-03	7.09E+00	2.74E-05	1.30E-08	2.82E-08	1.09E-01	3.68E-09	1.74E+03	0.00E+00	3.00E-02
BATCH-598	6/28/26	127		0.24	1.74E-10	3.72E+01	2.07E-01	0.00E+00	0.00E+00	1.20E-03	8.61E+00	3.88E-05	9.42E-09	3.60E-08	1.39E-01	1.03E-09	2.16E+03	0.00E+00	3.70E-02
BATCH-599	6/30/26	58		0.24	2.19E-09	7.66E+00	3.07E-01	0.00E+00	0.00E+00	9.70E-05	1.99E+00	2.57E-07	4.74E-08	7.12E-08	2.60E-02	1.80E-08	9.91E+02	0.00E+00	3.30E-02
BATCH-600	7/6/26	127		0.24	1.74E-10	3.72E+01	2.07E-01	0.00E+00	0.00E+00	1.20E-03	8.61E+00	3.88E-05	9.41E-09	3.60E-08	1.39E-01	1.03E-09	2.16E+03	0.00E+00	3.70E-02
BATCH-601	7/12/26	113		0.24	1.57E-10	3.32E+01	1.84E-01	0.00E+00	0.00E+00	1.00E-03	7.67E+00	3.45E-05	8.42E-09	3.21E-08	1.24E-01	9.30E-10	1.93E+03	0.00E+00	3.30E-02
BATCH-602	7/19/26	87		0.24	1.22E-10	2.57E+01	1.43E-01	0.00E+00	0.00E+00	8.00E-04	5.94E+00	2.68E-05	6.53E-09	2.48E-08	9.60E-02	7.25E-10	1.49E+03	0.00E+00	2.50E-02
BATCH-603	7/24/26	91		0.24	1.26E-10	2.68E+01	1.49E-01	0.00E+00	0.00E+00	8.00E-04	6.21E+00	2.80E-05	6.79E-09	2.60E-08	1.00E-01	7.40E-10	1.56E+03	0.00E+00	2.60E-02
BATCH-604	7/29/26	22		0.24	6.53E-10	2.28E+00	9.20E-02	0.00E+00	0.00E+00	2.89E-05	5.92E-01	7.65E-08	1.41E-08	2.12E-08	8.00E-03	5.35E-09	3.68E+02	0.00E+00	1.00E-02
BATCH-605	7/31/26	114		0.24	7.14E-10	3.19E+01	2.08E-01	0.00E+00	0.00E+00	1.20E-03	7.56E+00	3.23E-05	1.78E-08	3.60E-08	1.71E-01	5.58E-09	1.95E+03	0.00E+00	3.30E-02
BATCH-606	8/3/26	120		0.24	1.67E-09	3.07E+01	2.53E-01	0.00E+00	0.00E+00	1.20E-03	7.59E+00	2.95E-05	3.42E-08	4.36E-08	2.56E-01	1.36E-08	2.05E+03	0.00E+00	3.40E-02
BATCH-607	8/13/26	107		0.24	1.49E-09	2.74E+01	2.26E-01	0.00E+00	0.00E+00	1.20E-03	6.76E+00	2.63E-05	3.05E-08	3.89E-08	2.29E-01	1.21E-08	1.83E+03	0.00E+00	3.00E-02
BATCH-608	8/15/26	83		0.24	1.16E-09	2.12E+01	1.75E-01	0.00E+00	0.00E+00	8.00E-04	5.24E+00	2.04E-05	2.36E-08	3.01E-08	1.77E-01	9.37E-09	1.42E+03	0.00E+00	2.30E-02
BATCH-609	8/24/26	130		0.24	1.82E-09	3.34E+01	2.75E-01	0.00E+00	0.00E+00	1.40E-03	8.24E+00	3.20E-05	3.72E-08	4.73E-08	2.78E-01	1.47E-08	2.23E+03	0.00E+00	3.70E-02
BATCH-610	8/24/26	87		0.24	1.21E-09	2.22E+01	1.83E-01	0.00E+00	0.00E+00	1.00E-03	5.47E+00	2.12E-05	2.47E-08	3.14E-08	1.85E-01	9.79E-09	1.48E+03	0.00E+00	2.40E-02
BATCH-611	9/2/26	107		0.24	1.49E-09	2.75E+01	2.26E-01	0.00E+00	0.00E+00	1.20E-03	6.77E+00	2.63E-05	3.06E-08	3.89E-08	2.29E-01	1.21E-08	1.83E+03	0.00E+00	3.00E-02
BATCH-612	9/7/26	105		0.24	3.21E-09	3.08E+01	1.82E-01	0.00E+00	0.00E+00	1.00E-03	6.94E+00	3.38E-05	6.17E-08	4.31E-08	2.00E-01	2.69E-08	1.79E+03	0.00E+00	2.60E-02
BATCH-613	9/14/26	92		0.24	4.25E-09	3.05E+01	1.29E-01	0.00E+00	0.00E+00	6.00E-04	6.39E+00	3.65E-05	8.01E-08	4.21E-08	1.58E-01	3.59E-08	1.57E+03	0.00E+00	2.00E-02
BATCH-614	9/18/26	71		0.24	3.29E-09	2.36E+01	1.00E-01	0.00E+00	0.00E+00	6.00E-04	4.95E+00	2.83E-05	6.21E-08	3.27E-08	1.22E-01	2.78E-08	1.22E+03	0.00E+00	1.60E-02
BATCH-615	9/24/26	75		0.24	3.44E-09	2.47E+01	1.05E-01	0.00E+00	0.00E+00	6.00E-04	5.18E+00	2.96E-05	6.49E-08	3.42E-08	1.28E-01	2.91E-08	1.28E+03	0.00E+00	1.60E-02
BATCH-616	9/25/26	112		0.24	5.18E-09	3.71E+01	1.58E-01	0.00E+00	0.00E+00	8.00E-04	7.79E+00	4.44E-05	9.76E-08	5.13E-08	1.92E-01	4.37E-08	1.92E+03	0.00E+00	2.40E-02
BATCH-617	10/2/26	93		0.24	4.27E-09	3.06E+01	1.30E-01	0.00E+00	0.00E+00	6.00E-04	6.42E+00	3.66E-05	8.04E-08	4.23E-08	1.59E-01	3.60E-08	1.58E+03	0.00E+00	2.00E-02
BATCH-618	10/7/26	93		0.24	4.30E-09	3.08E+01	1.31E-01	0.00E+00	0.00E+00	6.00E-04	6.46E+00	3.69E-05	8.11E-08	4.26E-08	1.60E-01	3.63E-08	1.59E+03	0.00E+00	2.00E-02
BATCH-619	10/11/26	84		0.24	3.89E-09	2.79E+01	1.18E-01	0.00E+00	0.00E+00	6.00E-04	5.84E+00	3.33E-05	7.33E-08	3.85E-08	1.44E-01	3.28E-08	1.44E+03	0.00E+00	1.80E-02
BATCH-620	10/17/26	110		0.24	2.74E-09	1.65E+01	3.27E-01	0.00E+00	0.00E+00	4.00E-04	3.01E+00	3.64E-06	4.69E-08	2.23E-08	4.80E-02	2.41E-08	1.88E+03	0.00E+00	1.90E-02
BATCH-621	10/20/26	105		0.24	8.03E-10	1.58E+01	2.84E-01	0.00E+00	0.00E+00	4.00E-04	2.71E+00	4.85E-06	1.53E-08	9.99E-09	4.10E-02	6.78E-09	1.79E+03	0.00E+00	1.10E-02
BATCH-622	10/29/26	92		0.24	1.59E-08	3.28E+01	3.44E-01	0.00E+00	0.00E+00	1.00E-03	7.88E+00	7.00E-03	2.41E-06	8.64E-05	4.00E-01	1.11E-06	1.57E+03	0.00E+00	5.70E-02
BATCH-623	10/31/26	75		0.24	1.38E-08	2.70E+01	2.96E-01	0.00E+00	0.00E+00	8.00E-04	6.57E+00	6.00E-03	2.13E-06	7.65E-05	3.44E-01	9.80E-07	1.29E+03	0.00E+00	4.90E-02
BATCH-624	11/8/26	76		0.24	1.40E-08	2.73E+01	2.99E-01	0.00E+00	0.00E+00	8.00E-04	6.62E+00	6.00E-03	2.15E-06	7.71E-05	3.47E-01	9.89E-07	1.30E+03	0.00E+00	5.00E-02
BATCH-625	11/9/26	69		0.24	1.26E-08	2.47E+01	2.71E-01	0.00E+00	0.00E+00	8.00E-04	6.00E+00	6.00E-03	1.95E-06	6.99E-05	3.14E-01	8.96E-07	1.18E+03	0.00E+00	4.50E-02
BATCH-626	11/16/26	53		0.24	1.20E-09	7.22E+00	1.43E-01	0.00E+00	0.00E+00	1.39E-04	1.32E+00	1.59E-06	2.05E-08	9.76E-09	2.10E-02	1.05E-08	9.09E+02	0.00E+00	8.00E-03
BATCH-627	11/16/26	53		0.24	3.69E-10	7.28E+00	1.31E-01	0.00E+00	0.00E+00	1.45E-04	1.25E+00	2.23E-06	7.04E-09	4.59E-09	1.90E-02	3.11E-09	9.11E+02	0.00E+00	5.00E-03
BATCH-628	11/22/26	81		0.24	1.48E-08	2.89E+01	3.17E-01	0.00E+00	0.00E+00	1.00E-03	7.03E+00	7.00E-03	2.28E-06	8.19E-05	3.68E-01	1.05E-06	1.38E+03	0.00E+00	5.30E-02
BATCH-629	11/22/26	67		0.24	1.22E-08	2.38E+01	2.61E-01	0.00E+00	0.00E+00	8.00E-04	5.79E+00	6.00E-03	1.88E-06	6.75E-05	3.03E-01	8.65E-07	1.14E+03	0.00E+00	4.40E-02
BATCH-630	11/29/26	96		0.24	1.58E-09	1.23E+01	2.78E-01	0.00E+00	0.00E+00	2.00E-04	2.39E+00	4.05E-04	1.48E-07	4.84E-06	5.90E-02	6.79E-08	1.64E+03	0.00E+00	1.10E-02
BATCH-631	11/30/26	67		0.24	1.23E-08	2.40E+01	2.63E-01	0.00E+00	0.00E+00	8.00E-04	5.83E+00	6.00E-03	1.89E-06	6.80E-05	3.06E-01	8.72E-07	1.15E+03	0.00E+00	4.40E-02
BATCH-632	12/7/26	18		0.24	3.02E-10	1.83E+00	3.60E-02	0.00E+00	0.00E+00	3.52E-05	3.33E-01	4.02E-07	5.19E-09	2.47E-09	5.00E-03	2.67E-09	3.14E+02	0.00E+00	2.00E-03
BATCH-633	12/9/26	18		0.24	9.15E-11	1.81E+00	3.20E-02	0.00E+00	0.00E+00	3.60E-05	3.10E-01	5.53E-07	1.75E-09	1.14E-09	5.00E-03	7.73E-10	3.11E+02	0.00E+00	1.00E-03
BATCH-634	12/9/26	97		0.24	2.12E-09	1.00E+01	3.02E-01	0.00E+00	0.00E+00	4.00E-04	2.36E+00	8.43E-04	2.88E-07	1.01E-05	7.80E-02	1.32E-07	1.65E+03	0.00E+00	1.30E-02
BATCH-635	12/11/26	71		0.24	1.31E-08	2.55E+01	2.79E-01	0.00E+00	0.00E+00	8.00E-04	6.19E+00	6.00E-03	2.01E-06	7.21E-05	3.24E-01	9.25E-07	1.21E+03	0.00E+00	4.70E-02
BATCH-636	12/19/26	94		0.24	2.21E-09	9.62E+00	2.93E-01	0.00E+00	0.00E+00	4.00E-04	2.27E+00	8.33E-04	2.87E-07	1.00E-05	8.20E-02	1.32E-07	1.60E+03	0.00E+00	1.20E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	Sr+4	SO4-2	Sr+2	Tl+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-588	5/11/26	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.79E+00	2.30E-10	4.03E+00	1.86E+00	3.00E-03	3.30E-10	0.00E+00	2.00E-03	9.72E-07	4.17E-04
BATCH-589	5/14/26	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.68E+01	5.85E-10	1.25E+01	6.98E+00	1.20E-02	1.54E-09	0.00E+00	9.00E-03	5.30E-06	2.00E-03
BATCH-590	5/19/26	132	13.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	5.57E+01	7.44E-11	2.80E+00	8.08E+01	5.00E-03	3.28E-09	0.00E+00	2.30E-02	1.26E-06	7.00E-03
BATCH-591	5/19/26	135	14.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.40E-02	5.70E+01	7.60E-11	2.87E+00	8.28E+01	6.00E-03	3.35E-09	0.00E+00	2.40E-02	1.27E-06	7.00E-03
BATCH-592	6/2/26	21	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.72E+00	2.02E-10	3.31E+00	2.16E+00	5.00E-03	2.37E-10	0.00E+00	2.00E-03	1.62E-06	3.48E-04
BATCH-593	6/3/26	151	15.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	6.39E+01	8.52E-11	3.21E+00	9.27E+01	6.00E-03	3.76E-09	0.00E+00	2.70E-02	1.42E-06	8.00E-03
BATCH-594	6/4/26	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	2.83E+01	4.44E-10	9.57E+00	1.53E+01	2.10E-02	3.24E-09	0.00E+00	1.80E-02	1.19E-05	3.00E-03
BATCH-595	6/14/26	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.38E+00	1.52E-10	3.27E+00	1.82E+00	3.00E-03	4.00E-10	0.00E+00	2.00E-03	1.38E-06	4.02E-04
BATCH-596	6/16/26	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.80E-02	4.94E+01	6.59E-11	2.48E+00	7.18E+01	5.00E-03	2.91E-09	0.00E+00	2.10E-02	1.10E-06	6.00E-03
BATCH-597	6/19/26	102	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	4.95E+01	8.27E-11	3.89E+00	3.87E+01	6.00E-03	4.08E-10	0.00E+00	7.20E-02	2.02E-04	1.40E-02
BATCH-598	6/28/26	127	13.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.26E+01	1.07E-10	5.13E+00	4.39E+01	8.00E-03	1.37E-10	0.00E+00	1.00E-02	6.95E-06	2.00E-03
BATCH-599	6/30/26	58	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.65E+01	2.59E-10	5.58E+00	8.91E+00	1.20E-02	1.89E-09	0.00E+00	9.90E-02	2.86E-04	1.90E-02
BATCH-600	7/6/26	127	13.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.25E+01	1.07E-10	5.13E+00	4.39E+01	8.00E-03	1.37E-10	0.00E+00	8.80E-02	2.55E-04	1.70E-02
BATCH-601	7/12/26	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	5.57E+01	9.54E-11	4.57E+00	3.91E+01	7.00E-03	1.24E-10	0.00E+00	6.80E-02	1.97E-04	1.30E-02
BATCH-602	7/19/26	87	9.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.32E+01	7.39E-11	3.54E+00	3.03E+01	6.00E-03	9.62E-11	0.00E+00	6.80E-02	1.97E-04	1.30E-02
BATCH-603	7/24/26	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.51E+01	7.72E-11	3.70E+00	3.16E+01	6.00E-03	9.87E-11	0.00E+00	7.10E-02	2.06E-04	1.30E-02
BATCH-604	7/29/26	22	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.91E+00	7.71E-11	1.66E+00	2.66E+00	4.00E-03	5.63E-10	0.00E+00	3.00E-03	2.07E-06	4.84E-04
BATCH-605	7/31/26	114	11.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.43E+01	7.86E-11	4.57E+00	4.11E+01	1.00E-02	5.86E-10	0.00E+00	7.90E-02	1.62E-04	1.80E-02
BATCH-606	8/3/26	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	5.36E+01	5.25E-11	4.71E+00	4.58E+01	1.60E-02	1.38E-09	0.00E+00	6.70E-02	1.02E-05	2.20E-02
BATCH-607	8/13/26	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.78E+01	4.68E-11	4.20E+00	4.08E+01	1.40E-02	1.23E-09	0.00E+00	6.00E-02	9.14E-06	1.90E-02
BATCH-608	8/15/26	83	8.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.70E+01	3.63E-11	3.25E+00	3.16E+01	1.10E-02	9.54E-10	0.00E+00	4.60E-02	7.11E-06	1.50E-02
BATCH-609	8/24/26	130	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.82E+01	5.70E-11	5.11E+00	4.97E+01	1.80E-02	1.50E-09	0.00E+00	7.30E-02	1.10E-05	2.30E-02
BATCH-610	8/24/26	87	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.86E+01	3.79E-11	3.40E+00	3.30E+01	1.20E-02	9.96E-10	0.00E+00	4.80E-02	7.42E-06	1.60E-02
BATCH-611	9/2/26	107	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.79E+01	4.69E-11	4.21E+00	4.09E+01	1.40E-02	1.23E-09	0.00E+00	6.00E-02	9.10E-06	1.90E-02
BATCH-612	9/7/26	105	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.05E+01	8.64E-11	4.58E+00	4.01E+01	1.40E-02	2.78E-09	0.00E+00	7.40E-02	4.59E-06	2.00E-02
BATCH-613	9/14/26	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.76E+01	1.09E-10	4.42E+00	3.57E+01	1.20E-02	3.72E-09	0.00E+00	7.80E-02	6.64E-07	1.90E-02
BATCH-614	9/18/26	71	7.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.69E+01	8.45E-11	3.43E+00	2.77E+01	1.00E-02	2.88E-09	0.00E+00	6.00E-02	5.16E-07	1.40E-02
BATCH-615	9/24/26	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.86E+01	8.83E-11	3.59E+00	2.89E+01	1.00E-02	3.01E-09	0.00E+00	6.30E-02	5.39E-07	1.50E-02
BATCH-616	9/25/26	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.80E+01	1.33E-10	5.39E+00	4.35E+01	1.50E-02	4.53E-09	0.00E+00	9.50E-02	8.08E-07	2.30E-02
BATCH-617	10/2/26	93	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.78E+01	1.09E-10	4.44E+00	3.58E+01	1.20E-02	3.73E-09	0.00E+00	7.80E-02	6.66E-07	1.90E-02
BATCH-618	10/7/26	93	9.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.81E+01	1.10E-10	4.48E+00	3.61E+01	1.20E-02	3.76E-09	0.00E+00	7.90E-02	6.69E-07	1.90E-02
BATCH-619	10/11/26	84	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.35E+01	9.97E-11	4.05E+00	3.26E+01	1.10E-02	3.40E-09	0.00E+00	7.10E-02	6.02E-07	1.70E-02
BATCH-620	10/17/26	110	11.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.24E+01	6.26E-11	8.71E+00	2.14E+01	5.00E-03	2.53E-09	0.00E+00	2.50E-02	1.47E-05	4.00E-03
BATCH-621	10/20/26	105	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.10E+01	2.44E-11	8.16E+00	2.07E+01	2.00E-03	7.11E-10	0.00E+00	2.30E-02	1.89E-05	4.00E-03
BATCH-622	10/29/26	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.33E+01	3.03E-08	3.26E+00	3.63E+01	2.60E-02	1.21E-08	0.00E+00	1.21E-01	3.11E-04	2.10E-02
BATCH-623	10/31/26	75	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.53E+01	2.68E-08	2.60E+00	2.99E+01	2.20E-02	1.05E-08	0.00E+00	1.02E-01	2.75E-04	1.70E-02
BATCH-624	11/8/26	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.56E+01	2.70E-08	2.62E+00	3.01E+01	2.20E-02	1.06E-08	0.00E+00	1.03E-01	2.77E-04	1.70E-02
BATCH-625	11/9/26	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.22E+01	2.45E-08	2.37E+00	2.73E+01	2.00E-02	9.57E-09	0.00E+00	9.30E-02	2.51E-04	1.60E-02
BATCH-626	11/15/26	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.85E+01	2.73E-11	3.80E+00	9.32E+00	2.00E-03	1.11E-09	0.00E+00	1.10E-02	6.40E-06	2.00E-03
BATCH-627	11/16/26	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.88E+01	1.12E-11	3.75E+00	9.50E+00	1.00E-03	3.27E-10	0.00E+00	1.10E-02	8.71E-06	2.00E-03
BATCH-628	11/22/26	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.78E+01	2.87E-08	2.78E+00	3.20E+01	2.40E-02	1.12E-08	0.00E+00	1.09E-01	2.95E-04	1.80E-02
BATCH-629	11/22/26	67	6.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.11E+01	2.36E-08	2.29E+00	2.63E+01	1.90E-02	9.24E-09	0.00E+00	9.00E-02	2.43E-04	1.50E-02
BATCH-630	11/29/26	96	10.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.96E+01	1.71E-09	1.07E+01	1.60E+01	4.00E-03	1.28E-09	0.00E+00	3.00E-02	2.97E-05	5.00E-03
BATCH-631	11/30/26	67	7.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.13E+01	2.38E-08	2.31E+00	2.65E+01	2.00E-02	9.31E-09	0.00E+00	9.10E-02	2.45E-04	1.50E-02
BATCH-632	12/7/26	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	4.69E+00	6.91E-12	9.63E-01	2.36E+00	5.22E-04	2.80E-10	0.00E+00	3.00E-03	1.62E-06	4.65E-04
BATCH-633	12/9/26	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.42E-04	4.67E+00	2.79E-12	9.30E-01	2.36E+00	2.71E-04	8.11E-11	0.00E+00	3.00E-03	2.16E-06	4.19E-04
BATCH-634	12/9/26	97	10.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.07E+01	3.57E-09	1.30E+01	1.28E+01	5.00E-03	1.64E-09	0.00E+00	3.90E-02	6.51E-05	6.00E-03
BATCH-635	12/11/26	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.32E+01	2.53E-08	2.45E+00	2.81E+01	2.10E-02	9.88E-09	0.00E+00	9.60E-02	2.59E-04	1.60E-02
BATCH-636	12/19/26	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.99E+01	3.52E-09	1.31E+01	1.27E+01	5.00E-03	1.71E-09	0.00E+00	3.70E-02	5.02E-05	6.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
Losses																			
BATCH-637	12/20/26	52	5.5	0.24	0.00E+00	0.00E+00	2.60E-02	7.00E-03	2.02E+00	4.05E-02	6.56E+02	1.99E-01	2.80E-02	3.05E+00	2.72E-13	2.28E-01	6.68E-04	6.10E-02	1.50E-03
BATCH-638	12/25/26	91	9.5	0.24	0.00E+00	0.00E+00	9.70E-02	2.50E-02	7.50E+00	1.63E-01	1.82E+03	7.37E-01	1.04E-01	9.09E+00	1.48E-12	8.80E-01	2.00E-03	2.20E-01	5.75E-03
BATCH-639	12/29/26	90	9.4	0.24	0.00E+00	0.00E+00	9.00E-02	2.30E-02	6.96E+00	1.54E-01	1.80E+03	6.84E-01	9.70E-02	8.98E+00	5.54E-13	8.25E-01	2.00E-03	2.03E-01	5.50E-03
BATCH-640	1/4/27	78	8.2	0.24	0.00E+00	0.00E+00	4.60E-02	1.00E-02	3.50E+00	6.84E-02	1.17E+03	3.46E-01	4.70E-02	5.21E+00	8.15E-13	3.77E-01	9.03E-04	1.05E-01	2.50E-03
BATCH-641	1/7/27	50	5.2	0.24	0.00E+00	0.00E+00	2.80E-02	7.00E-03	2.13E+00	4.14E-02	6.88E+02	2.10E-01	2.80E-02	3.23E+00	2.61E-13	2.30E-01	5.51E-04	6.40E-02	1.50E-03
BATCH-642	1/12/27	18	1.9	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.10E-01	9.90E-03	1.63E+02	5.10E-02	7.00E-03	7.74E-01	3.47E-14	5.50E-02	1.32E-04	1.50E-02	5.00E-04
BATCH-643	1/13/27	51	5.3	0.24	0.00E+00	0.00E+00	2.80E-02	6.00E-03	2.12E+00	4.05E-02	6.88E+02	2.10E-01	2.80E-02	3.20E+00	2.69E-13	2.30E-01	5.50E-04	6.40E-02	1.50E-03
BATCH-644	1/14/27	75	7.8	0.24	0.00E+00	0.00E+00	7.50E-02	1.70E-02	5.73E+00	1.28E-01	1.50E+03	5.67E-01	7.60E-02	7.45E+00	2.31E-13	6.52E-01	1.00E-03	1.69E-01	4.50E-03
BATCH-645	1/18/27	75	7.8	0.24	0.00E+00	0.00E+00	7.50E-02	1.70E-02	5.72E+00	1.27E-01	1.49E+03	5.66E-01	7.60E-02	7.44E+00	2.31E-13	6.51E-01	1.00E-03	1.68E-01	4.50E-03
BATCH-646	1/22/27	49	5.2	0.24	0.00E+00	0.00E+00	2.60E-02	6.00E-03	1.98E+00	3.87E-02	6.61E+02	1.96E-01	2.60E-02	2.95E+00	4.61E-13	2.14E-01	5.11E-04	6.00E-02	1.50E-03
BATCH-647	1/26/27	18	1.8	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.38E-01	1.08E-02	1.74E+02	5.30E-02	7.00E-03	8.15E-01	6.59E-14	5.80E-02	1.39E-04	1.60E-02	5.00E-04
BATCH-648	1/28/27	90	9.4	0.24	0.00E+00	0.00E+00	9.00E-02	2.00E-02	6.90E+00	1.54E-01	1.80E+03	6.83E-01	9.20E-02	8.96E+00	2.78E-13	7.85E-01	2.00E-03	2.03E-01	5.50E-03
BATCH-649	1/28/27	18	1.9	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.45E-01	1.08E-02	1.77E+02	5.40E-02	7.00E-03	8.20E-01	6.89E-14	5.90E-02	1.41E-04	1.60E-02	5.00E-04
BATCH-650	1/30/27	62	6.4	0.24	0.00E+00	0.00E+00	6.20E-02	1.40E-02	4.73E+00	1.05E-01	1.23E+03	4.68E-01	6.30E-02	6.15E+00	1.91E-13	5.39E-01	1.00E-03	1.39E-01	3.75E-03
BATCH-651	2/6/27	59	6.1	0.24	0.00E+00	0.00E+00	5.20E-02	1.10E-02	3.94E+00	8.64E-02	1.17E+03	3.82E-01	5.10E-02	5.85E+00	7.63E-14	4.51E-01	9.83E-04	1.14E-01	3.25E-03
BATCH-652	2/6/27	17	1.8	0.24	0.00E+00	0.00E+00	7.00E-03	1.00E-03	5.01E-01	9.90E-03	1.67E+02	5.00E-02	7.00E-03	7.46E-01	1.17E-13	5.40E-02	1.29E-04	1.50E-02	2.50E-04
BATCH-653	2/8/27	89	9.2	0.24	0.00E+00	0.00E+00	7.20E-02	1.60E-02	5.48E+00	1.18E-01	1.77E+03	5.25E-01	7.00E-02	8.81E+00	3.06E-14	6.31E-01	1.00E-03	1.56E-01	4.50E-03
BATCH-654	2/12/27	88	9.2	0.24	0.00E+00	0.00E+00	7.20E-02	1.60E-02	5.48E+00	1.18E-01	1.77E+03	5.25E-01	7.00E-02	8.81E+00	3.06E-14	6.31E-01	1.00E-03	1.56E-01	4.50E-03
BATCH-655	2/18/27	76	7.9	0.24	0.00E+00	0.00E+00	2.50E-02	6.00E-03	1.89E+00	4.14E-02	6.66E+02	1.87E-01	2.50E-02	3.33E+00	1.70E-13	2.14E-01	4.82E-04	5.60E-02	1.50E-03
BATCH-656	2/22/27	73	7.6	0.24	0.00E+00	0.00E+00	5.90E-02	1.30E-02	4.54E+00	9.81E-02	1.47E+03	4.35E-01	5.80E-02	7.30E+00	2.55E-14	5.23E-01	1.00E-03	1.30E-01	3.75E-03
BATCH-657	2/26/27	88	9.2	0.24	0.00E+00	0.00E+00	7.20E-02	1.60E-02	5.47E+00	1.18E-01	1.77E+03	5.24E-01	7.00E-02	8.80E+00	3.06E-14	6.30E-01	1.00E-03	1.56E-01	4.50E-03
BATCH-658	3/1/27	84	8.8	0.24	0.00E+00	0.00E+00	2.60E-02	6.00E-03	1.95E+00	4.32E-02	6.92E+02	1.92E-01	2.60E-02	3.57E+00	7.24E-14	2.22E-01	4.94E-04	5.70E-02	1.50E-03
BATCH-659	3/7/27	72	7.5	0.24	0.00E+00	0.00E+00	5.80E-02	1.30E-02	4.43E+00	9.54E-02	1.43E+03	4.25E-01	5.70E-02	7.13E+00	2.48E-14	5.10E-01	1.00E-03	1.27E-01	3.75E-03
BATCH-660	3/10/27	69	7.2	0.24	0.00E+00	0.00E+00	6.00E-02	1.30E-02	4.57E+00	9.90E-02	1.39E+03	4.36E-01	5.80E-02	6.90E+00	2.77E-14	5.24E-01	1.00E-03	1.30E-01	3.75E-03
BATCH-661	3/15/27	48	5.0	0.24	0.00E+00	0.00E+00	1.40E-02	3.00E-03	1.07E+00	2.34E-02	3.76E+02	1.06E-01	1.40E-02	1.88E+00	9.61E-14	1.21E-01	2.72E-04	3.20E-02	7.50E-04
BATCH-662	3/18/27	67	7.0	0.24	0.00E+00	0.00E+00	6.30E-02	1.30E-02	4.79E+00	1.05E-01	1.33E+03	4.55E-01	6.10E-02	6.64E+00	3.19E-14	5.46E-01	1.00E-03	1.35E-01	4.00E-03
BATCH-663	3/20/27	80	8.4	0.24	0.00E+00	0.00E+00	7.60E-02	1.60E-02	5.78E+00	1.27E-01	1.61E+03	5.49E-01	7.30E-02	8.00E+00	3.84E-14	6.58E-01	1.00E-03	1.62E-01	4.75E-03
BATCH-664	3/25/27	48	5.0	0.24	0.00E+00	0.00E+00	1.30E-02	3.00E-03	9.97E-01	2.25E-02	3.54E+02	9.80E-02	1.30E-02	1.83E+00	3.71E-14	1.14E-01	2.53E-04	2.90E-02	7.50E-04
BATCH-665	3/29/27	65	6.8	0.24	0.00E+00	0.00E+00	6.10E-02	1.30E-02	4.69E+00	1.03E-01	1.30E+03	4.45E-01	5.90E-02	6.49E+00	3.12E-14	5.34E-01	1.00E-03	1.32E-01	4.00E-03
BATCH-666	3/30/27	61	6.4	0.24	0.00E+00	0.00E+00	5.80E-02	1.20E-02	4.39E+00	9.63E-02	1.22E+03	4.17E-01	5.60E-02	6.08E+00	2.92E-14	5.00E-01	1.00E-03	1.23E-01	3.75E-03
BATCH-667	4/5/27	17	1.8	0.24	0.00E+00	0.00E+00	4.00E-03	8.29E-04	2.81E-01	6.30E-03	9.88E+01	2.80E-02	4.00E-03	4.94E-01	2.53E-14	3.20E-02	7.15E-05	8.00E-03	2.22E-04
BATCH-668	4/6/27	83	8.7	0.24	0.00E+00	0.00E+00	2.30E-02	5.00E-03	1.77E+00	3.87E-02	6.81E+02	1.72E-01	2.30E-02	3.37E+00	3.59E-14	2.02E-01	4.40E-04	5.10E-02	1.50E-03
BATCH-669	4/7/27	67	7.0	0.24	0.00E+00	0.00E+00	6.30E-02	1.40E-02	4.82E+00	1.05E-01	1.34E+03	4.58E-01	6.10E-02	6.67E+00	3.20E-14	5.49E-01	1.00E-03	1.35E-01	4.00E-03
BATCH-670	4/14/27	18	1.8	0.24	0.00E+00	0.00E+00	3.00E-03	7.83E-04	2.66E-01	6.30E-03	9.45E+01	2.60E-02	4.00E-03	4.87E-01	9.89E-15	3.00E-02	6.75E-05	8.00E-03	2.13E-04
BATCH-671	4/15/27	90	9.4	0.24	0.00E+00	0.00E+00	2.30E-02	5.00E-03	1.72E+00	3.69E-02	6.90E+02	1.64E-01	2.20E-02	3.51E+00	1.01E-14	1.97E-01	4.21E-04	4.90E-02	1.50E-03
BATCH-672	4/16/27	100	10.5	0.24	0.00E+00	0.00E+00	2.60E-02	6.00E-03	1.98E+00	4.32E-02	7.97E+02	1.90E-01	2.50E-02	4.05E+00	1.17E-14	2.28E-01	4.87E-04	5.60E-02	1.75E-03
BATCH-673	4/25/27	99	10.3	0.24	0.00E+00	0.00E+00	9.30E-02	2.00E-02	7.10E+00	1.56E-01	1.97E+03	6.74E-01	9.00E-02	9.83E+00	4.72E-14	8.08E-01	2.00E-03	2.00E-01	6.00E-03
BATCH-674	4/27/27	87	9.1	0.24	0.00E+00	0.00E+00	2.30E-02	5.00E-03	1.79E+00	3.87E-02	7.40E+02	1.70E-01	2.30E-02	3.44E+00	1.12E-14	2.04E-01	4.37E-04	5.10E-02	1.50E-03
BATCH-675	5/5/27	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	3.00E-03	9.16E-01	1.98E-02	3.53E+02	8.90E-02	1.20E-02	1.74E+00	1.86E-14	1.05E-01	2.28E-04	2.60E-02	7.50E-04
BATCH-676	5/6/27	90	9.4	0.24	0.00E+00	0.00E+00	8.10E-02	1.70E-02	6.17E+00	1.37E-01	1.80E+03	5.86E-01	7.80E-02	8.96E+00	4.16E-14	7.03E-01	1.00E-03	1.73E-01	5.25E-03
BATCH-677	5/10/27	49	5.1	0.24	0.00E+00	0.00E+00	1.10E-02	2.00E-03	8.29E-01	1.80E-02	3.33E+02	7.90E-02	1.10E-02	1.69E+00	4.89E-15	9.50E-02	2.04E-04	2.40E-02	7.50E-04
BATCH-678	5/16/27	47	4.9	0.24	0.00E+00	0.00E+00	1.10E-02	2.00E-03	8.27E-01	1.80E-02	3.33E+02	7.90E-02	1.10E-02	1.69E+00	4.87E-15	9.50E-02	2.03E-04	2.40E-02	7.50E-04
BATCH-679	5/16/27	76	7.9	0.24	0.00E+00	0.00E+00	4.10E-02	9.00E-03	3.15E+00	8.19E-02	1.41E+03	3.03E-01	4.00E-02	7.59E+00	2.61E-14	3.71E-01	7.62E-04	8.80E-02	3.25E-03
BATCH-680	5/21/27	48	5.0	0.24	0.00E+00	0.00E+00	1.10E-02	2.00E-03	8.72E-01	1.89E-02	3.60E+02	8.30E-02	1.10E-02	1.68E+00	5.45E-15	1.00E-01	2.13E-04	2.50E-02	7.50E-04
BATCH-681	5/24/27	17	1.8	0.24	0.00E+00	0.00E+00	3.00E-03	6.83E-04	2.37E-01	5.40E-03	9.12E+01	2.30E-02	3.00E-03	4.51E-01	4.81E-15	2.70E-02	5.89E-05	7.00E-03	1.93E-04
BATCH-682	5/26/27	17	1.8	0.24	0.00E+00	0.00E+00	3.00E-03	6.06E-04	2.13E-01	4.50E-03	8.57E+01	2.00E-02	3.00E-03	4.35E-01	1.26E-15	2.40E-02	5.23E-05	6.00E-03	1.75E-04
BATCH-683	5/26/27	70	7.2	0.24	0.00E+00	0.00E+00	3.80E-02	8.00E-03	2.87E+00	7.47E-02	1.29E+03	2.77E-01	3.60E-02	6.92E+00	2.38E-14	3.39E-01	6.95E-04	8.00E-02	3.00E-03
BATCH-684	5/28/27	17	1.7	0.24	0.00E+00	0.00E+00	3.00E-03	5.87E-04	2.06E-01	4.50E-03	8.30E+01	2.00E-02	3.00E-03	4.22E-01	1.22E-15	2.40E-02	5.06E-05	6.00E-03	1.70E-04
BATCH-685	5/30/27	59	6.1	0.24	0.00E+00	0.00E+00	3.20E-02	7.00E-03	2.43E+00	6.30E-02	1.09E+03	2.34E-01	3.10E-02	5.85E+00	2.01E-14	2.86E-01	5.87E-04	6.80E-02	2.50E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-637	12/20/26	52	5.5	0.24	1.92E-08	1.57E+02	1.10E+02	9.00E-03	5.67E-01	3.20E-02	1.00E-03	3.86E-06	6.18E-05	3.93E-05	5.06E-05	1.14E-04	6.00E-03	3.30E-02	1.00E-02
BATCH-638	12/25/26	91	9.5	0.24	9.39E-08	2.73E+02	3.99E+02	3.40E-02	2.04E+00	1.18E-01	7.00E-03	1.38E-05	2.18E-04	1.30E-04	1.84E-04	3.69E-04	2.10E-02	1.09E-01	4.60E-02
BATCH-639	12/29/26	90	9.4	0.24	8.96E-08	2.71E+02	3.69E+02	3.10E-02	1.89E+00	1.09E-01	3.00E-03	1.27E-05	2.02E-04	1.19E-04	1.71E-04	3.38E-04	1.90E-02	1.00E-01	4.40E-02
BATCH-640	1/4/27	78	8.2	0.24	2.50E-08	2.34E+02	1.90E+02	1.50E-02	9.07E-01	4.90E-02	8.00E-03	6.47E-06	9.45E-05	6.65E-05	8.73E-05	1.93E-04	1.10E-02	5.70E-02	1.70E-02
BATCH-641	1/7/27	50	5.2	0.24	1.46E-08	1.51E+02	1.16E+02	9.00E-03	5.51E-01	3.00E-02	3.00E-03	3.95E-06	5.87E-05	4.14E-05	5.32E-05	1.21E-04	7.00E-03	3.50E-02	1.00E-02
BATCH-642	1/12/27	18	1.9	0.24	3.49E-09	5.45E+01	2.78E+01	2.00E-03	1.33E-01	7.00E-03	3.32E-04	9.50E-07	1.41E-05	9.97E-06	1.28E-05	2.91E-05	2.00E-03	8.00E-03	2.00E-03
BATCH-643	1/13/27	51	5.3	0.24	1.46E-08	1.53E+02	1.16E+02	9.00E-03	5.51E-01	3.00E-02	3.00E-03	3.94E-06	5.81E-05	4.10E-05	5.30E-05	1.20E-04	7.00E-03	3.50E-02	1.00E-02
BATCH-644	1/14/27	75	7.8	0.24	5.31E-08	2.24E+02	3.04E+02	2.50E-02	1.45E+00	7.90E-02	2.00E-03	1.02E-05	1.51E-04	9.86E-05	1.42E-04	2.80E-04	1.60E-02	8.30E-02	3.70E-02
BATCH-645	1/18/27	75	7.8	0.24	5.30E-08	2.24E+02	3.03E+02	2.50E-02	1.45E+00	7.90E-02	2.00E-03	1.02E-05	1.51E-04	9.84E-05	1.41E-04	2.80E-04	1.60E-02	8.20E-02	3.60E-02
BATCH-646	1/22/27	49	5.2	0.24	1.42E-08	1.48E+02	1.08E+02	9.00E-03	5.13E-01	2.80E-02	5.00E-03	3.66E-06	5.35E-05	3.76E-05	4.94E-05	1.09E-04	6.00E-03	3.20E-02	9.00E-03
BATCH-647	1/26/27	18	1.8	0.24	3.70E-09	5.29E+01	2.93E+01	2.00E-03	1.39E-01	7.00E-03	6.56E-04	9.98E-07	1.48E-05	1.05E-05	1.35E-05	3.06E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-648	1/28/27	90	9.4	0.24	6.39E-08	2.70E+02	3.66E+02	3.00E-02	1.74E+00	9.50E-02	2.00E-03	1.23E-05	1.82E-04	1.19E-04	1.70E-04	3.37E-04	1.90E-02	9.90E-02	4.40E-02
BATCH-649	1/28/27	18	1.9	0.24	3.74E-09	5.38E+01	2.97E+01	2.00E-03	1.41E-01	8.00E-03	6.87E-04	1.01E-06	1.49E-05	1.05E-05	1.36E-05	3.07E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-650	1/30/27	62	6.4	0.24	4.39E-08	1.85E+02	2.51E+02	2.00E-02	1.20E+00	6.50E-02	2.00E-03	8.45E-06	1.25E-04	8.14E-05	1.17E-04	2.31E-04	1.30E-02	6.80E-02	3.00E-02
BATCH-651	2/6/27	59	6.1	0.24	3.38E-08	1.76E+02	2.05E+02	1.70E-02	9.75E-01	5.30E-02	5.70E-04	6.92E-06	1.05E-04	6.69E-05	9.45E-05	1.10E-02	5.60E-02	3.10E-02	
BATCH-652	2/6/27	17	1.8	0.24	3.58E-09	5.23E+01	2.72E+01	2.00E-03	1.30E-01	7.00E-03	1.00E-03	9.26E-07	1.35E-05	9.51E-06	1.25E-05	2.77E-05	2.00E-03	8.00E-03	2.00E-03
BATCH-653	2/8/27	89	9.2	0.24	4.46E-08	2.65E+02	2.82E+02	2.30E-02	1.34E+00	7.30E-02	5.46E-06	9.52E-06	1.48E-04	9.24E-05	1.29E-04	2.61E-04	1.50E-02	7.60E-02	4.90E-02
BATCH-654	2/12/27	88	9.2	0.24	4.46E-08	2.65E+02	2.82E+02	2.30E-02	1.34E+00	7.30E-02	5.47E-06	9.51E-06	1.47E-04	9.23E-05	1.29E-04	2.61E-04	1.50E-02	7.60E-02	4.90E-02
BATCH-655	2/18/27	76	7.9	0.24	1.72E-08	2.27E+02	1.01E+02	8.00E-03	4.80E-01	2.60E-02	2.00E-03	3.39E-06	4.99E-05	3.29E-05	4.69E-05	9.37E-05	5.00E-03	2.80E-02	1.20E-02
BATCH-656	2/22/27	73	7.6	0.24	3.70E-08	2.20E+02	2.34E+02	1.90E-02	1.11E+00	6.10E-02	5.70E-06	7.89E-06	1.22E-04	7.65E-05	1.07E-04	2.16E-04	1.20E-02	6.30E-02	4.10E-02
BATCH-657	2/26/27	88	9.2	0.24	4.46E-08	2.65E+02	2.81E+02	2.30E-02	1.34E+00	7.30E-02	5.53E-06	9.50E-06	1.47E-04	9.22E-05	1.29E-04	2.60E-04	1.40E-02	7.60E-02	4.90E-02
BATCH-658	3/1/27	84	8.8	0.24	1.79E-08	2.52E+02	1.03E+02	8.00E-03	4.91E-01	2.70E-02	6.43E-04	3.47E-05	5.15E-05	3.34E-05	4.79E-05	9.49E-05	5.00E-03	2.80E-02	1.30E-02
BATCH-659	3/7/27	72	7.5	0.24	3.61E-08	2.15E+02	2.28E+02	1.90E-02	1.08E+00	5.90E-02	4.34E-06	7.70E-06	1.19E-04	7.47E-05	1.04E-04	2.11E-04	1.20E-02	6.20E-02	4.00E-02
BATCH-660	3/10/27	69	7.2	0.24	3.52E-08	2.08E+02	2.33E+02	1.90E-02	1.11E+00	6.00E-02	2.95E-05	7.89E-06	1.24E-04	7.69E-05	1.07E-04	2.17E-04	1.20E-02	6.30E-02	3.50E-02
BATCH-661	3/15/27	48	5.0	0.24	9.69E-09	1.43E+02	5.68E+01	5.00E-03	2.71E-01	1.50E-02	9.42E-04	1.92E-06	2.82E-05	1.86E-05	2.65E-05	5.29E-05	3.00E-03	1.60E-02	7.00E-03
BATCH-662	3/18/27	67	7.0	0.24	3.42E-08	2.00E+02	2.43E+02	2.00E-02	1.14E+00	6.20E-02	6.44E-05	8.21E-06	1.30E-04	8.06E-05	1.12E-04	2.26E-04	1.20E-02	6.50E-02	3.00E-02
BATCH-663	3/20/27	80	8.4	0.24	4.13E-08	2.41E+02	2.93E+02	2.40E-02	1.38E+00	7.50E-02	7.77E-05	9.90E-06	1.57E-04	9.72E-05	1.35E-04	2.73E-04	1.50E-02	7.90E-02	3.60E-02
BATCH-664	3/25/27	48	5.0	0.24	9.14E-09	1.44E+02	5.27E+01	4.00E-03	2.51E-01	1.40E-02	3.29E-04	1.78E-06	2.63E-05	1.71E-05	2.45E-05	4.86E-05	3.00E-03	1.40E-02	7.00E-03
BATCH-665	3/29/27	65	6.8	0.24	3.35E-08	1.95E+02	2.37E+02	1.90E-02	1.12E+00	6.10E-02	6.30E-05	8.03E-06	1.27E-04	7.89E-05	1.09E-04	2.21E-04	1.20E-02	6.40E-02	2.90E-02
BATCH-666	3/30/27	61	6.4	0.24	3.13E-08	1.83E+02	2.22E+02	1.80E-02	1.05E+00	5.70E-02	5.90E-05	7.52E-06	1.19E-04	7.39E-05	1.03E-04	2.07E-04	1.10E-02	6.00E-02	2.70E-02
BATCH-667	4/5/27	17	1.8	0.24	2.55E-09	5.20E+01	1.49E+01	1.00E-03	7.10E-02	4.00E-03	2.48E-04	5.04E-07	7.41E-06	4.88E-06	6.96E-06	1.39E-05	7.77E-04	4.00E-03	2.00E-03
BATCH-668	4/6/27	83	8.7	0.24	1.48E-08	2.50E+02	9.18E+01	7.00E-03	4.36E-01	2.40E-02	2.74E-04	3.10E-06	4.74E-05	3.01E-05	4.24E-05	8.50E-05	5.00E-03	2.50E-02	1.30E-02
BATCH-669	4/7/27	67	7.0	0.24	3.44E-08	2.01E+02	2.44E+02	2.00E-02	1.15E+00	6.30E-02	6.48E-05	8.26E-06	1.31E-04	8.11E-05	1.13E-04	2.28E-04	1.20E-02	6.60E-02	3.00E-02
BATCH-670	4/14/27	18	1.8	0.24	2.44E-09	5.27E+01	1.41E+01	1.00E-03	6.70E-02	4.00E-03	8.78E-05	4.74E-07	7.03E-06	4.57E-06	6.55E-06	1.30E-05	7.25E-04	4.00E-03	2.00E-03
BATCH-671	4/15/27	90	9.4	0.24	1.35E-08	2.69E+02	8.79E+01	7.00E-03	4.16E-01	2.30E-02	7.83E-06	2.97E-06	4.63E-05	2.89E-05	4.03E-05	8.15E-05	5.00E-03	2.40E-02	1.40E-02
BATCH-672	4/16/27	100	10.5	0.24	1.56E-08	3.01E+02	1.02E+02	8.00E-03	4.81E-01	2.60E-02	9.02E-06	3.43E-06	5.35E-05	3.34E-05	4.65E-05	9.41E-05	5.00E-03	2.70E-02	1.60E-02
BATCH-673	4/25/27	99	10.3	0.24	5.07E-08	2.96E+02	3.59E+02	2.90E-02	1.70E+00	9.20E-02	9.55E-05	1.22E-05	1.93E-04	1.19E-04	1.66E-04	3.35E-04	1.80E-02	9.70E-02	4.40E-02
BATCH-674	4/27/27	87	9.1	0.24	1.34E-08	2.62E+02	9.11E+01	7.00E-03	4.31E-01	2.40E-02	1.56E-05	3.08E-06	4.84E-05	3.01E-05	4.19E-05	8.47E-05	5.00E-03	2.50E-02	1.30E-02
BATCH-675	5/5/27	48	5.0	0.24	7.64E-09	1.45E+02	4.75E+01	4.00E-03	2.26E-01	1.20E-02	1.42E-04	1.60E-06	2.45E-05	1.56E-05	2.20E-05	4.40E-05	2.00E-03	1.30E-02	7.00E-03
BATCH-676	5/6/27	90	9.4	0.24	4.41E-08	2.70E+02	3.12E+02	2.50E-02	1.49E+00	8.10E-02	9.01E-05	1.06E-05	1.71E-04	1.04E-04	1.48E-04	2.92E-04	1.60E-02	8.40E-02	4.00E-02
BATCH-677	5/10/27	49	5.1	0.24	6.52E-09	1.45E+02	4.25E+01	3.00E-03	2.01E-01	1.10E-02	3.78E-06	1.44E-06	2.24E-05	1.40E-05	1.95E-05	3.94E-05	2.00E-03	1.10E-02	7.00E-03
BATCH-678	5/16/27	47	4.9	0.24	6.50E-09	1.41E+02	4.23E+01	3.00E-03	2.01E-01	1.10E-02	3.76E-06	1.43E-06	2.23E-05	1.39E-05	1.94E-05	3.93E-05	2.00E-03	1.10E-02	7.00E-03
BATCH-679	5/16/27	76	7.9	0.24	2.36E-08	2.28E+02	1.58E+02	1.50E-02	8.97E-01	4.60E-02	9.79E-05	5.36E-06	1.13E-04	5.51E-05	1.05E-04	1.54E-04	8.00E-03	4.40E-02	3.50E-02
BATCH-680	5/21/27	48	5.0	0.24	6.55E-09	1.43E+02	4.44E+01	4.00E-03	2.10E-01	1.10E-02	7.62E-06	1.50E-06	2.36E-05	1.47E-05	2.04E-05	4.13E-05	2.00E-03	1.20E-02	6.00E-03
BATCH-681	5/24/27	17	1.8	0.24	1.97E-09	5.20E+01	1.23E+01	9.98E-04	5.80E-02	3.00E-03	3.66E-05	4.15E-07	6.34E-06	4.02E-06	5.68E-06	1.14E-05	6.32E-04	3.00E-03	2.00E-03
BATCH-682	5/26/27	17	1.8	0.24	1.67E-09	5.20E+01	1.09E+01	8.86E-04	5.20E-02	3.00E-03	9.72E-07	3.69E-07	5.75E-06	3.59E-06	5.00E-06	1.01E-05	5.61E-04	3.00E-03	2.00E-03
BATCH-683	5/26/27	70	7.2	0.24	2.15E-08	2.08E+02	1.44E+02	1.30E-02	8.19E-01	4.20E-02	8.93E-05	4.89E-06	1.03E-04	5.02E-05	9.57E-05	1.40E-04	8.00E-03	4.00E-02	3.20E-02
BATCH-684	5/28/27	17	1.7	0.24	1.62E-09	5.02E+01	1.06E+01	8.58E-04	5.00E-02	3.00E-03	9.38E-07	3.57E-07	5.57E-06	3.48E-06	4.84E-06	9.80E-06	5.43E-04	3.00E-03	2.00E-03
BATCH-685	5/30/27	59	6.1	0.24	1.82E-08	1.76E+02	1.21E+02	1.10E-02	6.91E-01	3.60E-02	7.55E-05	4.13E-06	8.74E-05	4.24E-05	8.09E-05	1.19E-04	6.00E-03	3.40E-02	2.70E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-637	12/20/26	52	5.5	0.24	3.95E-04	3.04E-04	1.10E-02	1.40E-02	1.10E-02	6.35E-01	1.07E-01	6.62E-01	2.68E-01	1.09E-24	6.84E-06	2.46E-05	1.59E-04	9.92E-04	2.36E-07
BATCH-638	12/25/26	91	9.5	0.24	2.00E-03	1.00E-03	3.90E-02	4.90E-02	5.10E-02	2.26E+00	3.69E-01	2.50E+00	9.08E-01	2.53E-24	2.33E-05	9.09E-05	3.49E-04	2.00E-03	3.36E-06
BATCH-639	12/29/26	90	9.4	0.24	2.00E-03	1.00E-03	3.60E-02	4.60E-02	4.90E-02	2.11E+00	3.42E-01	2.33E+00	8.40E-01	2.27E-24	2.15E-05	8.45E-05	3.09E-04	2.00E-03	2.68E-06
BATCH-640	1/4/27	78	8.2	0.24	6.79E-04	5.24E-04	1.90E-02	2.40E-02	1.90E-02	1.05E+00	1.77E-01	1.14E+00	4.24E-01	2.95E-25	1.14E-05	4.26E-05	1.97E-04	1.00E-03	1.50E-06
BATCH-641	1/7/27	50	5.2	0.24	4.17E-04	3.22E-04	1.10E-02	1.50E-02	1.20E-02	6.59E-01	1.11E-01	6.97E-01	2.65E-01	2.16E-25	7.12E-06	2.60E-05	1.45E-04	8.82E-04	4.70E-07
BATCH-642	1/12/27	18	1.9	0.24	1.00E-04	7.72E-05	3.00E-03	4.00E-03	3.00E-03	1.61E-01	2.70E-02	1.68E-01	6.50E-02	5.86E-26	1.74E-06	6.25E-06	3.94E-05	2.42E-04	6.00E-08
BATCH-643	1/13/27	51	5.3	0.24	4.15E-04	3.20E-04	1.10E-02	1.50E-02	1.20E-02	6.48E-01	1.09E-01	6.94E-01	2.61E-01	1.95E-25	7.02E-06	2.59E-05	1.31E-04	7.95E-04	4.85E-07
BATCH-644	1/14/27	75	7.8	0.24	2.00E-03	8.86E-04	3.00E-02	3.80E-02	4.10E-02	1.75E+00	2.83E-01	1.93E+00	6.62E-01	3.99E-25	1.79E-05	7.01E-05	2.50E-04	2.00E-03	2.22E-06
BATCH-645	1/18/27	75	7.8	0.24	2.00E-03	8.84E-04	3.00E-02	3.80E-02	4.10E-02	1.74E+00	2.83E-01	1.93E+00	6.62E-01	3.99E-25	1.78E-05	7.00E-05	2.50E-04	2.00E-03	2.22E-06
BATCH-646	1/22/27	49	5.2	0.24	3.84E-04	2.96E-04	1.10E-02	1.30E-02	1.10E-02	5.94E-01	1.00E-01	6.46E-01	2.40E-01	1.67E-25	6.45E-06	2.41E-05	1.12E-04	6.66E-04	8.51E-07
BATCH-647	1/26/27	18	1.8	0.24	1.05E-04	8.14E-05	3.00E-03	4.00E-03	3.00E-03	1.67E-01	2.80E-02	1.76E-01	6.70E-02	5.46E-26	1.80E-06	6.56E-06	3.66E-05	2.23E-04	1.19E-07
BATCH-648	1/28/27	90	9.4	0.24	2.00E-03	1.00E-03	3.60E-02	4.50E-02	4.90E-02	2.10E+00	3.41E-01	2.32E+00	7.98E-01	4.81E-25	2.15E-05	8.43E-05	3.01E-04	2.00E-03	2.68E-06
BATCH-649	1/28/27	18	1.9	0.24	1.06E-04	8.21E-05	3.00E-03	4.00E-03	3.00E-03	1.66E-01	2.80E-02	1.78E-01	6.70E-02	5.01E-26	1.80E-06	6.64E-06	3.35E-05	2.04E-04	1.24E-07
BATCH-650	1/30/27	62	6.4	0.24	1.00E-03	7.31E-04	2.50E-02	3.10E-02	3.40E-02	1.44E+00	2.34E-01	1.59E+00	5.48E-01	3.30E-25	1.47E-05	5.78E-05	2.07E-04	1.00E-03	1.84E-06
BATCH-651	2/6/27	59	6.1	0.24	1.00E-03	6.48E-04	2.00E-02	2.60E-02	3.40E-02	1.24E+00	1.97E-01	1.35E+00	4.50E-01	2.63E-25	1.21E-05	4.78E-05	1.67E-04	1.00E-03	6.08E-07
BATCH-652	2/6/27	17	1.8	0.24	9.71E-05	7.49E-05	3.00E-03	3.00E-03	3.00E-03	1.50E-02	2.50E-02	1.63E-01	6.10E-02	4.22E-26	1.63E-06	6.10E-06	2.82E-05	1.68E-04	2.15E-07
BATCH-653	2/8/27	89	9.2	0.24	2.00E-03	9.37E-04	2.80E-02	3.50E-02	5.30E-02	1.77E+00	2.76E-01	1.90E+00	6.22E-01	3.56E-25	1.67E-05	6.62E-05	2.29E-04	1.00E-03	2.06E-09
BATCH-654	2/12/27	88	9.2	0.24	2.00E-03	9.37E-04	2.80E-02	3.50E-02	5.30E-02	1.77E+00	2.76E-01	1.90E+00	6.22E-01	3.55E-25	1.67E-05	6.62E-05	2.28E-04	1.00E-03	2.06E-09
BATCH-655	2/18/27	76	7.9	0.24	4.87E-04	2.91E-04	1.00E-02	1.20E-02	1.30E-02	5.75E-01	9.40E-02	6.35E-01	2.20E-01	1.36E-25	5.92E-06	2.31E-05	8.60E-05	5.30E-04	8.34E-07
BATCH-656	2/22/27	73	7.6	0.24	2.00E-03	7.77E-04	2.30E-02	2.90E-02	4.40E-02	1.47E+00	2.28E-01	1.57E+00	5.15E-01	2.95E-25	1.38E-05	5.48E-05	1.89E-04	1.00E-03	3.03E-09
BATCH-657	2/26/27	88	9.2	0.24	2.00E-03	9.36E-04	2.80E-02	3.50E-02	5.30E-02	1.77E+00	2.75E-01	1.90E+00	6.21E-01	3.55E-25	1.67E-05	6.61E-05	2.28E-04	1.00E-03	2.07E-09
BATCH-658	3/1/27	84	8.8	0.24	5.40E-04	3.04E-04	1.00E-02	1.30E-02	1.40E-02	5.96E-01	9.60E-02	6.58E-01	2.25E-01	1.35E-25	6.05E-06	2.38E-05	8.47E-05	5.27E-04	6.88E-07
BATCH-659	3/7/27	72	7.5	0.24	2.00E-03	7.58E-04	2.30E-02	2.90E-02	4.30E-02	1.43E+00	2.23E-01	1.54E+00	5.03E-01	2.88E-25	1.35E-05	5.35E-05	1.85E-04	1.00E-03	1.65E-09
BATCH-660	3/10/27	69	7.2	0.24	2.00E-03	7.36E-04	2.30E-02	2.90E-02	3.90E-02	1.41E+00	2.23E-01	1.53E+00	5.10E-01	3.08E-25	1.37E-05	5.41E-05	1.98E-04	1.00E-03	1.01E-08
BATCH-661	3/15/27	48	5.0	0.24	2.75E-04	1.64E-04	6.00E-03	7.00E-03	7.00E-03	3.25E-01	5.30E-02	3.59E-01	1.24E-01	7.67E-26	3.34E-06	1.31E-05	4.86E-05	2.99E-04	4.71E-07
BATCH-662	3/18/27	67	7.0	0.24	1.00E-03	7.11E-04	2.40E-02	2.90E-02	3.30E-02	1.38E+00	2.24E-01	1.54E+00	5.23E-01	3.38E-25	1.40E-05	5.53E-05	2.17E-04	1.00E-03	2.17E-08
BATCH-663	3/20/27	80	8.4	0.24	1.00E-03	8.57E-04	3.00E-02	3.50E-02	3.90E-02	1.67E+00	2.71E-01	1.86E+00	6.31E-01	4.07E-25	1.69E-05	6.67E-05	2.62E-04	2.00E-03	2.62E-08
BATCH-664	3/25/27	48	5.0	0.24	2.76E-04	1.56E-04	5.00E-03	7.00E-03	7.00E-03	3.05E-01	4.90E-02	3.37E-01	1.15E-01	6.91E-26	3.10E-06	1.22E-05	4.33E-05	2.70E-04	3.52E-07
BATCH-665	3/29/27	65	6.8	0.24	1.00E-03	6.95E-04	2.40E-02	2.90E-02	3.20E-02	1.35E+00	2.20E-01	1.50E+00	5.11E-01	3.30E-25	1.37E-05	5.41E-05	2.12E-04	1.00E-03	2.12E-08
BATCH-666	3/30/27	61	6.4	0.24	1.00E-03	6.51E-04	2.20E-02	2.70E-02	3.00E-02	1.27E+00	2.06E-01	1.41E+00	4.79E-01	3.09E-25	1.29E-05	5.06E-05	1.99E-04	1.00E-03	1.99E-08
BATCH-667	4/5/27	17	1.8	0.24	7.22E-05	4.32E-05	1.00E-03	2.00E-03	2.00E-03	8.50E-02	1.40E-02	9.40E-02	3.30E-02	2.02E-26	8.79E-07	3.43E-06	1.28E-05	7.86E-05	1.24E-07
BATCH-668	4/6/27	83	8.7	0.24	5.31E-04	2.79E-04	9.00E-03	1.10E-02	1.40E-02	5.41E-01	8.70E-02	5.94E-01	2.00E-01	1.21E-25	5.38E-06	2.12E-05	7.70E-05	4.77E-04	2.88E-07
BATCH-669	4/7/27	67	7.0	0.24	1.00E-03	7.14E-04	2.50E-02	2.90E-02	3.30E-02	1.39E+00	2.26E-01	1.55E+00	5.26E-01	3.40E-25	1.41E-05	5.56E-05	2.18E-04	1.00E-03	2.19E-08
BATCH-670	4/14/27	18	1.8	0.24	7.37E-05	4.15E-05	1.00E-03	2.00E-03	2.00E-03	8.10E-02	1.30E-02	9.00E-02	3.10E-02	1.84E-26	8.27E-07	3.25E-06	1.16E-05	7.20E-05	9.40E-08
BATCH-671	4/15/27	90	9.4	0.24	5.96E-04	2.82E-04	9.00E-03	1.10E-02	1.50E-02	5.37E-01	8.50E-02	5.82E-01	1.93E-01	1.14E-25	5.17E-06	2.05E-05	7.33E-05	4.51E-04	2.69E-09
BATCH-672	4/16/27	100	10.5	0.24	6.89E-04	3.26E-04	1.00E-02	1.30E-02	1.80E-02	6.21E-01	9.80E-02	6.72E-01	2.23E-01	1.32E-25	5.97E-06	2.36E-05	8.47E-05	5.21E-04	3.10E-09
BATCH-673	4/25/27	99	10.3	0.24	2.00E-03	1.00E-03	3.60E-02	4.30E-02	4.80E-02	2.05E+00	3.32E-01	2.28E+00	7.75E-01	5.00E-25	2.08E-05	8.19E-05	3.21E-04	2.00E-03	3.22E-08
BATCH-674	4/27/27	87	9.1	0.24	5.46E-04	2.81E-04	9.00E-03	1.10E-02	1.40E-02	5.39E-01	8.60E-02	5.91E-01	1.98E-01	1.22E-25	5.32E-06	2.10E-05	7.85E-05	4.66E-04	1.49E-07
BATCH-675	5/5/27	48	5.0	0.24	2.75E-04	1.45E-04	5.00E-03	6.00E-03	7.00E-03	2.80E-01	4.50E-02	3.07E-01	1.04E-01	6.27E-26	2.79E-06	1.10E-05	3.98E-05	2.47E-04	1.49E-07
BATCH-676	5/6/27	90	9.4	0.24	2.00E-03	9.32E-04	3.10E-02	3.80E-02	4.40E-02	1.83E+00	2.93E-01	1.99E+00	6.75E-01	4.34E-25	1.81E-05	7.11E-05	2.79E-04	2.00E-03	5.14E-08
BATCH-677	5/10/27	49	5.1	0.24	2.88E-04	1.36E-04	4.00E-03	5.00E-03	7.00E-03	2.60E-01	4.10E-02	2.81E-01	9.30E-02	5.51E-26	2.50E-06	9.89E-06	3.54E-05	2.18E-04	1.30E-09
BATCH-678	5/16/27	47	4.9	0.24	2.87E-04	1.36E-04	4.00E-03	5.00E-03	7.00E-03	2.59E-01	4.10E-02	2.80E-01	9.30E-02	5.50E-26	2.49E-06	9.86E-06	3.53E-05	2.17E-04	1.29E-09
BATCH-679	5/16/27	76	7.9	0.24	1.00E-03	6.07E-04	1.60E-02	2.10E-02	3.70E-02	1.31E+00	1.84E-01	1.07E+00	3.67E-01	2.18E-25	9.72E-06	3.69E-05	1.40E-04	8.93E-04	1.95E-07
BATCH-680	5/21/27	48	5.0	0.24	2.66E-04	1.37E-04	4.00E-03	5.00E-03	7.00E-03	2.63E-01	4.20E-02	2.88E-01	9.70E-02	5.96E-26	2.59E-06	1.02E-05	3.83E-05	2.37E-04	2.58E-09
BATCH-681	5/24/27	17	1.8	0.24	7.11E-05	3.74E-05	1.00E-03	2.00E-03	2.00E-03	7.20E-02	1.20E-02	7.90E-02	2.70E-02	1.62E-26	7.20E-07	2.84E-06	1.03E-05	6.39E-05	3.85E-08
BATCH-682	5/26/27	17	1.8	0.24	7.40E-05	3.51E-05	1.00E-03	1.00E-03	2.00E-03	6.70E-02	1.10E-02	7.20E-02	2.40E-02	1.42E-26	6.42E-07	2.54E-06	9.10E-06	5.60E-05	3.34E-10
BATCH-683	5/28/27	70	7.2	0.24	1.00E-03	5.54E-04	1.50E-02	2.00E-02	3.40E-02	1.19E+00	1.68E-01	9.72E-01	3.35E-01	1.99E-25	8.87E-06	3.37E-05	1.28E-04	8.15E-04	1.78E-07
BATCH-684	5/28/27	17	1.7	0.24	7.17E-05	3.40E-05	1.00E-03	1.00E-03	2.00E-03	6.50E-02	1.00E-02	7.00E-02	2.30E-02	1.37E-26	6.21E-07	2.46E-06	8.81E-06	5.42E-05	3.22E-10
BATCH-685	5/30/27	59	6.1	0.24	1.00E-03	4.68E-04	1.20E-02	1.70E-02	2.80E-02	1.01E+00	1.42E-01	8.21E-01	2.83E-01	1.68E-25	7.49E-06	2.84E-05	1.08E-04	6.88E-04	1.50E-07

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses				0.24	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-637	12/20/26	52	5.5	0.24	1.31E+02	0.00E+00	1.85E-07	4.20E-04	7.00E-08	3.77E-19	1.40E-02	2.38E-01	1.69E-07	6.86E-04	2.98E+00	0.00E+00	1.54E+01	0.00E+00	2.14E-05
BATCH-638	12/25/26	91	9.5	0.24	4.00E-03	8.64E+01	5.86E-06	7.29E-04	2.70E-06	2.49E-23	2.79E-01	1.12E+00	2.11E-06	2.40E-02	1.60E+01	0.00E+00	5.01E-04	5.55E+00	1.08E-04
BATCH-639	12/29/26	90	9.4	0.24	5.00E-03	7.81E+01	5.65E-06	7.85E-04	2.67E-06	2.32E-23	2.93E-01	1.17E+00	1.62E-06	2.50E-02	1.54E+01	0.00E+00	5.63E-04	5.19E+00	8.09E-05
BATCH-640	1/4/27	78	8.2	0.24	2.01E+02	0.00E+00	1.18E-06	5.75E-05	4.43E-07	1.37E-52	8.10E-02	3.47E-01	1.05E-06	2.00E-03	5.61E+00	0.00E+00	2.57E+01	0.00E+00	5.39E-05
BATCH-641	1/7/27	50	5.2	0.24	1.25E+02	0.00E+00	3.68E-07	9.35E-04	1.38E-07	2.86E-19	2.50E-02	1.94E-01	3.29E-07	6.88E-04	3.29E+00	0.00E+00	1.47E+01	0.00E+00	2.45E-05
BATCH-642	1/12/27	18	1.9	0.24	3.33E+01	0.00E+00	4.70E-08	1.07E-04	1.78E-08	9.57E-20	4.00E-03	6.00E-02	4.30E-08	1.74E-04	7.58E-01	0.00E+00	3.90E+00	0.00E+00	5.44E-06
BATCH-643	1/13/27	51	5.3	0.24	1.25E+02	0.00E+00	3.80E-07	4.87E-04	1.43E-07	7.71E-19	2.60E-02	1.94E-01	3.41E-07	6.82E-04	3.25E+00	0.00E+00	1.51E+01	0.00E+00	2.44E-05
BATCH-644	1/14/27	75	7.8	0.24	2.13E-06	6.48E+01	4.69E-06	6.51E-04	2.21E-06	1.27E-26	2.43E-01	9.66E-01	1.34E-06	2.10E-02	1.28E+01	0.00E+00	2.56E-07	4.30E+00	8.09E-05
BATCH-645	1/18/27	75	7.8	0.24	2.47E-06	6.47E+01	4.68E-06	6.50E-04	2.21E-06	1.18E-26	2.43E-01	9.65E-01	1.34E-06	2.10E-02	1.28E+01	0.00E+00	2.88E-07	4.30E+00	8.09E-05
BATCH-646	1/22/27	49	5.2	0.24	1.14E+02	0.00E+00	6.67E-07	3.25E-05	2.51E-07	7.75E-53	4.60E-02	1.97E-01	5.96E-07	9.93E-04	3.17E+00	0.00E+00	1.45E+01	0.00E+00	2.58E-05
BATCH-647	1/26/27	18	1.8	0.24	3.15E+01	0.00E+00	9.30E-08	2.36E-04	3.49E-08	7.23E-20	6.00E-03	4.90E-02	8.33E-08	1.74E-04	8.31E-01	0.00E+00	3.72E+00	0.00E+00	6.20E-06
BATCH-648	1/28/27	90	9.4	0.24	5.00E-03	7.79E+01	5.64E-06	7.83E-04	2.66E-06	1.46E-23	2.92E-01	1.16E+00	1.61E-06	2.50E-02	1.54E+01	0.00E+00	5.97E-04	5.18E+00	8.09E-05
BATCH-649	1/28/27	18	1.9	0.24	3.21E+01	0.00E+00	9.74E-08	1.25E-04	3.66E-08	1.98E-19	7.00E-03	5.00E-02	8.74E-08	1.75E-04	8.35E-01	0.00E+00	3.87E+00	0.00E+00	6.26E-06
BATCH-650	1/30/27	62	6.4	0.24	1.31E-09	5.35E+01	3.87E-06	5.37E-04	1.83E-06	7.83E-30	2.01E-01	7.98E-01	1.11E-06	1.70E-02	1.06E+01	0.00E+00	1.58E-10	3.55E+00	5.39E-05
BATCH-651	2/6/27	59	6.1	0.24	1.23E-09	4.16E+01	1.28E-06	1.86E-04	6.06E-07	5.90E-30	1.88E-01	8.17E-01	3.72E-07	1.80E-02	9.97E+00	0.00E+00	1.43E-10	3.06E+00	5.39E-05
BATCH-652	2/6/27	17	1.8	0.24	2.87E+01	0.00E+00	1.69E-07	8.23E-06	6.33E-08	1.96E-53	1.20E-02	5.00E-02	1.51E-07	2.51E-04	8.02E-01	0.00E+00	3.67E+00	0.00E+00	6.52E-06
BATCH-653	2/8/27	89	9.2	0.24	5.00E-03	5.52E+01	9.93E-09	1.98E-05	4.00E-09	1.08E-23	2.80E-01	1.28E+00	1.40E-08	2.90E-02	1.50E+01	0.00E+00	5.54E-04	4.35E+00	5.39E-05
BATCH-654	2/12/27	88	9.2	0.24	5.00E-03	5.52E+01	9.93E-09	1.98E-05	4.00E-09	3.00E-23	2.80E-01	1.28E+00	1.40E-08	2.90E-02	1.50E+01	0.00E+00	5.88E-04	4.35E+00	5.39E-05
BATCH-655	2/18/27	76	7.9	0.24	1.44E+02	0.00E+00	1.50E-06	1.91E-04	6.94E-07	5.26E-24	2.10E-01	5.62E-01	5.21E-07	6.00E-03	4.09E+00	0.00E+00	1.58E+01	0.00E+00	2.64E-05
BATCH-656	2/22/27	73	7.6	0.24	2.55E-06	4.58E+01	1.10E-08	1.68E-05	4.64E-09	7.34E-27	2.32E-01	1.06E+00	1.24E-08	2.40E-02	1.24E+01	0.00E+00	2.99E-07	3.61E+00	5.39E-05
BATCH-657	2/26/27	88	9.2	0.24	4.00E-03	5.51E+01	9.93E-09	1.97E-05	4.00E-09	2.91E-57	2.80E-01	1.28E+00	1.40E-08	2.90E-02	1.49E+01	0.00E+00	5.46E-04	4.34E+00	5.39E-05
BATCH-658	3/1/27	84	8.8	0.24	1.56E+02	0.00E+00	1.45E-06	2.02E-04	6.85E-07	2.48E-24	2.30E-01	6.30E-01	4.15E-07	7.00E-03	4.43E+00	0.00E+00	1.58E+01	0.00E+00	2.58E-05
BATCH-659	3/7/27	72	7.5	0.24	2.40E-06	4.47E+01	8.02E-09	1.60E-05	3.23E-09	5.51E-27	2.27E-01	1.03E+00	1.13E-08	2.30E-02	1.21E+01	0.00E+00	2.84E-07	3.52E+00	2.70E-05
BATCH-660	3/10/27	69	7.2	0.24	2.11E-06	4.79E+01	9.18E-09	1.46E-05	5.11E-09	1.30E-25	1.89E-01	9.59E-01	4.09E-08	2.20E-02	1.17E+01	0.00E+00	2.55E-07	3.55E+00	5.39E-05
BATCH-661	3/15/27	48	5.0	0.24	8.13E+01	0.00E+00	8.47E-07	1.08E-04	3.92E-07	2.97E-24	1.18E-01	3.17E-01	2.94E-07	3.00E-03	2.31E+00	0.00E+00	8.89E+00	0.00E+00	1.49E-05
BATCH-662	3/18/27	67	7.0	0.24	1.62E-09	5.26E+01	1.09E-08	1.28E-05	7.74E-09	4.65E-30	1.39E-01	8.64E-01	8.22E-08	1.90E-02	1.13E+01	0.00E+00	1.90E-10	3.61E+00	5.39E-05
BATCH-663	3/20/27	80	8.4	0.24	2.24E-06	6.34E+01	1.31E-08	1.55E-05	9.33E-09	1.53E-60	1.68E-01	1.04E+00	9.92E-08	2.40E-02	1.36E+01	0.00E+00	2.87E-07	4.36E+00	5.39E-05
BATCH-664	3/25/27	48	5.0	0.24	7.96E+01	0.00E+00	7.42E-07	1.03E-04	3.51E-07	1.27E-24	1.18E-01	3.23E-01	2.12E-07	4.00E-03	2.27E+00	0.00E+00	8.07E+00	0.00E+00	1.32E-05
BATCH-665	3/29/27	65	6.8	0.24	1.56E-09	5.14E+01	1.06E-08	1.26E-05	7.57E-09	3.57E-30	1.36E-01	8.45E-01	8.04E-08	1.90E-02	1.10E+01	0.00E+00	1.84E-10	3.53E+00	5.39E-05
BATCH-666	3/30/27	61	6.4	0.24	1.46E-09	4.82E+01	9.95E-09	1.18E-05	7.09E-09	8.99E-30	1.28E-01	7.92E-01	7.53E-08	1.80E-02	1.03E+01	0.00E+00	1.76E-10	3.31E+00	5.39E-05
BATCH-667	4/5/27	17	1.8	0.24	2.14E+01	0.00E+00	2.23E-07	2.83E-05	1.03E-07	7.80E-25	3.10E-02	8.30E-02	7.73E-08	9.17E-04	6.07E-01	0.00E+00	2.34E+00	0.00E+00	3.92E-06
BATCH-668	4/6/27	83	8.7	0.24	1.68E+02	0.00E+00	6.03E-07	8.68E-05	2.85E-07	1.56E-24	2.07E-01	6.43E-01	1.82E-07	8.00E-03	4.28E+00	0.00E+00	1.37E+01	0.00E+00	1.96E-05
BATCH-669	4/7/27	67	7.0	0.24	1.41E-09	5.29E+01	1.09E-08	1.29E-05	7.78E-09	9.62E-64	1.40E-01	8.69E-01	8.27E-08	2.00E-02	1.13E+01	0.00E+00	1.80E-10	3.63E+00	5.39E-05
BATCH-670	4/14/27	18	1.8	0.24	2.12E+01	0.00E+00	1.98E-07	2.76E-05	9.36E-08	3.38E-25	3.10E-02	8.60E-02	5.67E-08	1.00E-03	6.05E-01	0.00E+00	2.15E+00	0.00E+00	3.52E-06
BATCH-671	4/15/27	90	9.4	0.24	1.82E+02	0.00E+00	3.33E-09	5.74E-06	1.69E-09	1.33E-24	2.12E-01	6.91E-01	1.16E-08	8.00E-03	4.50E+00	0.00E+00	1.24E+01	0.00E+00	1.56E-05
BATCH-672	4/16/27	100	10.5	0.24	1.92E+02	0.00E+00	3.85E-09	6.63E-06	1.95E-09	3.95E-24	2.27E-01	7.65E-01	1.33E-08	1.00E-02	5.20E+00	0.00E+00	1.30E+01	0.00E+00	1.81E-05
BATCH-673	4/25/27	99	10.3	0.24	3.00E-03	7.79E+01	1.61E-08	1.90E-05	1.15E-08	1.25E-28	2.06E-01	1.28E+00	1.22E-07	2.90E-02	1.67E+01	0.00E+00	3.75E-04	5.35E+00	8.09E-05
BATCH-674	4/27/27	87	9.1	0.24	1.86E+02	0.00E+00	3.75E-09	5.42E-06	2.29E-09	3.60E-58	1.91E-01	6.86E-01	2.08E-08	8.00E-03	4.46E+00	0.00E+00	1.22E+01	0.00E+00	1.67E-05
BATCH-675	5/5/27	48	5.0	0.24	8.67E+01	0.00E+00	3.12E-07	4.49E-05	1.48E-07	8.08E-25	1.07E-01	3.33E-01	9.40E-08	4.00E-03	2.21E+00	0.00E+00	7.08E+00	0.00E+00	1.01E-05
BATCH-676	5/6/27	90	9.4	0.24	3.00E-03	6.87E+01	1.56E-08	1.97E-05	1.20E-08	4.94E-29	1.84E-01	1.23E+00	1.30E-07	2.70E-02	1.50E+01	0.00E+00	3.14E-04	4.73E+00	5.39E-05
BATCH-677	5/10/27	49	5.1	0.24	8.81E+01	0.00E+00	1.61E-09	2.77E-06	8.16E-10	6.44E-25	1.03E-01	3.34E-01	5.59E-09	4.00E-03	2.17E+00	0.00E+00	5.98E+00	0.00E+00	7.56E-06
BATCH-678	5/16/27	47	4.9	0.24	1.63E-06	4.24E+01	1.61E-09	2.76E-06	8.12E-10	1.65E-24	9.50E-02	3.19E-01	5.56E-09	4.00E-03	2.17E+00	0.00E+00	5.40E+00	0.00E+00	7.54E-06
BATCH-679	5/16/27	76	7.9	0.24	1.63E-06	4.24E+01	1.96E-08	3.31E-05	2.09E-08	5.94E-32	1.32E-01	1.46E+00	2.37E-07	2.50E-02	1.15E+01	0.00E+00	1.78E-07	3.03E+00	2.70E-05
BATCH-680	5/21/27	48	5.0	0.24	9.04E+01	0.00E+00	1.83E-09	2.64E-06	1.12E-09	1.75E-58	9.30E-02	3.34E-01	1.01E-08	4.00E-03	2.17E+00	0.00E+00	5.93E+00	0.00E+00	8.12E-06
BATCH-681	5/24/27	17	1.8	0.24	2.24E+01	0.00E+00	8.07E-08	1.16E-05	3.82E-08	2.09E-25	2.80E-02	8.60E-02	2.43E-08	1.00E-03	5.73E-01	0.00E+00	1.83E+00	0.00E+00	2.62E-06
BATCH-682	5/26/27	17	1.8	0.24	2.26E+01	0.00E+00	4.14E-10	7.12E-07	2.10E-10	1.65E-25	2.60E-02	8.60E-02	1.44E-09	1.00E-03	5.59E-01	0.00E+00	1.54E+00	0.00E+00	1.94E-06
BATCH-683	5/26/27	70	7.2	0.24	1.61E-06	3.87E+01	1.79E-08	3.02E-05	1.91E-08	2.57E-32	1.20E-01	1.33E+00	2.16E-07	2.30E-02	1.05E+01	0.00E+00	1.64E-07	2.76E+00	2.70E-05
BATCH-684	5/28/27	17	1.7	0.24	2.00E+01	0.00E+00	4.01E-10	6.89E-07	2.03E-10	4.11E-25	2.40E-02	8.00E-02	1.39E-09	1.00E-03	5.41E-01	0.00E+00	1.35E+00	0.00E+00	1.88E-06
BATCH-685	5/30/27	59	6.1	0.24	1.00E-09	3.27E+01	1.51E-08	2.55E-05	1.61E-08	3.66E-35	1.01E-01	1.13E+00	1.83E-07	1.90E-02	8.89E+00	0.00E+00	1.10E-10	2.33E+00	2.36E-05

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-637	12/20/26	52	5.5	0.24	7.78E-10	6.06E+00	1.37E-01	0.00E+00	0.00E+00	1.44E-04	1.18E+00	1.99E-04	7.29E-08	2.38E-06	2.90E-02	3.34E-08	8.94E+02	0.00E+00	5.00E-03
BATCH-638	12/25/26	91	9.5	0.24	2.25E-08	4.77E+01	5.74E-01	0.00E+00	0.00E+00	1.40E-03	1.02E+01	1.30E-02	1.93E-06	1.47E-04	5.09E-01	5.63E-07	1.56E+03	0.00E+00	6.20E-02
BATCH-639	12/29/26	90	9.4	0.24	2.29E-08	4.89E+01	5.91E-01	0.00E+00	0.00E+00	1.40E-03	1.03E+01	1.30E-02	1.84E-06	1.52E-04	5.15E-01	4.89E-07	1.54E+03	0.00E+00	6.20E-02
BATCH-640	1/4/27	78	8.2	0.24	3.08E-09	8.61E+00	2.86E-01	0.00E+00	0.00E+00	2.00E-04	2.03E+00	1.00E-03	4.29E-07	1.52E-05	8.90E-02	1.97E-07	1.34E+03	0.00E+00	1.30E-02
BATCH-641	1/7/27	50	5.2	0.24	9.92E-10	4.69E+00	1.41E-01	0.00E+00	0.00E+00	1.49E-04	1.10E+00	3.94E-04	1.35E-07	4.74E-06	3.70E-02	6.18E-08	8.60E+02	0.00E+00	6.00E-03
BATCH-642	1/12/27	18	1.9	0.24	1.98E-10	1.54E+00	3.50E-02	0.00E+00	0.00E+00	3.66E-05	2.99E-01	5.06E-05	1.85E-08	6.05E-07	7.00E-03	8.48E-09	3.11E+02	0.00E+00	1.00E-03
BATCH-643	1/13/27	51	5.3	0.24	1.08E-09	4.70E+00	1.43E-01	0.00E+00	0.00E+00	1.53E-04	1.11E+00	4.06E-04	1.40E-07	4.89E-06	4.00E-02	6.42E-08	8.70E+02	0.00E+00	6.00E-03
BATCH-644	1/14/27	75	7.8	0.24	1.90E-08	4.05E+01	4.90E-01	0.00E+00	0.00E+00	1.20E-03	8.53E+00	1.10E-02	1.52E-06	1.26E-04	4.27E-01	4.06E-07	1.28E+03	0.00E+00	5.10E-02
BATCH-645	1/18/27	75	7.8	0.24	1.90E-08	4.05E+01	4.90E-01	0.00E+00	0.00E+00	1.20E-03	8.52E+00	1.10E-02	1.52E-06	1.25E-04	4.26E-01	4.05E-07	1.28E+03	0.00E+00	5.10E-02
BATCH-646	1/22/27	49	5.2	0.24	1.74E-09	4.87E+00	1.62E-01	0.00E+00	0.00E+00	1.55E-04	1.15E+00	7.11E-04	2.43E-07	8.58E-06	5.10E-02	1.12E-07	8.45E+02	0.00E+00	7.00E-03
BATCH-647	1/26/27	18	1.8	0.24	2.51E-10	1.19E+00	3.60E-02	0.00E+00	0.00E+00	3.77E-05	2.78E-01	9.96E-05	3.40E-08	1.20E-06	9.00E-03	1.56E-08	3.02E+02	0.00E+00	1.00E-03
BATCH-648	1/28/27	90	9.4	0.24	2.29E-08	4.88E+01	5.90E-01	0.00E+00	0.00E+00	1.40E-03	1.03E+01	1.30E-02	1.83E-06	1.51E-04	5.13E-01	4.88E-07	1.54E+03	0.00E+00	6.20E-02
BATCH-649	1/28/27	16	1.9	0.24	2.77E-10	1.20E+00	3.70E-02	0.00E+00	0.00E+00	3.94E-05	2.84E-01	1.04E-04	3.59E-08	1.25E-06	1.65E-08	3.06E-02	0.00E+00	0.00E+00	2.00E-03
BATCH-650	1/30/27	62	6.4	0.24	1.57E-08	3.35E+01	4.05E-01	0.00E+00	0.00E+00	1.00E-03	7.05E+00	9.00E-03	1.26E-06	1.04E-04	3.52E-01	3.35E-07	1.06E+03	0.00E+00	4.20E-02
BATCH-651	2/6/27	59	6.1	0.24	5.20E-09	3.37E+01	4.39E-01	0.00E+00	0.00E+00	8.00E-04	5.51E+00	6.00E-03	4.39E-07	3.46E-05	2.83E-01	1.11E-07	1.00E+03	0.00E+00	4.40E-02
BATCH-652	2/6/27	17	1.8	0.24	4.41E-10	1.23E+00	4.10E-02	0.00E+00	0.00E+00	3.91E-05	2.91E-01	1.80E-04	6.13E-08	2.17E-06	1.30E-02	2.82E-08	2.98E+02	0.00E+00	2.00E-03
BATCH-653	2/8/27	89	9.2	0.24	1.64E-11	5.22E+01	7.05E-01	0.00E+00	0.00E+00	1.20E-03	7.33E+00	8.00E-03	5.31E-08	5.60E-07	3.86E-01	2.32E-12	1.51E+03	0.00E+00	7.00E-02
BATCH-654	2/12/27	88	9.2	0.24	1.64E-11	5.22E+01	7.05E-01	0.00E+00	0.00E+00	1.20E-03	7.33E+00	8.00E-03	5.31E-08	5.60E-07	3.85E-01	2.50E-12	1.51E+03	0.00E+00	7.00E-02
BATCH-655	2/18/27	76	7.9	0.24	5.82E-09	1.24E+01	6.12E-01	0.00E+00	0.00E+00	4.00E-04	2.62E+00	3.00E-03	4.93E-07	3.81E-05	1.32E-01	1.42E-07	1.29E+03	0.00E+00	1.60E-02
BATCH-656	2/22/27	73	7.6	0.24	2.50E-11	4.33E+01	5.84E-01	0.00E+00	0.00E+00	1.00E-03	6.08E+00	7.00E-03	4.49E-08	5.39E-07	2.45E-10	1.25E-03	0.00E+00	0.00E+00	5.80E-02
BATCH-657	2/26/27	88	9.2	0.24	1.64E-11	5.21E+01	7.04E-01	0.00E+00	0.00E+00	1.20E-03	7.32E+00	8.00E-03	5.31E-08	5.59E-07	3.85E-01	4.19E-12	1.51E+03	0.00E+00	7.00E-02
BATCH-658	3/1/27	84	8.8	0.24	5.88E-09	1.42E+01	6.91E-01	0.00E+00	0.00E+00	4.00E-04	2.87E+00	4.00E-03	4.73E-07	3.89E-05	1.44E-01	1.26E-07	1.44E+03	0.00E+00	1.80E-02
BATCH-659	3/7/27	72	7.5	0.24	1.33E-11	4.23E+01	5.70E-01	0.00E+00	0.00E+00	1.00E-03	5.93E+00	7.00E-03	4.30E-08	4.53E-07	3.12E-01	1.19E-15	1.22E+03	0.00E+00	5.60E-02
BATCH-660	3/10/27	69	7.2	0.24	1.22E-10	3.86E+01	5.38E-01	0.00E+00	0.00E+00	1.00E-03	5.30E+00	5.00E-03	6.95E-08	4.33E-06	2.91E-01	1.14E-06	1.18E+03	0.00E+00	6.00E-02
BATCH-661	3/15/27	48	5.0	0.24	3.29E-09	6.98E+00	3.46E-01	0.00E+00	0.00E+00	2.00E-04	1.48E+00	2.00E-03	2.78E-07	2.15E-05	7.40E-02	8.00E-08	8.16E+02	0.00E+00	9.00E-03
BATCH-662	3/18/27	67	7.0	0.24	2.73E-10	3.39E+01	4.98E-01	0.00E+00	0.00E+00	1.00E-03	4.47E+00	4.00E-03	1.07E-07	9.71E-06	2.65E-01	2.72E-06	1.14E+03	0.00E+00	6.50E-02
BATCH-663	3/20/27	80	8.4	0.24	3.30E-10	4.09E+01	6.00E-01	0.00E+00	0.00E+00	1.20E-03	5.39E+00	4.00E-03	1.29E-07	1.17E-05	3.19E-01	3.28E-06	1.37E+03	0.00E+00	7.80E-02
BATCH-664	3/25/27	48	5.0	0.24	3.01E-09	3.54E+01	0.00E+00	0.00E+00	0.00E+00	2.00E-04	1.47E+00	2.00E-03	2.42E-07	1.99E-05	7.40E-02	6.42E-08	8.22E+02	0.00E+00	9.00E-03
BATCH-665	3/29/27	65	6.8	0.24	2.67E-10	3.31E+01	4.87E-01	0.00E+00	0.00E+00	1.00E-03	4.37E+00	3.00E-03	1.04E-07	9.50E-06	2.59E-01	2.66E-06	1.11E+03	0.00E+00	6.40E-02
BATCH-666	3/30/27	61	6.4	0.24	2.50E-10	3.10E+01	4.56E-01	0.00E+00	0.00E+00	1.00E-03	4.10E+00	3.00E-03	9.78E-08	8.90E-06	2.43E-01	2.49E-06	1.04E+03	0.00E+00	6.00E-02
BATCH-667	4/5/27	17	1.8	0.24	8.63E-10	1.83E+00	9.10E-02	0.00E+00	0.00E+00	5.35E-05	3.89E-01	4.91E-04	7.31E-08	5.65E-06	2.00E-02	2.10E-08	2.97E+02	0.00E+00	2.00E-03
BATCH-668	4/6/27	83	8.7	0.24	2.47E-09	1.39E+01	7.36E-01	0.00E+00	0.00E+00	4.00E-04	2.28E+00	3.00E-03	2.12E-07	1.72E-05	1.20E-01	3.30E-07	1.43E+03	0.00E+00	2.00E-02
BATCH-669	4/7/27	67	7.0	0.24	2.75E-10	3.41E+01	5.00E-01	0.00E+00	0.00E+00	1.00E-03	4.49E+00	4.00E-03	1.07E-07	9.77E-06	2.66E-01	2.73E-06	1.15E+03	0.00E+00	6.50E-02
BATCH-670	4/14/27	18	1.8	0.24	8.03E-10	1.94E+00	9.40E-02	0.00E+00	0.00E+00	5.49E-05	3.92E-01	4.97E-04	6.46E-08	5.31E-06	2.00E-02	1.71E-08	3.00E+02	0.00E+00	2.00E-03
BATCH-671	4/15/27	90	9.4	0.24	3.18E-11	1.51E+01	8.24E-01	0.00E+00	0.00E+00	4.00E-04	2.10E+00	2.00E-03	2.28E-08	1.12E-06	1.13E-01	2.80E-07	1.53E+03	0.00E+00	2.20E-02
BATCH-672	4/16/27	100	10.5	0.24	3.66E-11	1.75E+01	8.75E-01	0.00E+00	0.00E+00	4.00E-04	2.42E+00	3.00E-03	2.64E-08	1.29E-06	1.31E-01	3.21E-07	1.72E+03	0.00E+00	2.60E-02
BATCH-673	4/25/27	99	10.3	0.24	4.05E-10	5.02E+01	7.37E-01	0.00E+00	0.00E+00	1.40E-03	6.62E+00	5.00E-03	1.58E-07	1.44E-05	3.92E-01	4.03E-06	1.69E+03	0.00E+00	9.60E-02
BATCH-674	4/27/27	87	9.1	0.24	6.55E-11	1.43E+01	7.96E-01	0.00E+00	0.00E+00	4.00E-04	1.94E+00	2.00E-03	3.13E-08	2.32E-06	1.09E-01	6.31E-07	1.49E+03	0.00E+00	2.40E-02
BATCH-675	5/5/27	48	5.0	0.24	1.28E-09	7.17E+00	3.81E-01	0.00E+00	0.00E+00	1.94E-04	1.18E+00	1.00E-03	1.10E-07	8.88E-06	6.20E-02	1.71E-07	8.25E+02	0.00E+00	1.00E-02
BATCH-676	5/6/27	90	9.4	0.24	9.32E-10	4.83E+01	8.13E-01	0.00E+00	0.00E+00	1.40E-03	5.85E+00	4.00E-03	2.26E-07	1.32E-05	3.39E-01	3.81E-06	1.54E+03	0.00E+00	8.40E-02
BATCH-677	5/10/27	49	5.1	0.24	1.53E-11	7.32E+00	3.98E-01	0.00E+00	0.00E+00	1.81E-04	1.01E+00	1.00E-03	1.10E-08	5.43E-07	5.50E-02	1.35E-07	8.29E+02	0.00E+00	1.10E-02
BATCH-678	5/16/27	47	4.9	0.24	1.53E-11	7.30E+00	3.65E-01	0.00E+00	0.00E+00	1.81E-04	1.01E+00	1.00E-03	1.10E-08	5.40E-07	5.50E-02	1.34E-07	8.05E+02	0.00E+00	1.10E-02
BATCH-679	5/16/27	76	7.9	0.24	4.65E-09	5.87E+01	1.66E+00	0.00E+00	0.00E+00	8.00E-04	3.69E+00	2.00E-03	7.53E-07	1.18E-05	1.66E-01	4.23E-06	1.30E+03	0.00E+00	4.30E-02
BATCH-680	5/21/27	48	5.0	0.24	3.19E-11	6.97E+00	3.88E-01	0.00E+00	0.00E+00	1.87E-04	9.46E-01	8.91E-04	1.53E-08	1.13E-06	5.30E-02	3.07E-07	8.16E+02	0.00E+00	1.20E-02
BATCH-681	5/24/27	17	1.8	0.24	3.30E-10	1.85E+00	9.80E-02	0.00E+00	0.00E+00	5.01E-05	3.05E-01	3.44E-04	2.83E-08	2.30E-06	1.60E-02	4.42E-08	2.96E+02	0.00E+00	3.00E-03
BATCH-682	5/26/27	17	1.8	0.24	3.94E-12	1.88E+00	1.02E-01	0.00E+00	0.00E+00	4.66E-05	2.60E-01	2.70E-04	2.84E-09	1.40E-07	1.40E-02	3.47E-08	2.96E+02	0.00E+00	3.00E-03
BATCH-683	5/26/27	70	7.2	0.24	4.24E-09	5.35E+01	1.52E+00	0.00E+00	0.00E+00	8.00E-04	3.37E+00	1.00E-03	6.87E-07	1.08E-05	1.51E-01	3.86E-06	1.19E+03	0.00E+00	4.00E-02
BATCH-684	5/29/27	17	1.7	0.24	3.80E-12	1.82E+00	9.10E-02	0.00E+00	0.00E+00	4.51E-05	2.52E-01	2.62E-04	2.74E-09	1.35E-07	1.40E-02	3.34E-08	2.86E+02	0.00E+00	3.00E-03
BATCH-685	5/30/27	59	6.1	0.24	3.58E-09	4.52E+01	1.28E+00	0.00E+00	0.00E+00	6.00E-04	2.85E+00	1.00E-03	5.81E-07	9.08E-06	1.28E-01	3.25E-06	1.00E+03	0.00E+00	3.30E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by_LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-637	12/20/26	52	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.95E+01	8.44E-10	5.24E+00	7.88E+00	2.00E-03	6.31E-10	0.00E+00	1.50E-02	1.46E-05	2.00E-03
BATCH-638	12/25/26	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.67E+01	2.28E-08	7.86E+00	3.92E+01	6.10E-02	5.60E-09	0.00E+00	1.81E-01	9.39E-05	2.10E-02
BATCH-639	12/29/26	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.66E+01	2.15E-08	8.29E+00	3.92E+01	6.40E-02	4.77E-09	0.00E+00	1.86E-01	6.67E-05	2.10E-02
BATCH-640	1/4/27	78	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.70E-04	4.24E+01	5.32E-09	1.30E+01	1.08E+01	6.00E-03	2.37E-09	0.00E+00	3.40E-02	5.50E-05	5.00E-03
BATCH-641	1/7/27	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.90E+01	1.67E-09	6.08E+00	5.98E+00	2.00E-03	7.64E-10	0.00E+00	1.80E-02	3.04E-05	3.00E-03
BATCH-642	1/12/27	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.68E-04	4.94E+00	2.14E-10	1.33E+00	2.00E+00	4.77E-04	1.60E-10	0.00E+00	4.00E-03	3.71E-06	5.97E-04
BATCH-643	1/13/27	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.89E-04	1.95E+01	1.72E-09	6.38E+00	6.18E+00	3.00E-03	8.36E-10	0.00E+00	1.80E-02	2.45E-05	3.00E-03
BATCH-644	1/14/27	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.87E+01	1.78E-08	6.88E+00	3.25E+01	5.30E-02	3.95E-09	0.00E+00	1.54E-01	5.53E-05	1.70E-02
BATCH-645	1/18/27	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.86E+01	1.78E-08	6.87E+00	3.24E+01	5.30E-02	3.95E-09	0.00E+00	1.54E-01	5.52E-05	1.70E-02
BATCH-646	1/22/27	49	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.49E-04	2.40E+01	3.01E-09	7.37E+00	6.12E+00	3.00E-03	1.34E-09	0.00E+00	1.90E-02	3.11E-05	3.00E-03
BATCH-647	1/26/27	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.01E-04	4.81E+00	4.21E-10	1.54E+00	1.51E+00	5.94E-04	1.93E-10	0.00E+00	5.00E-03	7.69E-06	7.00E-04
BATCH-648	1/28/27	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.65E+01	2.14E-08	8.28E+00	3.91E+01	6.40E-02	4.76E-09	0.00E+00	1.85E-01	6.66E-05	2.00E-02
BATCH-649	1/28/27	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-04	5.00E+00	4.41E-10	1.64E+00	1.58E+00	6.68E-04	2.14E-10	0.00E+00	5.00E-03	6.28E-06	7.48E-04
BATCH-650	1/30/27	62	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.19E+01	1.47E-08	5.68E+00	2.68E+01	4.40E-02	3.26E-09	0.00E+00	1.27E-01	4.57E-05	1.40E-02
BATCH-651	2/5/27	59	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.26E+01	4.87E-09	6.40E+00	2.73E+01	3.40E-02	1.08E-09	0.00E+00	1.15E-01	1.53E-05	1.50E-02
BATCH-652	2/6/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E-04	6.07E+00	7.61E-10	1.86E+00	1.55E+00	8.38E-04	3.39E-10	0.00E+00	5.00E-03	7.87E-06	7.83E-04
BATCH-653	2/8/27	89	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.10E+01	6.27E-14	1.04E+01	4.26E+01	4.60E-02	2.88E-14	0.00E+00	1.68E-01	3.62E-07	2.30E-02
BATCH-654	2/12/27	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.09E+01	6.70E-14	1.04E+01	4.26E+01	4.60E-02	3.26E-14	0.00E+00	1.68E-01	3.62E-07	2.30E-02
BATCH-655	2/18/27	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	9.68E+01	5.81E-09	2.38E+01	1.07E+01	1.60E-02	1.41E-09	0.00E+00	4.80E-02	2.30E-05	5.00E-03
BATCH-656	2/22/27	73	7.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.22E+01	1.07E-11	8.65E+00	3.53E+01	3.80E-02	2.38E-12	0.00E+00	1.39E-01	3.32E-07	1.90E-02
BATCH-657	2/26/27	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.09E+01	1.13E-13	1.04E+01	4.26E+01	4.60E-02	5.04E-14	0.00E+00	1.68E-01	3.61E-07	2.30E-02
BATCH-658	3/1/27	84	8.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.10E+02	5.51E-09	2.67E+01	1.20E+01	1.80E-02	1.22E-09	0.00E+00	5.40E-02	1.71E-05	6.00E-03
BATCH-659	3/7/27	72	7.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.12E+01	3.21E-17	8.45E+00	3.45E+01	3.70E-02	1.47E-17	0.00E+00	1.36E-01	2.92E-07	1.90E-02
BATCH-660	3/10/27	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.98E+01	9.35E-10	8.01E+00	3.31E+01	3.20E-02	1.82E-07	0.00E+00	1.42E-01	9.45E-06	1.70E-02
BATCH-661	3/15/27	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.46E+01	3.28E-09	1.34E+01	6.01E+00	9.00E-03	7.93E-10	0.00E+00	2.70E-02	1.30E-05	3.00E-03
BATCH-662	3/18/27	67	7.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.81E+01	2.23E-09	7.46E+00	3.15E+01	2.40E-02	4.35E-07	0.00E+00	1.51E-01	2.22E-05	1.60E-02
BATCH-663	3/20/27	80	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.60E+01	2.69E-09	9.00E+00	3.80E+01	2.90E-02	5.25E-07	0.00E+00	1.82E-01	2.67E-05	1.90E-02
BATCH-664	3/25/27	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.63E+01	2.82E-09	1.37E+01	6.15E+00	9.00E-03	6.26E-10	0.00E+00	2.80E-02	8.77E-06	3.00E-03
BATCH-665	3/29/27	65	6.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.73E+01	2.18E-09	7.30E+00	3.08E+01	2.40E-02	4.26E-07	0.00E+00	1.48E-01	2.17E-05	1.60E-02
BATCH-666	3/30/27	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.49E+01	2.05E-09	6.84E+00	2.88E+01	2.20E-02	3.99E-07	0.00E+00	1.38E-01	2.03E-05	1.50E-02
BATCH-667	4/5/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.64E-04	1.44E+01	8.62E-10	3.53E+00	1.58E+00	2.00E-03	2.09E-10	0.00E+00	7.00E-03	3.41E-06	7.90E-04
BATCH-668	4/6/27	83	8.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.18E+02	2.52E-09	2.85E+01	1.23E+01	1.40E-02	4.50E-08	0.00E+00	5.30E-02	9.40E-06	6.00E-03
BATCH-669	4/7/27	67	7.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.83E+01	2.25E-09	7.50E+00	3.17E+01	2.50E-02	4.38E-07	0.00E+00	1.52E-01	2.23E-05	1.60E-02
BATCH-670	4/14/27	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-04	1.50E+01	7.53E-10	3.65E+00	1.64E+00	2.00E-03	1.67E-10	0.00E+00	7.00E-03	2.34E-06	8.18E-04
BATCH-671	4/15/27	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.35E+02	2.30E-10	3.20E+01	1.35E+01	1.30E-02	4.48E-08	0.00E+00	5.40E-02	2.36E-06	7.00E-03
BATCH-672	4/16/27	100	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.40E+02	2.64E-10	3.33E+01	1.58E+01	1.50E-02	5.15E-08	0.00E+00	6.30E-02	2.72E-06	8.00E-03
BATCH-673	4/25/27	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.65E+01	3.31E-09	1.11E+01	4.66E+01	3.60E-02	6.45E-07	0.00E+00	2.23E-01	3.29E-05	2.40E-02
BATCH-674	4/27/27	87	9.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.27E+02	5.18E-10	3.07E+01	1.33E+01	1.10E-02	1.01E-07	0.00E+00	5.70E-02	5.19E-06	7.00E-03
BATCH-675	5/5/27	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.51E-04	6.09E+01	1.30E-09	1.48E+01	6.37E+00	7.00E-03	2.33E-08	0.00E+00	2.70E-02	4.87E-06	3.00E-03
BATCH-676	5/6/27	90	9.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.45E+01	3.21E-09	9.97E+00	4.42E+01	3.20E-02	5.90E-07	0.00E+00	1.96E-01	3.03E-05	2.10E-02
BATCH-677	5/10/27	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.31E-04	6.53E+01	1.11E-10	1.55E+01	6.54E+00	6.00E-03	2.16E-08	0.00E+00	2.60E-02	1.14E-06	3.00E-03
BATCH-678	5/16/27	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.29E-04	5.83E+01	1.10E-10	1.39E+01	6.49E+00	6.00E-03	2.15E-08	0.00E+00	2.60E-02	1.13E-06	3.00E-03
BATCH-679	5/16/27	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	6.74E+01	4.10E-09	7.75E+00	4.93E+01	2.10E-02	5.19E-07	0.00E+00	1.14E-01	2.82E-05	1.30E-02
BATCH-680	5/21/27	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.52E-04	6.17E+01	2.53E-10	1.50E+01	6.50E+00	6.00E-03	4.92E-08	0.00E+00	2.80E-02	2.53E-06	3.00E-03
BATCH-681	5/24/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.46E-04	1.58E+01	3.37E-10	3.82E+00	1.65E+00	2.00E-03	6.03E-09	0.00E+00	7.00E-03	1.26E-06	8.14E-04
BATCH-682	5/26/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.39E-04	1.68E+01	2.85E-11	3.97E+00	1.68E+00	2.00E-03	5.56E-09	0.00E+00	7.00E-03	2.93E-07	8.39E-04
BATCH-683	5/26/27	70	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	6.15E+01	3.74E-09	7.07E+00	4.50E+01	1.90E-02	4.73E-07	0.00E+00	1.04E-01	2.57E-05	1.20E-02
BATCH-684	5/28/27	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-04	1.46E+01	2.75E-11	3.46E+00	1.62E+00	2.00E-03	5.36E-09	0.00E+00	7.00E-03	2.83E-07	8.12E-04
BATCH-685	5/30/27	59	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	5.19E+01	3.16E-09	5.97E+00	3.80E+01	1.60E-02	4.00E-07	0.00E+00	8.70E-02	2.17E-05	1.00E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-686	6/3/27	17	1.8	0.24	0.00E+00	0.00E+00	3.00E-03	6.11E-04	2.16E-01	4.50E-03	8.94E+01	2.10E-02	3.00E-03	4.16E-01	1.35E-15	2.50E-02	5.28E-05	6.00E-03	1.79E-04
BATCH-687	6/5/27	91	9.5	0.24	0.00E+00	0.00E+00	4.90E-02	1.10E-02	3.76E+00	9.72E-02	1.68E+03	3.62E-01	4.80E-02	9.06E+00	3.12E-14	4.43E-01	9.09E-04	1.05E-01	4.00E-03
BATCH-688	6/5/27	91	9.5	0.24	0.00E+00	0.00E+00	4.90E-02	1.10E-02	3.76E+00	9.72E-02	1.68E+03	3.62E-01	4.80E-02	9.06E+00	3.11E-14	4.43E-01	9.08E-04	1.05E-01	4.00E-03
BATCH-689	6/14/27	91	9.5	0.24	0.00E+00	0.00E+00	4.90E-02	1.00E-02	3.75E+00	9.72E-02	1.68E+03	3.62E-01	4.80E-02	9.05E+00	3.11E-14	4.42E-01	9.07E-04	1.05E-01	4.00E-03
BATCH-690	6/15/27	61	6.4	0.24	0.00E+00	0.00E+00	2.40E-02	5.00E-03	1.83E+00	1.32E-01	6.87E+02	2.44E-01	3.40E-02	5.08E+00	1.11E-14	1.88E-01	4.23E-04	4.80E-02	2.25E-03
BATCH-691	6/21/27	111	11.6	0.24	0.00E+00	0.00E+00	2.20E-02	5.00E-03	1.70E+00	4.05E-02	7.45E+02	1.63E-01	2.20E-02	3.74E+00	1.28E-14	1.97E-01	4.12E-04	4.80E-02	1.50E-03
BATCH-692	6/24/27	124	12.9	0.24	0.00E+00	0.00E+00	4.00E-02	7.00E-03	3.07E+00	3.26E-01	9.94E+02	4.93E-01	7.00E-02	9.06E+00	1.37E-14	2.82E-01	6.87E-04	7.60E-02	4.50E-03
BATCH-693	7/3/27	95	9.9	0.24	0.00E+00	0.00E+00	3.10E-02	5.00E-03	2.37E+00	2.51E-01	7.67E+02	3.80E-01	5.40E-02	6.99E+00	1.06E-14	2.18E-01	5.30E-04	5.90E-02	3.50E-03
BATCH-694	7/7/27	95	9.9	0.24	0.00E+00	0.00E+00	3.10E-02	5.00E-03	2.37E+00	2.51E-01	7.67E+02	3.80E-01	5.40E-02	6.99E+00	1.06E-14	2.18E-01	5.30E-04	5.90E-02	3.50E-03
BATCH-695	7/13/27	130	13.5	0.24	0.00E+00	0.00E+00	2.90E-02	6.00E-03	2.22E+00	6.12E-02	9.51E+02	2.18E-01	2.90E-02	4.73E+00	1.59E-14	2.53E-01	5.35E-04	6.20E-02	2.00E-03
BATCH-696	7/17/27	95	9.9	0.24	0.00E+00	0.00E+00	3.10E-02	5.00E-03	2.37E+00	2.51E-01	7.67E+02	3.80E-01	5.40E-02	6.99E+00	1.05E-14	2.18E-01	5.30E-04	5.90E-02	3.50E-03
BATCH-697	7/27/27	51	5.3	0.24	0.00E+00	0.00E+00	9.00E-03	2.00E-03	7.09E-01	1.71E-02	3.10E+02	6.80E-02	9.00E-03	1.56E+00	7.02E+00	5.32E-04	5.32E-04	5.90E-02	3.50E-03
BATCH-698	8/1/27	96	10.0	0.24	0.00E+00	0.00E+00	3.10E-02	6.00E-03	2.38E+00	2.52E-01	7.71E+02	3.82E-01	5.40E-02	7.02E+00	1.06E-14	2.19E-01	5.32E-04	5.90E-02	2.75E-03
BATCH-699	8/1/27	74	7.7	0.24	0.00E+00	0.00E+00	2.40E-02	4.00E-03	1.83E+00	1.94E-01	5.94E+02	2.94E-01	4.20E-02	5.41E+00	8.16E-15	1.68E-01	4.10E-04	4.50E-02	2.25E-03
BATCH-700	8/6/27	64	6.7	0.24	0.00E+00	0.00E+00	2.10E-02	4.00E-03	1.60E+00	1.71E-01	5.16E+02	2.55E-01	3.60E-02	4.71E+00	7.08E-15	1.47E-01	3.56E-04	4.00E-02	2.25E-03
BATCH-701	8/9/27	49	5.1	0.24	0.00E+00	0.00E+00	1.00E-02	2.00E-03	7.55E-01	2.07E-02	3.24E+02	7.40E-02	1.00E-02	1.61E+00	5.42E-15	8.60E-02	1.82E-04	2.10E-02	7.50E-04
BATCH-702	8/13/27	64	6.7	0.24	0.00E+00	0.00E+00	2.60E-02	3.00E-03	1.97E+00	3.90E-01	4.33E+02	2.13E-01	6.80E-02	5.39E+00	5.29E-15	2.71E-01	2.92E-04	4.50E-02	2.75E-03
BATCH-703	8/15/27	19	1.9	0.24	0.00E+00	0.00E+00	3.00E-03	5.36E-04	1.92E-01	4.50E-03	8.39E+01	1.80E-02	2.00E-03	4.21E-01	1.44E-15	2.20E-02	4.64E-05	5.00E-03	1.81E-04
BATCH-704	8/17/27	77	8.0	0.24	0.00E+00	0.00E+00	1.00E-02	2.00E-03	7.80E-01	8.28E-02	2.53E+02	1.25E-01	1.80E-02	2.31E+00	3.48E-15	7.20E-02	1.75E-04	1.90E-02	1.25E-03
BATCH-705	8/20/27	111	11.6	0.24	0.00E+00	0.00E+00	1.60E-02	3.00E-03	1.23E+00	8.28E-02	4.71E+02	1.59E-01	2.20E-02	3.39E+00	7.74E-15	1.28E-01	2.86E-04	3.20E-02	1.50E-03
BATCH-706	8/25/27	131	13.6	0.24	0.00E+00	0.00E+00	1.90E-02	4.00E-03	1.47E+00	1.04E-01	5.53E+02	1.95E-01	2.70E-02	4.07E+00	8.96E-15	1.51E-01	3.40E-04	3.80E-02	2.00E-03
BATCH-707	9/1/27	18	1.9	0.24	0.00E+00	0.00E+00	3.00E-03	5.52E-04	1.99E-01	5.40E-03	8.54E+01	2.00E-02	3.00E-03	4.25E-01	1.43E-15	2.30E-02	4.80E-05	6.00E-03	1.87E-04
BATCH-708	9/3/27	107	11.1	0.24	0.00E+00	0.00E+00	4.30E-02	5.00E-03	3.28E+00	6.48E-01	7.21E+02	3.54E-01	1.14E-01	8.97E+00	4.50E-01	4.86E-04	7.40E-02	4.50E-03	
BATCH-709	9/8/27	118	12.3	0.24	0.00E+00	0.00E+00	1.70E-02	3.00E-03	1.32E+00	1.23E-01	4.64E+02	1.54E-01	2.80E-02	3.56E+00	7.55E-15	1.52E-01	2.79E-04	3.40E-02	1.75E-03
BATCH-710	9/14/27	49	5.1	0.24	0.00E+00	0.00E+00	6.00E-03	1.00E-03	4.40E-01	4.68E-02	1.43E+02	7.10E-02	1.00E-02	1.30E+00	1.96E-15	4.00E-02	9.86E-05	9.80E-03	7.50E-04
BATCH-711	9/20/27	55	5.7	0.24	0.00E+00	0.00E+00	7.00E-03	1.00E-03	5.52E-01	2.12E+02	7.20E-02	1.00E-02	1.52E+00	3.48E-15	5.80E-02	1.28E-04	1.50E-02	7.50E-04	
BATCH-712	9/20/27	107	11.1	0.24	0.00E+00	0.00E+00	4.30E-02	5.00E-03	3.28E+00	6.48E-01	7.21E+02	3.54E-01	1.14E-01	8.96E+00	4.50E-01	4.86E-04	7.40E-02	4.50E-03	
BATCH-713	9/25/27	54	5.6	0.24	0.00E+00	0.00E+00	3.00E-02	1.00E-03	5.50E-01	3.96E-02	2.08E+02	7.30E-02	1.00E-02	1.53E+00	3.36E-15	5.70E-02	1.27E-04	1.40E-02	7.50E-04
BATCH-714	10/1/27	81	8.4	0.24	0.00E+00	0.00E+00	3.20E-02	4.00E-03	2.47E+00	4.90E-01	5.44E+02	2.68E-01	8.60E-02	6.77E+00	6.64E-15	3.40E-01	3.67E-04	3.25E-03	
BATCH-715	10/1/27	17	1.8	0.24	0.00E+00	0.00E+00	1.00E-02	2.49E-04	1.07E-01	1.17E-02	3.48E+01	1.70E-02	2.00E-03	3.18E-01	4.79E-16	1.00E-02	2.41E-05	3.00E-03	1.59E-04
BATCH-716	10/4/27	55	5.7	0.24	0.00E+00	0.00E+00	7.00E-03	1.00E-03	5.59E-01	5.22E-02	1.97E+02	6.60E-02	1.20E-02	1.52E+00	3.21E-15	6.50E-02	1.19E-04	1.40E-02	7.50E-04
BATCH-717	10/10/27	21	2.2	0.24	0.00E+00	0.00E+00	2.00E-03	4.29E-04	7.09E-01	1.17E-02	6.46E+01	2.20E-02	3.00E-03	4.64E-01	1.06E-15	1.80E-02	3.92E-05	4.00E-03	2.13E-04
BATCH-718	10/10/27	20	2.1	0.24	0.00E+00	0.00E+00	2.00E-03	4.16E-04	1.65E-01	1.17E-02	6.22E+01	2.20E-02	3.00E-03	4.58E-01	1.01E-15	1.70E-02	3.82E-05	4.00E-03	2.13E-04
BATCH-719	10/12/27	81	8.4	0.24	0.00E+00	0.00E+00	3.20E-02	4.00E-03	2.47E+00	4.89E-01	5.44E+02	2.67E-01	8.60E-02	6.76E+00	6.63E-15	3.40E-01	3.67E-04	3.25E-03	
BATCH-720	10/12/27	106	11.1	0.24	0.00E+00	0.00E+00	4.30E-02	5.00E-03	3.27E+00	6.46E-01	7.19E+02	3.53E-01	1.13E-01	8.94E+00	8.77E-15	4.49E-01	4.85E-04	7.40E-02	4.50E-03
BATCH-721	10/21/27	21	2.2	0.24	0.00E+00	0.00E+00	2.00E-03	4.01E-04	1.70E-01	1.62E-02	6.01E+01	2.00E-02	4.00E-03	4.61E-01	9.76E-16	2.00E-02	3.61E-05	4.00E-03	2.12E-04
BATCH-722	10/23/27	95	9.9	0.24	0.00E+00	0.00E+00	1.30E-02	2.00E-03	1.02E+00	2.03E-01	2.25E+02	1.11E-01	3.50E-02	2.80E+00	2.75E-15	1.41E-01	1.52E-04	2.30E-02	1.50E-03
BATCH-723	10/24/27	80	8.3	0.24	0.00E+00	0.00E+00	1.31E-01	8.00E-03	1.00E+01	3.10E+00	9.02E+02	4.09E-01	4.76E-01	7.93E+00	7.45E-15	1.86E+00	6.34E-04	2.18E-01	7.50E-03
BATCH-724	11/1/27	73	7.6	0.24	0.00E+00	0.00E+00	2.00E-01	1.10E-02	1.53E+01	4.96E+00	1.12E+03	4.90E-01	7.53E-01	7.22E+00	7.50E-15	2.94E+00	7.98E-04	3.31E-01	1.03E-02
BATCH-725	11/2/27	95	9.9	0.24	0.00E+00	0.00E+00	1.30E-02	2.00E-03	1.02E+00	2.02E-01	2.25E+02	1.10E-01	3.50E-02	2.79E+00	2.74E-15	1.40E-01	1.52E-04	2.30E-02	1.50E-03
BATCH-726	11/9/27	55	5.7	0.24	0.00E+00	0.00E+00	1.51E-01	8.00E-03	1.16E+01	3.75E+00	8.45E+02	3.70E-01	5.69E-01	5.46E+00	5.67E-15	2.22E+00	6.03E-04	2.50E-01	7.75E-03
BATCH-727	11/12/27	72	7.6	0.24	0.00E+00	0.00E+00	2.00E-01	1.10E-02	1.53E+01	4.96E+00	1.12E+03	4.89E-01	7.53E-01	7.21E+00	7.49E-15	2.93E+00	7.98E-04	3.31E-01	1.03E-02
BATCH-728	11/15/27	50	5.2	0.24	0.00E+00	0.00E+00	1.38E-01	7.00E-03	1.06E+01	3.41E+00	7.69E+02	3.37E-01	5.18E-01	4.97E+00	5.16E-15	2.02E+00	5.49E-04	2.28E-01	7.25E-03
BATCH-729	11/20/27	48	5.1	0.24	0.00E+00	0.00E+00	6.00E-03	7.58E-04	4.64E-01	9.18E-02	1.02E+02	5.00E-02	1.60E-02	1.27E+00	1.25E-15	6.40E-02	6.89E-05	1.10E-02	7.50E-04
BATCH-730	11/20/27	53	5.5	0.24	0.00E+00	0.00E+00	1.45E-01	8.00E-03	1.11E+01	3.59E+00	8.10E+02	3.55E-01	5.46E-01	5.23E+00	5.43E-15	2.13E+00	5.78E-04	2.40E-01	7.50E-03
BATCH-731	11/25/27	48	5.1	0.24	0.00E+00	0.00E+00	6.00E-03	7.57E-04	4.63E-01	9.18E-02	1.02E+02	5.00E-02	1.60E-02	1.27E+00	1.24E-15	6.40E-02	6.88E-05	1.10E-02	7.50E-04
BATCH-732	11/26/27	99	10.3	0.24	0.00E+00	0.00E+00	3.90E-02	3.00E-03	3.01E+00	9.01E-01	3.05E+02	1.41E-01	1.39E-01	5.17E+00	2.75E-15	5.45E-01	2.13E-04	6.60E-02	2.50E-03
BATCH-733	12/1/27	115	12.0	0.24	0.00E+00	0.00E+00	5.30E-02	3.00E-03	4.03E+00	1.23E+00	3.82E+02	1.74E-01	1.89E-01	6.68E+00	3.28E-15	7.39E-01	2.67E-04	8.80E-02	3.25E-03
BATCH-734	12/6/27	53	5.5	0.24	0.00E+00	0.00E+00	1.45E-01	8.00E-03	1.11E+01	3.59E+00	8.09E+02	3.54E-01	5.45E-01	5.23E+00	5.43E-15	2.13E+00	5.78E-04	2.40E-01	7.50E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-686	6/3/27	17	1.8	0.24	1.63E-09	5.06E+01	1.10E+01	8.93E-04	5.20E-02	3.00E-03	1.89E-06	3.72E-07	5.86E-06	3.64E-06	5.06E-06	1.02E-05	5.65E-04	3.00E-03	2.00E-03
BATCH-687	6/5/27	91	9.5	0.24	2.81E-08	2.73E+02	1.88E+02	1.70E-02	1.07E+00	5.60E-02	1.17E-04	6.39E-06	1.35E-04	6.58E-05	1.25E-04	1.84E-04	1.00E-02	5.20E-02	4.10E-02
BATCH-688	6/5/27	91	9.5	0.24	2.81E-08	2.73E+02	1.88E+02	1.70E-02	1.07E+00	5.50E-02	1.17E-04	6.39E-06	1.35E-04	6.57E-05	1.25E-04	1.84E-04	1.00E-02	5.20E-02	4.10E-02
BATCH-689	6/14/27	91	9.5	0.24	2.81E-08	2.72E+02	1.88E+02	1.70E-02	1.07E+00	5.50E-02	1.17E-04	6.38E-06	1.35E-04	6.56E-05	1.25E-04	1.83E-04	1.00E-02	5.20E-02	4.10E-02
BATCH-690	6/15/27	61	6.4	0.24	2.43E-08	1.84E+02	8.43E+01	8.00E-03	4.99E-01	2.60E-02	2.58E-05	2.89E-06	6.13E-05	3.00E-05	9.68E-05	8.34E-05	5.00E-03	2.50E-02	1.80E-02
BATCH-691	6/21/27	111	11.6	0.24	1.25E-08	3.33E+02	8.56E+01	7.00E-03	4.49E-01	2.40E-02	3.92E-05	2.90E-06	5.44E-05	2.92E-05	4.89E-05	8.19E-05	4.00E-03	2.40E-02	1.50E-02
BATCH-692	6/24/27	124	12.9	0.24	5.37E-08	3.71E+02	1.33E+02	1.30E-02	8.11E-01	4.30E-02	5.31E-06	4.60E-06	9.73E-05	4.78E-05	2.06E-04	1.33E-04	8.00E-03	4.00E-02	2.80E-02
BATCH-693	7/3/27	95	9.9	0.24	4.14E-08	2.86E+02	1.02E+02	1.00E-02	6.26E-01	3.30E-02	4.15E-06	3.55E-06	7.51E-05	3.69E-05	1.59E-04	1.03E-04	6.00E-03	3.10E-02	2.10E-02
BATCH-694	7/7/27	95	9.9	0.24	4.14E-08	2.86E+02	1.02E+02	1.00E-02	6.26E-01	3.30E-02	4.15E-06	3.55E-06	7.51E-05	3.69E-05	1.59E-04	1.03E-04	6.00E-03	3.10E-02	2.10E-02
BATCH-695	7/13/27	130	13.5	0.24	1.72E-08	3.89E+02	1.11E+02	1.00E-02	5.71E-01	3.00E-02	4.38E-05	3.76E-06	6.83E-05	3.77E-05	6.50E-05	1.06E-04	6.00E-03	3.00E-02	1.80E-02
BATCH-696	7/17/27	95	9.9	0.24	4.14E-08	2.86E+02	1.02E+02	1.00E-02	6.26E-01	3.30E-02	4.15E-06	3.55E-06	7.51E-05	3.69E-05	1.59E-04	1.03E-04	6.00E-03	3.10E-02	2.10E-02
BATCH-697	7/27/27	51	5.3	0.24	5.19E-09	1.53E+02	3.57E+01	3.00E-03	1.87E-01	1.00E-02	1.63E-05	1.21E-06	2.27E-05	1.22E-05	2.04E-05	3.41E-05	2.00E-03	1.00E-02	6.00E-03
BATCH-698	7/27/27	96	10.0	0.24	4.16E-08	2.87E+02	1.03E+02	1.00E-02	6.29E-01	3.30E-02	4.11E-06	3.56E-06	7.55E-05	3.71E-05	1.60E-04	1.03E-04	6.00E-03	3.10E-02	2.10E-02
BATCH-699	8/1/27	74	7.7	0.24	3.21E-08	2.21E+02	7.93E+01	8.00E-03	4.84E-01	2.60E-02	3.17E-06	2.75E-06	5.82E-05	2.86E-05	1.23E-04	7.93E-05	5.00E-03	2.40E-02	1.70E-02
BATCH-700	8/6/27	64	6.7	0.24	2.79E-08	1.93E+02	6.88E+01	7.00E-03	4.21E-01	2.20E-02	2.76E-06	2.38E-06	5.06E-05	2.48E-05	1.07E-04	6.89E-05	4.00E-03	2.10E-02	1.40E-02
BATCH-701	8/9/27	49	5.1	0.24	5.87E-09	1.48E+02	3.78E+01	3.00E-03	1.95E-01	1.00E-02	1.49E-05	1.28E-06	2.33E-05	1.29E-05	2.22E-05	3.60E-05	2.00E-03	1.00E-02	6.00E-03
BATCH-702	8/13/27	64	6.7	0.24	2.69E-08	1.92E+02	5.08E+01	6.00E-03	4.07E-01	2.00E-02	2.60E-06	1.77E-06	5.55E-05	1.99E-05	1.04E-04	5.48E-05	3.00E-03	1.70E-02	1.40E-02
BATCH-703	8/15/27	19	1.9	0.24	1.40E-09	5.55E+01	9.64E+00	8.38E-04	5.10E-02	3.00E-03	4.41E-06	3.27E-07	6.13E-06	3.29E-06	5.51E-06	9.22E-06	5.02E-04	3.00E-03	2.00E-03
BATCH-704	8/17/27	77	8.0	0.24	1.37E-08	2.30E+02	3.38E+01	3.00E-03	2.06E-01	1.10E-02	1.35E-06	1.17E-06	2.48E-05	1.22E-05	5.25E-05	3.38E-05	2.00E-03	1.00E-02	7.00E-03
BATCH-705	8/20/27	111	11.6	0.24	1.56E-08	3.34E+02	5.72E+01	5.00E-03	3.37E-01	1.80E-02	1.95E-05	1.96E-06	4.15E-05	2.03E-05	6.26E-05	5.65E-05	3.00E-03	1.70E-02	1.20E-02
BATCH-706	8/25/27	131	13.6	0.24	1.93E-08	3.92E+02	6.77E+01	7.00E-03	4.01E-01	2.10E-02	2.12E-05	2.33E-06	4.92E-05	2.41E-05	7.71E-05	6.70E-05	4.00E-03	2.00E-02	1.40E-02
BATCH-707	9/1/27	18	1.9	0.24	1.54E-09	5.32E+01	9.94E+00	8.56E-04	5.10E-02	3.00E-03	3.93E-06	3.37E-07	6.13E-06	3.38E-06	5.84E-06	9.47E-06	5.18E-04	3.00E-03	2.00E-03
BATCH-708	9/3/27	107	11.1	0.24	4.49E-08	3.20E+02	8.45E+01	1.00E-02	6.77E-01	3.30E-02	4.33E-06	2.94E-06	9.24E-05	3.31E-05	1.73E-04	9.12E-05	5.00E-03	2.80E-02	2.40E-02
BATCH-709	9/8/27	118	12.3	0.24	1.57E-08	3.54E+02	5.49E+01	5.00E-03	3.40E-01	1.70E-02	1.98E-05	1.88E-06	4.31E-05	1.97E-05	6.30E-05	5.49E-05	3.00E-03	1.60E-02	1.20E-02
BATCH-710	9/14/27	49	5.1	0.24	7.71E-09	1.46E+02	1.91E+01	2.00E-03	1.16E-01	6.00E-03	7.62E-07	6.60E-07	1.40E-05	6.87E-06	2.96E-05	1.91E-05	1.00E-03	6.00E-03	4.00E-03
BATCH-711	9/20/27	55	5.7	0.24	7.00E-09	1.64E+02	2.57E+01	2.00E-03	1.52E-01	8.00E-03	8.78E-06	8.81E-07	1.87E-05	9.12E-06	2.81E-05	2.54E-05	1.00E-03	7.00E-03	6.00E-03
BATCH-712	9/20/27	107	11.1	0.24	4.48E-08	3.20E+02	8.45E+01	1.00E-02	6.76E-01	3.30E-02	4.33E-06	2.94E-06	9.23E-05	3.30E-05	1.73E-04	9.11E-05	5.00E-03	2.80E-02	2.40E-02
BATCH-713	9/25/27	54	5.6	0.24	7.25E-09	1.61E+02	2.54E+01	2.00E-03	1.50E-01	8.00E-03	7.94E-06	8.72E-07	1.85E-05	9.03E-06	2.90E-05	2.51E-05	1.00E-03	7.00E-03	5.00E-03
BATCH-714	10/1/27	81	8.4	0.24	3.38E-08	2.42E+02	6.38E+01	8.00E-03	5.11E-01	2.50E-02	3.27E-06	2.22E-06	6.97E-05	2.49E-05	1.31E-04	6.88E-05	4.00E-03	2.10E-02	1.80E-02
BATCH-715	10/2/27	17	1.8	0.24	1.88E-09	5.07E+01	4.65E+00	4.64E-04	2.80E-02	2.00E-03	1.86E-07	1.61E-07	3.41E-06	1.68E-06	7.24E-06	4.66E-06	2.66E-04	1.00E-03	9.69E-04
BATCH-716	10/4/27	55	5.7	0.24	6.66E-09	1.64E+02	2.34E+01	2.00E-03	1.45E-01	7.00E-03	8.43E-06	8.01E-07	1.83E-05	8.39E-06	2.68E-05	2.34E-05	1.00E-03	7.00E-03	5.00E-03
BATCH-717	10/10/27	21	2.2	0.24	2.14E-09	6.25E+01	7.84E+00	7.51E-04	4.60E-02	2.00E-03	2.68E-06	2.69E-07	5.69E-06	2.78E-06	8.58E-06	7.75E-06	4.31E-04	2.00E-03	2.00E-03
BATCH-718	10/10/27	20	2.1	0.24	2.17E-09	6.09E+01	7.62E+00	7.33E-04	4.50E-02	2.00E-03	2.38E-06	2.61E-07	5.54E-06	2.71E-06	8.67E-06	7.53E-06	4.20E-04	2.00E-03	2.00E-03
BATCH-719	10/12/27	81	8.4	0.24	3.38E-08	2.41E+02	6.37E+01	8.00E-03	5.10E-01	2.50E-02	3.27E-06	2.22E-06	6.97E-05	2.49E-05	1.30E-04	6.88E-05	4.00E-03	2.10E-02	1.80E-02
BATCH-720	10/12/27	106	11.1	0.24	4.47E-08	3.19E+02	8.42E+01	1.00E-02	6.75E-01	3.20E-02	4.32E-06	2.93E-06	9.21E-05	3.30E-05	1.72E-04	9.09E-05	5.00E-03	2.80E-02	2.40E-02
BATCH-721	10/21/27	21	2.2	0.24	2.03E-09	6.24E+01	7.10E+00	7.01E-04	4.40E-02	2.00E-03	2.56E-06	2.44E-07	5.57E-06	2.55E-06	8.15E-06	7.10E-06	3.96E-04	2.00E-03	2.00E-03
BATCH-722	10/23/27	95	9.9	0.24	1.40E-08	2.85E+02	2.64E+01	3.00E-03	2.11E-01	1.00E-02	1.35E-06	9.18E-07	2.88E-05	1.03E-05	5.40E-05	2.85E-05	2.00E-03	9.00E-03	7.00E-03
BATCH-723	10/24/27	80	8.3	0.24	7.92E-08	2.39E+02	6.62E+01	4.50E-02	2.53E+00	3.22E-01	6.89E-06	2.30E-06	6.11E-05	3.35E-05	1.26E-04	7.65E-05	4.00E-03	2.10E-02	2.10E-02
BATCH-724	11/1/27	73	7.6	0.24	1.09E-07	2.17E+02	6.28E+01	7.20E-02	3.95E+00	5.36E-01	9.26E-06	2.19E-06	4.92E-05	3.77E-05	1.12E-04	7.66E-05	4.00E-03	1.90E-02	2.10E-02
BATCH-725	11/2/27	95	9.9	0.24	1.40E-08	2.84E+02	2.63E+01	3.00E-03	2.11E-01	1.00E-02	1.35E-06	9.17E-07	2.88E-05	1.03E-05	5.39E-05	2.84E-05	2.00E-03	9.00E-03	7.00E-03
BATCH-726	11/9/27	55	5.7	0.24	8.27E-08	1.64E+02	4.75E+01	5.40E-02	2.99E+00	4.05E-01	7.00E-06	1.65E-06	3.72E-05	2.85E-05	8.46E-05	5.79E-05	3.00E-03	1.50E-02	1.60E-02
BATCH-727	11/12/27	72	7.6	0.24	1.09E-07	2.17E+02	6.28E+01	7.20E-02	3.95E+00	5.35E-01	9.25E-06	2.18E-06	4.92E-05	3.76E-05	1.12E-04	7.65E-05	4.00E-03	1.90E-02	1.40E-02
BATCH-728	11/15/27	50	5.2	0.24	7.53E-08	1.50E+02	4.32E+01	4.90E-02	2.72E+00	3.69E-01	6.37E-06	1.50E-06	3.39E-05	2.59E-05	7.70E-05	5.27E-05	3.00E-03	1.30E-02	1.40E-02
BATCH-729	11/20/27	48	5.1	0.24	6.35E-09	1.45E+02	1.20E+01	1.00E-03	9.60E-02	5.00E-03	6.13E-07	4.17E-07	1.31E-05	4.68E-06	2.45E-05	1.29E-05	7.53E-04	4.00E-03	3.00E-03
BATCH-730	11/20/27	53	5.5	0.24	7.93E-08	1.58E+02	4.55E+01	5.20E-02	2.86E+00	3.88E-01	6.71E-06	1.58E-06	3.57E-05	2.73E-05	8.10E-05	5.55E-05	3.00E-03	1.40E-02	1.50E-02
BATCH-731	11/25/27	48	5.1	0.24	6.34E-09	1.45E+02	1.20E+01	1.00E-03	9.60E-02	5.00E-03	6.13E-07	4.16E-07	1.31E-05	4.68E-06	2.45E-05	1.29E-05	7.52E-04	4.00E-03	3.00E-03
BATCH-732	11/26/27	99	10.3	0.24	2.53E-08	2.96E+02	2.50E+01	1.30E-02	7.46E-01	9.10E-02	2.24E-06	8.70E-07	2.42E-05	1.19E-05	4.85E-05	2.84E-05	2.00E-03	8.00E-03	8.00E-03
BATCH-733	12/1/27	115	12.0	0.24	3.26E-08	3.46E+02	2.95E+01	1.80E-02	1.26E-01	3.69E-01	2.86E-06	1.03E-06	2.79E-05	1.45E-05	5.66E-05	3.38E-05	2.00E-03	9.00E-03	9.00E-03
BATCH-734	12/6/27	53	5.5	0.24	7.92E-08	1.57E+02	4.55E+01	5.20E-02	2.86E+00	3.88E-01	6.70E-06	1.58E-06	3.56E-05	2.73E-05	8.09E-05	5.54E-05	3.00E-03	1.40E-02	1.50E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-686	6/3/27	17	1.8	0.24	6.60E-05	3.39E-05	1.00E-03	1.00E-03	2.00E-03	6.50E-02	1.00E-02	7.10E-02	2.40E-02	1.48E-26	6.43E-07	2.54E-06	9.50E-06	5.87E-05	6.41E-10
BATCH-687	6/5/27	91	9.5	0.24	2.00E-03	7.25E-04	1.90E-02	2.60E-02	4.40E-02	1.56E+00	2.20E-01	1.27E+00	4.38E-01	2.61E-25	1.16E-05	4.41E-05	1.67E-04	1.00E-03	2.33E-07
BATCH-688	6/5/27	91	9.5	0.24	2.00E-03	7.24E-04	1.90E-02	2.60E-02	4.40E-02	1.56E+00	2.19E-01	1.27E+00	4.38E-01	2.60E-25	1.16E-05	4.40E-05	1.67E-04	1.00E-03	2.33E-07
BATCH-689	6/14/27	91	9.5	0.24	2.00E-03	7.23E-04	1.90E-02	2.60E-02	4.40E-02	1.56E+00	2.19E-01	1.27E+00	4.38E-01	2.60E-25	1.16E-05	4.40E-05	1.67E-04	1.00E-03	2.33E-07
BATCH-690	6/15/27	61	6.4	0.24	7.66E-04	3.64E-04	9.00E-03	1.10E-02	1.90E-02	5.96E-01	9.00E-02	7.29E-01	1.90E-01	4.37E-25	5.06E-06	2.53E-05	1.60E-04	7.56E-04	4.78E-08
BATCH-691	6/21/27	111	11.6	0.24	6.37E-04	2.93E-04	9.00E-03	1.10E-02	1.60E-02	6.07E-01	9.00E-02	5.62E-01	1.93E-01	1.19E-25	5.13E-06	1.98E-05	7.63E-05	4.81E-04	6.07E-08
BATCH-692	6/24/27	124	12.9	0.24	1.00E-03	6.24E-04	1.40E-02	1.60E-02	2.90E-02	8.01E-01	1.29E-01	1.36E+00	2.92E-01	1.11E-24	7.77E-06	4.72E-05	3.63E-04	2.00E-03	9.38E-13
BATCH-693	7/3/27	95	9.9	0.24	9.01E-04	4.81E-04	1.10E-02	1.30E-02	2.20E-02	6.18E-01	1.00E-01	1.05E+00	2.25E-01	8.58E-25	6.00E-06	3.65E-05	2.80E-04	1.00E-03	1.21E-10
BATCH-694	7/7/27	95	9.9	0.24	9.01E-04	4.81E-04	1.10E-02	1.30E-02	2.20E-02	6.18E-01	1.00E-01	1.05E+00	2.25E-01	8.57E-25	6.00E-06	3.64E-05	2.80E-04	1.00E-03	1.21E-10
BATCH-695	7/13/27	130	13.5	0.24	7.70E-04	3.73E-04	1.10E-02	1.40E-02	2.00E-02	7.45E-01	1.13E-01	7.39E-01	2.47E-01	1.86E-25	6.58E-06	2.61E-05	1.07E-04	6.49E-04	5.92E-08
BATCH-696	7/17/27	95	9.9	0.24	9.01E-04	4.81E-04	1.10E-02	1.30E-02	2.20E-02	6.18E-01	1.00E-01	1.05E+00	2.25E-01	8.57E-25	5.99E-06	3.64E-05	2.80E-04	1.00E-03	1.21E-10
BATCH-697	7/27/27	51	5.3	0.24	2.65E-04	1.22E-04	4.00E-03	5.00E-03	7.00E-03	2.53E-01	3.80E-02	2.34E-01	8.00E-02	4.95E-26	2.14E-06	8.25E-06	3.18E-05	2.00E-04	2.53E-08
BATCH-698	7/27/27	96	10.0	0.24	6.97E-04	4.84E-04	1.10E-02	1.30E-02	2.20E-02	6.21E-01	1.00E-01	1.05E+00	2.26E-01	8.62E-25	6.02E-06	3.66E-05	2.82E-04	1.00E-03	6.58E-13
BATCH-699	8/1/27	74	7.7	0.24	6.06E-04	3.24E-04	7.00E-03	9.00E-03	1.50E-02	4.20E-01	6.80E-02	7.41E-01	1.53E-01	6.34E-26	2.24E-06	8.90E-06	3.66E-05	2.21E-04	2.02E-08
BATCH-700	8/6/27	64	6.7	0.24	2.62E-04	1.27E-04	4.00E-03	5.00E-03	7.00E-03	2.54E-01	3.90E-02	2.52E-01	8.40E-02	6.34E-26	2.24E-06	8.90E-06	3.66E-05	2.21E-04	2.02E-08
BATCH-701	8/9/27	49	5.1	0.24	6.05E-04	2.90E-04	5.00E-03	1.50E-02	1.50E-02	8.43E-01	1.24E-01	4.76E+00	2.70E-01	7.42E-25	7.39E-06	6.21E-05	3.37E-04	5.00E-03	3.30E-10
BATCH-702	8/13/27	64	6.7	0.24	6.05E-04	2.90E-04	5.00E-03	1.50E-02	1.50E-02	8.43E-01	1.24E-01	4.76E+00	2.70E-01	7.42E-25	7.39E-06	6.21E-05	3.37E-04	5.00E-03	3.30E-10
BATCH-703	8/15/27	19	1.9	0.24	7.17E-05	3.30E-05	9.78E-04	1.00E-03	2.00E-03	6.80E-02	1.00E-02	6.30E-02	2.20E-02	1.34E-26	5.78E-07	2.23E-06	8.60E-06	5.42E-05	6.84E-09
BATCH-704	8/17/27	77	8.0	0.24	2.97E-04	1.59E-04	4.00E-03	4.00E-03	7.00E-03	2.04E-01	3.30E-02	3.46E-01	7.40E-02	2.83E-25	1.98E-06	1.20E-05	9.25E-05	1.02E-04	4.91E-04	3.67E-08
BATCH-705	8/20/27	111	11.6	0.24	5.22E-04	2.44E-04	6.00E-03	7.00E-03	1.30E-02	4.12E-01	6.10E-02	4.82E-01	1.30E-01	2.72E-25	3.44E-06	1.67E-05	1.27E-04	6.03E-04	3.93E-08
BATCH-706	8/25/27	131	13.6	0.24	6.16E-04	2.91E-04	7.00E-03	9.00E-03	1.50E-02	4.80E-01	7.20E-02	5.83E-01	1.53E-01	3.46E-25	4.07E-06	2.03E-05	1.27E-04	6.03E-04	3.93E-08
BATCH-707	9/1/27	18	1.9	0.24	6.91E-05	3.34E-05	1.00E-03	1.00E-03	2.00E-03	6.70E-02	1.00E-02	6.60E-02	2.20E-02	1.67E-26	5.90E-07	2.34E-06	9.64E-06	5.83E-05	5.32E-09
BATCH-708	9/3/27	107	11.1	0.24	1.00E-03	4.82E-04	9.00E-03	2.60E-02	2.50E-02	1.40E+00	2.06E-01	7.92E+00	4.50E-01	1.24E-24	1.23E-05	1.04E-04	5.61E-04	8.00E-03	5.50E-10
BATCH-709	9/8/27	118	12.3	0.24	5.30E-04	2.42E-04	6.00E-03	9.00E-03	1.30E-02	4.94E-01	7.20E-02	1.21E+00	1.53E-01	3.05E-25	4.09E-06	2.37E-05	1.30E-04	1.00E-03	3.74E-08
BATCH-710	9/14/27	49	5.1	0.24	1.68E-04	8.96E-05	2.00E-03	2.00E-03	4.00E-03	1.15E-01	1.90E-02	1.95E-01	4.20E-02	1.60E-25	1.12E-06	6.78E-06	5.22E-05	2.24E-04	1.29E-13
BATCH-711	9/20/27	55	5.7	0.24	2.35E-04	1.10E-04	3.00E-03	3.00E-03	6.00E-03	1.85E-01	2.80E-02	2.17E-01	5.80E-02	1.22E-25	1.55E-06	7.53E-06	4.58E-05	2.21E-04	1.65E-08
BATCH-712	9/20/27	107	11.1	0.24	1.00E-03	4.82E-04	9.00E-03	2.60E-02	2.50E-02	1.40E+00	2.06E-01	7.92E+00	4.50E-01	1.23E-24	1.23E-05	1.03E-04	5.61E-04	8.00E-03	5.50E-10
BATCH-713	9/25/27	54	5.6	0.24	2.31E-04	1.09E-04	3.00E-03	3.00E-03	6.00E-03	1.80E-01	2.70E-02	2.19E-01	5.70E-02	1.30E-25	1.53E-06	7.60E-06	4.76E-05	2.26E-04	1.47E-08
BATCH-714	10/1/27	81	8.4	0.24	7.60E-04	3.64E-04	7.00E-03	1.90E-02	1.90E-02	1.06E+00	1.56E-01	5.98E+00	3.40E-01	9.32E-25	9.29E-06	7.81E-05	4.24E-04	6.00E-03	4.14E-10
BATCH-715	10/2/27	17	1.8	0.24	4.09E-05	2.19E-05	4.88E-04	5.78E-04	1.00E-03	2.80E-02	5.00E-03	4.80E-02	1.00E-02	3.90E-26	2.72E-07	1.86E-06	1.27E-05	5.47E-05	3.15E-14
BATCH-716	10/4/27	55	5.7	0.24	2.26E-04	1.03E-04	2.00E-03	4.00E-03	6.00E-03	2.10E-01	3.10E-02	5.12E-01	6.50E-02	1.30E-25	1.74E-06	1.01E-05	5.51E-05	5.29E-04	1.59E-08
BATCH-717	10/10/27	21	2.2	0.24	7.16E-05	3.34E-05	8.09E-04	1.00E-03	2.00E-03	5.60E-02	8.00E-03	6.60E-02	1.80E-02	3.73E-26	4.72E-07	2.30E-06	1.40E-05	6.74E-05	5.03E-09
BATCH-718	10/10/27	20	2.1	0.24	6.93E-05	3.28E-05	7.87E-04	9.88E-04	2.00E-03	5.40E-02	8.00E-03	6.60E-02	1.70E-02	3.89E-26	4.57E-07	2.28E-06	1.43E-05	6.78E-05	4.42E-09
BATCH-719	10/12/27	81	8.4	0.24	7.59E-04	3.64E-04	7.00E-03	1.90E-02	1.90E-02	1.06E+00	1.55E-01	5.97E+00	3.39E-01	9.31E-25	9.28E-06	7.80E-05	4.23E-04	6.00E-03	4.14E-10
BATCH-720	10/12/27	106	11.1	0.24	1.00E-03	4.81E-04	9.00E-03	2.60E-02	2.40E-02	1.40E+00	2.05E-01	7.90E+00	4.49E-01	1.23E-24	1.23E-05	1.03E-04	5.60E-04	8.00E-03	5.48E-10
BATCH-721	10/21/27	21	2.2	0.24	6.86E-05	3.12E-05	7.34E-04	1.00E-03	2.00E-03	6.40E-02	9.00E-03	1.56E-01	2.00E-02	3.95E-26	5.29E-07	3.06E-06	1.68E-05	1.61E-04	4.83E-09
BATCH-722	10/23/27	95	9.9	0.24	3.14E-04	1.50E-04	3.00E-03	8.00E-03	8.00E-03	4.38E-01	6.40E-02	2.47E+00	1.40E-01	3.85E-25	3.84E-06	3.23E-05	1.75E-04	3.00E-03	1.72E-10
BATCH-723	10/24/27	80	8.3	0.24	7.82E-04	3.92E-04	8.00E-03	9.00E-02	2.10E-02	3.41E+00	6.05E-01	4.39E+01	1.68E+00	3.58E-24	4.67E-05	6.11E-04	2.00E-03	4.90E-02	6.21E-09
BATCH-724	11/1/27	73	7.6	0.24	7.37E-04	3.83E-04	8.00E-03	1.40E-01	2.20E-02	5.04E+00	9.19E-01	7.10E+01	2.63E+00	5.43E-24	7.31E-05	9.92E-04	3.00E-03	7.90E-02	1.04E-08
BATCH-725	11/2/27	95	9.9	0.24	3.14E-04	1.50E-04	3.00E-03	8.00E-03	8.00E-03	4.37E-01	6.40E-02	2.47E+00	1.40E-01	3.85E-25	3.83E-06	3.22E-05	1.75E-04	3.00E-03	1.71E-10
BATCH-726	11/9/27	55	5.7	0.24	5.57E-04	2.89E-04	6.00E-03	1.06E-01	1.70E-02	3.81E+00	6.95E-01	5.37E+01	1.99E+00	4.11E-24	5.52E-05	7.50E-04	3.00E-03	6.00E-02	7.85E-09
BATCH-727	11/12/27	72	7.6	0.24	7.36E-04	3.82E-04	8.00E-03	1.40E-01	2.20E-02	5.03E+00	9.18E-01	7.10E+01	2.63E+00	5.43E-24	7.30E-05	9.91E-04	3.00E-03	7.90E-02	1.04E-08
BATCH-728	11/15/27	50	5.2	0.24	5.07E-04	2.63E-04	5.00E-03	9.60E-02	1.50E-02	3.47E+00	6.32E-01	4.89E+01	1.81E+00	3.74E-24	5.03E-05	6.82E-04	2.00E-03	5.40E-02	7.14E-09
BATCH-729	11/20/27	48	5.1	0.24	1.43E-04	6.83E-05	1.00E-03	4.00E-03	3.00E-03	1.99E-01	2.90E-02	1.12E+00	6.40E-02	1.75E-25	1.74E-06	1.47E-05	7.95E-05	1.00E-03	7.79E-11
BATCH-730	11/20/27	53	5.5	0.24	5.34E-04	2.77E-04	5.00E-03	1.01E-01	1.60E-02	3.65E+00	6.66E-01	5.15E+01	1.90E+00	3.94E-24	5.30E-05	7.19E-04	2.00E-03	5.70E-02	7.53E-09
BATCH-731	11/25/27	48	5.1	0.24	1.42E-04	6.82E-05	1.00E-03	4.00E-03	3.00E-03	1.99E-01	2.90E-02	1.12E+00	6.40E-02	1.75E-25	1.74E-06	1.46E-05	7.94E-05	1.00E-03	7.77E-11
BATCH-732	11/26/27	99	10.3	0.24	2.96E-04	1.46E-04	3.00E-03	2.70E-02	8.00E-03	1.05E+00	1.82E-01	1.27E+01	4.96E-01	1.06E-24	1.38E-05	1.76E-04	6.44E-04	1.40E-02	1.74E-09
BATCH-733	12/1/27	115	12.0	0.24	3.49E-04	1.74E-04	3.00E-03	3.60E-02	9.00E-03	1.38E+00	2.43E-01	1.73E+01	6.69E-01	1.44E-24	1.86E-05	2.41E-04	8.71E-04	1.90E-02	2.42E-09
BATCH-734	12/6/27	53	5.5	0.24	5.33E-04	2.77E-04	5.00E-03	1.01E-01	1.60E-02	3.65E+00	6.65E-01	5.14E+01	1.90E+00	3.93E-24	5.29E-05	7.18E-04	2.00E-03	5.70E-02	7.52E-09

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-686	6/3/27	17	1.8	0.24	2.24E+01	0.00E+00	4.53E-10	6.55E-07	2.77E-10	4.35E-59	2.30E-02	8.30E-02	2.52E-09	9.75E-04	5.39E-01	0.00E+00	1.47E+00	0.00E+00	2.01E-06
BATCH-687	6/5/27	91	9.5	0.24	3.00E-03	5.07E+01	2.34E-08	3.96E-05	2.50E-08	3.05E-29	1.57E-01	1.75E+00	2.83E-07	3.00E-02	1.38E+01	0.00E+00	2.67E-04	3.62E+00	2.70E-05
BATCH-688	6/5/27	91	9.5	0.24	3.00E-03	5.06E+01	2.34E-08	3.95E-05	2.50E-08	2.39E-29	1.57E-01	1.74E+00	2.83E-07	3.00E-02	1.38E+01	0.00E+00	2.22E-04	3.62E+00	2.70E-05
BATCH-689	6/14/27	91	9.5	0.24	3.00E-03	5.06E+01	2.34E-08	3.95E-05	2.49E-08	5.70E-29	1.57E-01	1.74E+00	2.82E-07	2.90E-02	1.37E+01	0.00E+00	1.87E-04	3.61E+00	2.70E-05
BATCH-690	6/15/27	61	6.4	0.24	8.26E-10	1.32E+02	4.80E-09	1.23E-05	5.13E-09	1.32E-35	3.60E-02	5.98E-01	5.94E-08	6.00E-03	1.76E+01	0.00E+00	8.37E-11	7.44E+00	1.59E-05
BATCH-691	6/21/27	111	11.6	0.24	2.64E+02	0.00E+00	7.51E-09	1.18E-05	7.39E-09	1.37E-29	1.78E-01	1.05E+00	8.28E-08	1.00E-02	5.21E+00	0.00E+00	1.18E+01	0.00E+00	1.64E-05
BATCH-692	6/24/27	124	12.9	0.24	3.00E-03	3.53E+02	3.39E-13	1.23E-05	9.44E-13	6.04E-63	1.00E-02	6.98E-01	4.06E-09	1.00E-03	4.29E+01	0.00E+00	2.04E-04	1.94E+01	2.45E-05
BATCH-693	7/3/27	95	9.9	0.24	1.70E-06	2.72E+02	1.23E-11	9.47E-06	1.37E-11	1.58E-32	8.00E-03	5.39E-01	3.28E-09	8.86E-04	3.31E+01	0.00E+00	1.39E-07	1.50E+01	1.89E-05
BATCH-694	7/7/27	95	9.9	0.24	1.70E-06	2.72E+02	1.23E-11	9.47E-06	1.36E-11	1.24E-32	8.00E-03	5.39E-01	3.28E-09	8.86E-04	3.31E+01	0.00E+00	1.15E-07	1.50E+01	1.89E-05
BATCH-695	7/13/27	130	13.5	0.24	2.78E+02	0.00E+00	8.20E-09	1.29E-05	7.76E-09	1.07E-29	1.80E-01	1.14E+00	8.66E-08	1.20E-02	7.58E+00	0.00E+00	1.58E+01	0.00E+00	2.11E-05
BATCH-696	7/17/27	95	9.9	0.24	1.44E-06	2.72E+02	1.23E-11	9.47E-06	1.36E-11	2.95E-32	8.00E-03	5.39E-01	3.28E-09	8.86E-04	3.31E+01	0.00E+00	9.69E-08	1.50E+01	1.89E-05
BATCH-697	7/27/27	51	5.3	0.24	1.10E+02	0.00E+00	3.13E-09	4.92E-06	3.08E-09	5.72E-30	7.40E-02	4.37E-01	3.45E-08	4.00E-03	2.17E+00	0.00E+00	4.93E+00	0.00E+00	6.84E-06
BATCH-698	7/27/27	96	10.0	0.24	1.60E-06	2.73E+02	2.14E-13	9.50E-06	7.02E-13	3.11E-66	8.00E-03	5.41E-01	3.15E-09	8.76E-04	3.33E+01	0.00E+00	1.05E-07	1.51E+01	1.90E-05
BATCH-699	8/1/27	74	7.7	0.24	1.13E-09	2.11E+02	1.73E-13	7.32E-06	5.49E-13	1.06E-35	6.00E-03	4.17E-01	2.43E-09	6.75E-04	2.56E+01	0.00E+00	9.25E-11	1.16E+01	1.46E-05
BATCH-700	8/6/27	64	6.7	0.24	9.86E-10	1.83E+02	4.64E-11	6.31E-06	8.11E-11	6.32E-10	5.00E-03	3.66E-01	2.60E-09	6.32E-04	2.23E+01	0.00E+00	6.69E-11	1.01E+01	1.27E-05
BATCH-701	8/9/27	49	5.1	0.24	9.46E+01	0.00E+00	2.80E-09	4.38E-06	2.64E-09	3.64E-30	6.10E-02	3.89E-01	2.95E-08	4.00E-03	2.58E+00	0.00E+00	5.38E+00	0.00E+00	7.20E-06
BATCH-702	8/13/27	64	6.7	0.24	9.33E-10	1.46E+02	5.41E-09	2.19E-07	9.44E-09	7.40E-08	1.20E-02	7.58E-01	5.97E-08	6.00E-03	1.94E+01	0.00E+00	6.29E-11	8.10E+00	9.43E-06
BATCH-703	8/15/27	19	1.9	0.24	2.97E+01	0.00E+00	8.46E-10	1.33E-06	8.32E-10	1.55E-30	2.00E-02	1.18E-01	9.33E-09	1.00E-03	5.87E-01	0.00E+00	1.33E+00	0.00E+00	1.85E-06
BATCH-704	8/17/27	77	8.0	0.24	2.36E+02	0.00E+00	7.94E-14	3.12E-06	2.36E-13	8.67E-64	2.70E-02	5.48E-01	1.03E-09	2.88E-04	1.09E+01	0.00E+00	2.47E+01	0.00E+00	6.24E-06
BATCH-705	8/20/27	111	11.6	0.24	3.11E+02	0.00E+00	3.69E-09	8.77E-06	3.94E-09	4.80E-30	9.20E-02	9.39E-01	4.54E-08	5.00E-03	1.11E+01	0.00E+00	2.46E+01	0.00E+00	1.08E-05
BATCH-706	8/25/27	131	13.6	0.24	3.51E+02	0.00E+00	3.95E-09	1.00E-05	4.21E-09	1.35E-12	9.90E-02	1.04E+00	4.88E-08	5.00E-03	1.40E+01	0.00E+00	2.73E+01	0.00E+00	1.28E-05
BATCH-707	9/1/27	18	1.9	0.24	2.49E+01	0.00E+00	7.36E-10	1.15E-06	6.96E-10	9.57E-31	1.60E-02	1.02E-01	7.77E-09	1.00E-03	6.80E-01	0.00E+00	1.42E+00	0.00E+00	1.90E-06
BATCH-708	9/3/27	107	11.1	0.24	5.00E-03	2.42E+02	9.02E-09	3.55E-07	1.57E-08	1.23E-07	2.00E-02	1.26E+00	9.95E-08	1.00E-02	3.23E+01	0.00E+00	2.04E-04	1.35E+01	1.57E-05
BATCH-709	9/8/27	118	12.3	0.24	3.34E+02	0.00E+00	4.70E-09	7.84E-06	5.67E-09	1.31E-08	9.70E-02	1.08E+00	5.63E-08	6.00E-03	1.07E+01	0.00E+00	2.34E+01	0.00E+00	1.04E-05
BATCH-710	9/14/27	49	5.1	0.24	1.33E+02	0.00E+00	4.48E-14	1.76E-06	1.33E-13	4.89E-64	1.50E-02	3.09E-01	2.04E-08	2.00E-03	4.98E+00	0.00E+00	1.39E-01	0.00E+00	3.52E-06
BATCH-711	9/20/27	55	5.7	0.24	1.40E+02	0.00E+00	1.66E-09	3.95E-06	1.77E-09	2.16E-30	4.10E-02	4.22E-01	2.04E-08	2.00E-03	4.98E+00	0.00E+00	1.11E+01	0.00E+00	4.87E-06
BATCH-712	9/20/27	107	11.1	0.24	4.00E-03	2.42E+02	9.01E-09	3.54E-07	1.57E-08	1.23E-07	2.00E-02	1.26E+00	9.95E-08	1.00E-02	3.22E+01	0.00E+00	2.09E-04	1.35E+01	1.57E-05
BATCH-713	9/25/27	54	5.6	0.24	1.32E+02	0.00E+00	1.48E-09	3.75E-06	1.58E-09	5.08E-13	3.70E-02	3.90E-01	1.83E-08	2.00E-03	5.24E+00	0.00E+00	1.02E+01	0.00E+00	4.81E-06
BATCH-714	10/1/27	81	8.4	0.24	2.34E-06	1.83E+02	6.81E-09	2.68E-07	1.19E-08	9.30E-08	1.50E-02	9.53E-01	7.51E-08	7.00E-03	2.43E+01	0.00E+00	1.05E-07	1.02E+01	1.18E-05
BATCH-715	10/2/27	17	1.8	0.24	3.25E+01	0.00E+00	1.09E-14	4.30E-07	3.25E-14	1.19E-64	4.00E-03	7.50E-02	1.42E-10	3.96E-05	1.51E+00	0.00E+00	3.40E+00	0.00E+00	8.59E-07
BATCH-716	10/4/27	55	5.7	0.24	1.42E+02	0.00E+00	2.00E-09	3.33E-06	2.41E-09	5.55E-09	4.10E-02	4.59E-01	2.40E-08	3.00E-03	4.57E+00	0.00E+00	9.94E+00	0.00E+00	4.44E-06
BATCH-717	10/10/27	21	2.2	0.24	4.27E+01	0.00E+00	5.06E-10	1.20E-06	5.40E-10	6.59E-31	1.30E-02	1.29E-01	6.23E-09	6.70E-04	1.52E+00	0.00E+00	3.37E+00	0.00E+00	1.49E-06
BATCH-718	10/10/27	20	2.1	0.24	3.95E+01	0.00E+00	4.44E-10	1.12E-06	4.74E-10	1.52E-13	1.10E-02	1.17E-01	5.49E-09	5.94E-04	1.57E+00	0.00E+00	3.07E+00	0.00E+00	1.44E-06
BATCH-719	10/12/27	81	8.4	0.24	1.89E-06	1.83E+02	6.80E-09	2.67E-07	1.19E-08	9.30E-08	1.50E-02	9.52E-01	7.51E-08	7.00E-03	2.43E+01	0.00E+00	1.08E-07	1.02E+01	1.18E-05
BATCH-720	10/12/27	106	11.1	0.24	4.00E-03	2.42E+02	8.99E-09	3.53E-07	1.57E-08	1.23E-07	2.00E-02	1.26E+00	9.92E-08	1.00E-02	3.22E+01	0.00E+00	4.53E-04	1.34E+01	1.56E-05
BATCH-721	10/21/27	21	2.2	0.24	4.32E+01	0.00E+00	6.08E-10	1.01E-06	7.33E-10	1.69E-09	1.30E-02	1.40E-01	7.29E-09	7.63E-04	1.39E+00	0.00E+00	3.02E+00	0.00E+00	1.35E-06
BATCH-722	10/23/27	95	9.9	0.24	3.00E+02	0.00E+00	2.81E-09	1.11E-07	4.91E-09	3.85E-08	3.80E-02	9.46E-01	3.11E-08	3.00E-03	1.01E+01	0.00E+00	2.14E+01	0.00E+00	4.90E-06
BATCH-723	10/24/27	80	8.3	0.24	6.00E-03	1.26E+02	3.20E-09	3.90E-07	5.59E-09	4.35E-08	4.10E-02	6.83E-01	3.58E-08	1.00E-02	2.89E+01	0.00E+00	4.52E-04	6.73E+00	1.24E-05
BATCH-724	11/1/27	73	7.6	0.24	7.00E-03	6.95E+01	2.30E-11	4.57E-07	6.20E-11	2.62E-17	5.90E-02	4.10E-01	1.23E-09	1.10E-02	3.03E+01	0.00E+00	5.29E-04	3.41E+00	1.18E-05
BATCH-725	11/2/27	95	9.9	0.24	3.00E+02	0.00E+00	2.81E-09	1.11E-07	4.90E-09	3.84E-08	3.80E-02	9.45E-01	3.10E-08	3.00E-03	1.00E+01	0.00E+00	2.14E+01	0.00E+00	4.89E-06
BATCH-726	11/9/27	55	5.7	0.24	2.15E-06	5.26E+01	2.18E-11	3.46E-07	5.46E-11	6.11E-11	4.50E-02	3.10E-01	9.78E-10	8.00E-03	2.29E+01	0.00E+00	2.25E-07	2.58E+00	8.91E-06
BATCH-727	11/12/27	72	7.6	0.24	8.00E-03	6.94E+01	2.31E-11	4.57E-07	6.20E-11	2.98E-13	5.90E-02	4.10E-01	1.23E-09	1.10E-02	3.03E+01	0.00E+00	5.33E-04	3.40E+00	1.18E-05
BATCH-728	11/15/27	50	5.2	0.24	3.12E-06	4.79E+01	1.75E-11	3.15E-07	4.56E-11	2.37E-11	4.10E-02	2.82E-01	8.64E-10	7.00E-03	2.09E+01	0.00E+00	2.46E-07	2.35E+00	8.11E-06
BATCH-729	11/20/27	48	5.1	0.24	1.36E+02	0.00E+00	1.28E-09	5.02E-08	2.23E-09	1.75E-08	1.70E-02	4.29E-01	1.41E-08	1.00E-03	4.57E+00	0.00E+00	9.71E+00	0.00E+00	2.22E-06
BATCH-730	11/20/27	53	5.5	0.24	3.53E-06	5.04E+01	1.66E-11	3.31E-07	4.48E-11	1.36E-20	4.30E-02	2.97E-01	8.90E-10	8.00E-03	2.20E+01	0.00E+00	2.74E-07	2.47E+00	8.54E-06
BATCH-731	11/25/27	48	5.1	0.24	1.36E+02	0.00E+00	1.28E-09	5.02E-08	2.23E-09	1.74E-08	1.70E-02	4.29E-01	1.41E-08	1.00E-03	4.56E+00	0.00E+00	9.70E+00	0.00E+00	2.22E-06
BATCH-732	11/26/27	99	10.3	0.24	2.98E+02	0.00E+00	1.61E-09	1.36E-07	2.81E-09	2.19E-08	4.50E-02	1.09E+00	1.79E-08	3.00E-03	1.05E+01	0.00E+00	1.85E+01	0.00E+00	4.66E-06
BATCH-733	12/1/27	115	12.0	0.24	3.22E+02	0.00E+00	1.65E-09	1.67E-07	2.89E-09	2.25E-08	5.10E-02	1.31E+00	1.85E-08	4.00E-03	1.27E+01	0.00E+00	1.81E+01	0.00E+00	5.50E-06
BATCH-734	12/6/27	53	5.5	0.24	3.95E-06	5.03E+01	1.66E-11	3.31E-07	4.48E-11	1.54E-16	4.30E-02	2.97E-01	8.89E-10	8.00E-03	2.19E+01	0.00E+00	2.76E-07	2.47E+00	8.53E-06

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-686	6/3/27	17	1.8	0.24	7.91E-12	1.73E+00	9.60E-02	0.00E+00	0.00E+00	4.64E-05	2.35E-01	2.21E-04	3.79E-09	2.81E-07	1.30E-02	7.63E-08	2.88E+02	0.00E+00	3.00E-03
BATCH-687	6/5/27	91	9.5	0.24	5.56E-09	7.01E+01	1.98E+00	0.00E+00	0.00E+00	1.00E-03	4.41E+00	2.00E-03	9.00E-07	1.41E-05	1.98E-01	5.06E-06	1.56E+03	0.00E+00	5.20E-02
BATCH-688	6/5/27	91	9.5	0.24	5.55E-09	7.00E+01	1.98E+00	0.00E+00	0.00E+00	1.00E-03	4.41E+00	2.00E-03	8.99E-07	1.41E-05	1.98E-01	5.05E-06	1.55E+03	0.00E+00	5.20E-02
BATCH-689	6/14/27	91	9.5	0.24	5.54E-09	6.99E+01	1.98E+00	0.00E+00	0.00E+00	1.00E-03	4.40E+00	2.00E-03	8.98E-07	1.40E-05	1.97E-01	5.04E-06	1.55E+03	0.00E+00	5.20E-02
BATCH-690	6/15/27	61	6.4	0.24	1.14E-09	3.19E+01	1.52E+00	0.00E+00	0.00E+00	4.00E-04	3.42E+00	2.00E-03	1.85E-07	2.89E-06	1.09E-01	1.04E-06	1.05E+03	0.00E+00	1.20E-02
BATCH-691	6/21/27	111	11.6	0.24	1.41E-09	2.27E+01	1.24E+00	0.00E+00	0.00E+00	4.00E-04	1.81E+00	1.00E-03	2.38E-07	5.03E-06	9.20E-02	1.68E-06	1.90E+03	0.00E+00	2.30E-02
BATCH-692	6/24/27	124	12.9	0.24	7.21E-13	5.08E+01	3.24E+00	0.00E+00	0.00E+00	4.00E-04	7.30E+00	4.00E-03	2.67E-11	1.16E-08	1.98E-01	1.38E-11	2.11E+03	0.00E+00	5.00E-03
BATCH-693	7/3/27	95	9.9	0.24	3.43E-12	3.92E+01	2.50E+00	0.00E+00	0.00E+00	2.00E-04	5.63E+00	3.00E-03	4.87E-10	1.62E-08	1.52E-01	2.62E-09	1.63E+03	0.00E+00	4.00E-03
BATCH-694	7/7/27	95	9.9	0.24	3.43E-12	3.92E+01	2.50E+00	0.00E+00	0.00E+00	2.00E-04	5.63E+00	3.00E-03	4.86E-10	1.62E-08	1.52E-01	2.62E-09	1.63E+03	0.00E+00	4.00E-03
BATCH-695	7/13/27	130	13.5	0.24	1.35E-09	2.67E+01	1.38E+00	0.00E+00	0.00E+00	6.00E-04	2.43E+00	2.00E-03	2.35E-07	5.78E-06	1.21E-01	1.87E-06	2.22E+03	0.00E+00	2.90E-02
BATCH-696	7/17/27	95	9.9	0.24	3.43E-12	3.92E+01	2.50E+00	0.00E+00	0.00E+00	2.00E-04	5.63E+00	2.00E-03	4.85E-10	1.62E-08	1.52E-01	2.62E-09	1.63E+03	0.00E+00	4.00E-03
BATCH-697	7/27/27	51	5.3	0.24	5.87E-10	9.46E+00	5.18E-01	0.00E+00	0.00E+00	1.75E-04	7.54E-01	4.38E-04	9.92E-08	2.10E-06	3.80E-02	7.01E-07	8.75E+02	0.00E+00	1.00E-02
BATCH-698	7/27/27	96	10.0	0.24	5.58E-13	3.94E+01	2.51E+00	0.00E+00	0.00E+00	2.00E-04	5.66E+00	3.00E-03	2.03E-11	8.96E-09	1.53E-01	2.47E-12	1.64E+03	0.00E+00	4.00E-03
BATCH-699	8/1/27	74	7.7	0.24	4.32E-13	3.04E+01	1.93E+00	0.00E+00	0.00E+00	1.97E-04	4.36E+00	2.00E-03	1.60E-11	6.91E-09	1.18E-01	3.65E-12	1.26E+03	0.00E+00	3.00E-03
BATCH-700	8/6/27	64	6.7	0.24	3.82E-13	2.65E+01	1.68E+00	0.00E+00	0.00E+00	1.79E-04	3.78E+00	2.00E-03	1.40E-11	5.96E-09	1.03E-01	2.04E-11	1.10E+03	0.00E+00	2.00E-03
BATCH-701	8/9/27	49	5.1	0.24	4.60E-10	9.09E+00	4.71E-01	0.00E+00	0.00E+00	1.75E-04	8.27E-01	5.12E-04	8.00E-08	1.96E-06	4.10E-02	6.37E-07	8.41E+02	0.00E+00	1.00E-02
BATCH-702	8/13/27	64	6.7	0.24	1.18E-12	3.34E+01	1.81E+00	0.00E+00	0.00E+00	1.00E-03	2.59E+00	3.06E-05	2.46E-11	2.50E-11	9.40E-02	2.02E-09	1.10E+03	0.00E+00	6.00E-03
BATCH-703	8/15/27	19	1.9	0.24	1.59E-10	2.56E+00	1.40E-01	0.00E+00	0.00E+00	4.74E-05	2.04E-01	1.18E-04	2.68E-08	5.67E-07	1.00E-02	1.89E-07	3.16E+02	0.00E+00	3.00E-03
BATCH-704	8/17/27	77	8.0	0.24	1.83E-13	1.29E+01	1.27E+00	0.00E+00	0.00E+00	8.39E-05	1.86E+00	1.00E-03	6.75E-12	2.95E-09	5.00E-02	2.33E-12	1.31E+03	0.00E+00	1.00E-03
BATCH-705	8/20/27	111	11.6	0.24	8.75E-10	2.16E+01	1.63E+00	0.00E+00	0.00E+00	2.00E-04	2.21E+00	1.00E-03	1.42E-07	2.22E-06	7.20E-02	7.96E-07	1.90E+03	0.00E+00	9.00E-03
BATCH-706	8/25/27	131	13.6	0.24	9.37E-10	2.56E+01	1.91E+00	0.00E+00	0.00E+00	2.00E-04	2.72E+00	1.00E-03	1.52E-07	2.38E-06	8.70E-02	8.52E-07	2.23E+03	0.00E+00	1.00E-02
BATCH-707	9/1/27	18	1.9	0.24	1.21E-10	2.39E+00	1.24E-01	0.00E+00	0.00E+00	4.61E-05	2.18E-01	1.35E-04	2.11E-08	5.17E-07	1.10E-02	1.68E-07	3.03E+02	0.00E+00	3.00E-03
BATCH-708	9/3/27	107	11.1	0.24	1.98E-12	5.55E+01	3.01E+00	0.00E+00	0.00E+00	1.80E-03	4.32E+00	4.77E-05	4.45E-11	1.11E-10	1.57E-01	3.39E-09	1.82E+03	0.00E+00	9.00E-03
BATCH-709	9/8/27	118	12.3	0.24	8.90E-10	2.32E+01	1.69E+00	0.00E+00	0.00E+00	4.00E-04	2.03E+00	7.83E-04	1.44E-07	2.25E-06	7.20E-02	8.10E-07	2.02E+03	0.00E+00	1.00E-02
BATCH-710	9/14/27	49	5.1	0.24	1.03E-13	7.30E+00	7.18E-01	0.00E+00	0.00E+00	4.73E-05	1.05E+00	5.65E-04	3.81E-12	1.66E-09	2.80E-02	1.31E-12	8.30E+02	0.00E+00	6.61E-04
BATCH-711	9/20/27	55	5.7	0.24	3.93E-10	9.71E+00	7.34E-01	0.00E+00	0.00E+00	1.05E-04	9.93E-01	5.04E-04	6.37E-08	9.97E-07	3.20E-02	3.58E-07	9.33E+02	0.00E+00	4.00E-03
BATCH-712	9/20/27	107	11.1	0.24	1.97E-12	5.55E+01	3.01E+00	0.00E+00	0.00E+00	1.80E-03	4.31E+00	4.77E-05	4.35E-11	1.00E-10	1.57E-01	3.38E-09	1.82E+03	0.00E+00	9.00E-03
BATCH-713	9/25/27	54	5.6	0.24	3.52E-10	9.61E+00	7.16E-01	0.00E+00	0.00E+00	1.00E-04	1.02E+00	5.23E-04	5.69E-08	8.91E-07	3.30E-02	3.20E-07	9.15E+02	0.00E+00	4.00E-03
BATCH-714	10/1/27	81	8.4	0.24	1.48E-12	4.19E+01	2.27E+00	0.00E+00	0.00E+00	1.20E-03	3.26E+00	3.60E-05	3.05E-11	1.82E-11	1.18E-01	2.54E-09	1.38E+03	0.00E+00	7.00E-03
BATCH-715	10/2/27	17	1.8	0.24	2.53E-14	1.78E+00	1.75E-01	0.00E+00	0.00E+00	1.16E-05	2.56E-01	1.38E-04	9.29E-13	4.06E-10	7.00E-03	3.21E-13	2.89E+02	0.00E+00	1.61E-04
BATCH-716	10/4/27	55	5.7	0.24	3.78E-10	9.86E+00	7.19E-01	0.00E+00	0.00E+00	1.65E-04	8.65E-01	3.33E-04	6.13E-08	9.59E-07	3.10E-02	3.44E-07	9.34E+02	0.00E+00	4.00E-03
BATCH-717	10/10/27	21	2.2	0.24	1.20E-10	2.96E+00	2.24E-01	0.00E+00	0.00E+00	3.20E-05	3.03E-01	1.54E-04	1.94E-08	3.04E-07	1.00E-02	1.09E-07	3.56E+02	0.00E+00	1.00E-03
BATCH-718	10/10/27	20	2.1	0.24	1.05E-10	2.88E+00	2.15E-01	0.00E+00	0.00E+00	3.00E-05	3.06E-01	1.57E-04	1.71E-08	2.67E-07	1.00E-02	9.58E-08	3.47E+02	0.00E+00	1.00E-03
BATCH-719	10/12/27	81	8.4	0.24	1.48E-12	4.19E+01	2.27E+00	0.00E+00	0.00E+00	1.20E-03	3.26E+00	3.60E-05	3.05E-11	1.82E-11	1.18E-01	2.54E-09	1.38E+03	0.00E+00	7.00E-03
BATCH-720	10/12/27	106	11.1	0.24	1.95E-12	5.54E+01	3.00E+00	0.00E+00	0.00E+00	1.80E-03	4.30E+00	4.76E-05	4.03E-11	2.41E-11	1.56E-01	3.35E-09	1.82E+03	0.00E+00	9.00E-03
BATCH-721	10/21/27	21	2.2	0.24	1.15E-10	3.00E+00	2.19E-01	0.00E+00	0.00E+00	5.02E-05	2.63E-01	1.01E-04	1.86E-08	2.92E-07	9.00E-03	1.05E-07	3.56E+02	0.00E+00	1.00E-03
BATCH-722	10/23/27	95	9.9	0.24	6.15E-13	1.73E+01	1.44E+00	0.00E+00	0.00E+00	6.00E-04	1.35E+00	1.49E-05	1.33E-11	2.29E-11	4.90E-02	1.05E-09	1.62E+03	0.00E+00	3.00E-03
BATCH-723	10/24/27	80	8.3	0.24	1.19E-12	3.23E+01	1.15E+00	0.00E+00	0.00E+00	7.60E-03	5.40E+00	4.79E-04	3.11E-10	1.27E-10	1.83E-01	3.79E-08	1.36E+03	0.00E+00	3.30E-02
BATCH-724	11/1/27	73	7.6	0.24	8.56E-13	2.19E+01	1.42E-01	0.00E+00	0.00E+00	1.22E-02	6.70E+00	7.98E-04	5.11E-10	1.80E-10	2.20E-01	6.34E-08	1.24E+03	0.00E+00	5.20E-02
BATCH-725	11/2/27	95	9.9	0.24	6.13E-13	1.73E+01	1.44E+00	0.00E+00	0.00E+00	6.00E-04	1.35E+00	1.49E-05	1.32E-11	2.10E-11	4.90E-02	1.05E-09	1.62E+03	0.00E+00	3.00E-03
BATCH-726	11/9/27	55	5.7	0.24	6.34E-13	1.66E+01	1.09E-01	0.00E+00	0.00E+00	9.20E-03	5.07E+00	6.03E-04	3.84E-10	1.01E-10	1.66E-01	4.79E-08	9.37E+02	0.00E+00	3.90E-02
BATCH-727	11/12/27	72	7.6	0.24	8.57E-13	2.19E+01	1.42E-01	0.00E+00	0.00E+00	1.22E-02	6.70E+00	7.98E-04	5.11E-10	1.85E-10	2.20E-01	6.34E-08	1.24E+03	0.00E+00	5.20E-02
BATCH-728	11/15/27	50	5.2	0.24	5.77E-13	1.51E+01	9.80E-02	0.00E+00	0.00E+00	8.40E-03	4.61E+00	5.49E-04	3.49E-10	9.19E-11	1.51E-01	4.36E-08	8.53E+02	0.00E+00	3.60E-02
BATCH-729	11/20/27	48	5.1	0.24	2.79E-13	7.87E+00	6.52E-01	0.00E+00	0.00E+00	2.00E-04	6.11E-01	6.76E-06	6.06E-12	1.04E-11	2.20E-02	4.78E-10	8.29E+02	0.00E+00	1.00E-03
BATCH-730	11/20/27	53	5.5	0.24	6.07E-13	1.59E+01	1.03E-01	0.00E+00	0.00E+00	8.80E-03	4.86E+00	5.78E-04	3.68E-10	9.68E-11	1.59E-01	4.59E-08	8.98E+02	0.00E+00	3.80E-02
BATCH-731	11/25/27	48	5.1	0.24	2.78E-13	7.86E+00	6.51E-01	0.00E+00	0.00E+00	2.00E-04	6.11E-01	6.75E-06	5.97E-12	9.55E-12	2.20E-02	4.77E-10	8.28E+02	0.00E+00	1.00E-03
BATCH-732	11/26/27	99	10.3	0.24	4.81E-13	1.34E+01	1.22E+00	0.00E+00	0.00E+00	2.20E-03	1.83E+00	1.35E-04	8.76E-11	2.54E-11	6.30E-02	1.06E-08	1.69E+03	0.00E+00	1.00E-02
BATCH-733	12/1/27	115	12.0	0.24	5.53E-13	1.50E+01	1.37E+00	0.00E+00	0.00E+00	3.00E-03	2.29E+00	1.87E-04	1.22E-10	5.53E-11	7.80E-02	1.48E-08	1.97E+03	0.00E+00	1.30E-02
BATCH-734	12/6/27	53	5.5	0.24	6.06E-13	1.59E+01	1.03E-01	0.00E+00	0.00E+00	8.80E-03	4.85E+00	5.78E-04	3.67E-10	9.67E-11	1.59E-01	4.59E-08	8.97E+02	0.00E+00	3.80E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUN kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-686	6/3/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-04	1.53E+01	6.27E-11	3.72E+00	1.61E+00	1.00E-03	1.22E-08	0.00E+00	7.00E-03	6.28E-07	7.88E-04
BATCH-687	6/5/27	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	8.05E+01	4.90E-09	9.25E+00	5.89E+01	2.50E-02	6.20E-07	0.00E+00	1.36E-01	3.37E-05	1.60E-02
BATCH-688	6/5/27	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	8.04E+01	4.90E-09	9.24E+00	5.88E+01	2.50E-02	6.19E-07	0.00E+00	1.35E-01	3.36E-05	1.60E-02
BATCH-689	6/14/27	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	8.03E+01	4.89E-09	9.23E+00	5.88E+01	2.50E-02	6.19E-07	0.00E+00	1.35E-01	3.36E-05	1.60E-02
BATCH-690	6/15/27	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.09E+01	1.00E-09	4.79E+00	3.18E+01	1.10E-02	1.27E-07	0.00E+00	3.50E-02	6.97E-06	4.00E-03
BATCH-691	6/21/27	111	11.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.58E+02	1.57E-09	3.60E+01	2.14E+01	1.00E-02	2.23E-07	0.00E+00	5.90E-02	1.19E-05	6.00E-03
BATCH-692	6/24/27	124	12.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	7.09E+01	1.63E-14	8.38E+00	5.71E+01	1.70E-02	2.03E-12	0.00E+00	2.00E-02	1.91E-07	1.00E-03
BATCH-693	7/3/27	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.47E+01	2.54E-12	6.47E+00	4.41E+01	1.30E-02	3.22E-10	0.00E+00	1.60E-02	1.65E-07	8.49E-04
BATCH-694	7/7/27	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.47E+01	2.54E-12	6.47E+00	4.41E+01	1.30E-02	3.21E-10	0.00E+00	1.60E-02	1.65E-07	8.49E-04
BATCH-695	7/13/27	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.54E+02	1.71E-09	3.36E+01	2.55E+01	1.30E-02	2.56E-07	0.00E+00	7.20E-02	1.35E-05	8.00E-03
BATCH-696	7/17/27	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.47E+01	2.54E-12	6.47E+00	4.41E+01	1.30E-02	3.21E-10	0.00E+00	1.60E-02	1.65E-07	8.48E-04
BATCH-697	7/27/27	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.59E+01	6.52E-10	1.50E+01	8.92E+00	4.00E-03	9.29E-08	0.00E+00	2.50E-02	4.94E-06	3.00E-03
BATCH-698	7/27/27	96	10.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	5.50E+01	5.87E-15	6.50E+00	4.43E+01	1.30E-02	2.60E-13	0.00E+00	1.60E-02	1.48E-07	8.45E-04
BATCH-699	8/1/27	74	7.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	4.24E+01	6.22E-15	5.01E+00	3.41E+01	1.00E-02	4.14E-13	0.00E+00	1.20E-02	1.14E-07	6.51E-04
BATCH-700	8/6/27	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.69E+01	1.69E-13	4.36E+00	2.97E+01	9.00E-03	3.67E-13	0.00E+00	1.10E-02	9.85E-08	5.65E-04
BATCH-701	8/9/27	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	5.25E+01	5.81E-10	1.14E+01	8.68E+00	4.00E-03	8.71E-08	0.00E+00	2.50E-02	4.60E-06	3.00E-03
BATCH-702	8/13/27	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	4.90E+01	1.92E-11	4.51E+00	3.55E+01	1.00E-02	1.20E-12	0.00E+00	1.00E-02	1.13E-08	4.28E-04
BATCH-703	8/15/27	19	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.45E-04	1.78E+01	1.76E-10	4.06E+00	2.41E+00	1.00E-03	2.51E-08	0.00E+00	7.00E-03	1.34E-06	7.27E-04
BATCH-704	8/17/27	77	8.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.99E+01	3.18E-15	6.54E+00	1.56E+01	4.00E-03	3.28E-13	0.00E+00	6.00E-03	4.87E-08	2.78E-04
BATCH-705	8/20/27	111	11.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.19E+02	7.71E-10	2.07E+01	2.30E+01	7.00E-03	9.76E-08	0.00E+00	2.60E-02	5.34E-06	3.00E-03
BATCH-706	8/25/27	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.31E+02	8.26E-10	2.26E+01	2.74E+01	9.00E-03	1.05E-07	0.00E+00	2.90E-02	5.73E-06	3.00E-03
BATCH-707	9/1/27	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.18E-04	1.38E+01	1.53E-10	3.01E+00	2.29E+00	1.00E-03	2.29E-08	0.00E+00	6.00E-03	1.21E-06	6.99E-04
BATCH-708	9/3/27	107	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	8.15E+01	3.20E-11	7.50E+00	5.91E+01	1.70E-02	5.49E-12	0.00E+00	1.60E-02	1.88E-08	7.12E-04
BATCH-709	9/8/27	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.28E+02	7.88E-10	2.76E+01	2.47E+01	8.00E-03	9.92E-08	0.00E+00	2.70E-02	5.41E-06	3.00E-03
BATCH-710	9/14/27	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.38E+01	1.79E-15	3.69E+00	8.78E+00	2.00E-03	1.85E-13	0.00E+00	3.00E-03	2.75E-08	1.57E-04
BATCH-711	9/20/27	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	5.37E+01	3.47E-10	9.30E+00	1.03E+01	3.00E-03	4.39E-08	0.00E+00	1.20E-02	2.40E-06	1.00E-03
BATCH-712	9/20/27	107	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	8.15E+01	3.20E-11	7.50E+00	5.90E+01	1.70E-02	5.03E-12	0.00E+00	1.60E-02	1.88E-08	7.11E-04
BATCH-713	9/25/27	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.93E+01	3.10E-10	8.49E+00	1.03E+01	3.00E-03	3.92E-08	0.00E+00	1.10E-02	2.15E-06	1.00E-03
BATCH-714	10/1/27	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.15E+01	2.41E-11	5.66E+00	4.46E+01	1.30E-02	1.25E-12	0.00E+00	1.20E-02	1.40E-08	5.37E-04
BATCH-715	10/2/27	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.33E-04	8.24E+00	4.37E-16	9.00E-01	2.14E+00	5.85E-04	4.52E-14	0.00E+00	8.06E-04	6.70E-09	3.82E-05
BATCH-716	10/4/27	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.43E+01	3.35E-10	1.17E+01	1.05E+01	3.00E-03	4.22E-08	0.00E+00	1.10E-02	2.30E-06	1.00E-03
BATCH-717	10/10/27	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.25E-04	1.64E+01	1.06E-10	2.84E+00	3.15E+00	1.00E-03	1.34E-08	0.00E+00	4.00E-03	7.32E-07	3.72E-04
BATCH-718	10/10/27	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.21E-04	1.48E+01	9.29E-11	2.54E+00	3.08E+00	9.86E-04	1.18E-08	0.00E+00	3.00E-03	6.44E-07	3.33E-04
BATCH-719	10/12/27	81	8.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.15E+01	2.41E-11	5.66E+00	4.45E+01	1.30E-02	1.25E-12	0.00E+00	1.20E-02	1.40E-08	5.37E-04
BATCH-720	10/12/27	106	11.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	8.13E+01	3.19E-11	7.48E+00	5.89E+01	1.70E-02	1.65E-12	0.00E+00	1.60E-02	1.85E-08	7.10E-04
BATCH-721	10/21/27	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.43E-04	1.65E+01	1.02E-10	3.57E+00	3.20E+00	1.00E-03	1.28E-08	0.00E+00	3.00E-03	7.00E-07	3.53E-04
BATCH-722	10/23/27	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	8.21E+01	9.99E-12	2.63E+01	2.06E+01	5.00E-03	1.20E-12	0.00E+00	6.00E-03	5.84E-09	2.22E-04
BATCH-723	10/24/27	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-02	7.53E+01	1.13E-11	4.26E+00	3.62E+01	1.10E-02	2.72E-12	0.00E+00	3.00E-02	2.03E-07	3.00E-03
BATCH-724	11/1/27	73	7.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.10E-02	8.03E+01	3.90E-14	2.79E+00	2.65E+01	8.00E-03	2.62E-12	0.00E+00	4.30E-02	3.39E-07	4.00E-03
BATCH-725	11/2/27	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	8.20E+01	9.97E-12	2.63E+01	2.05E+01	5.00E-03	1.12E-12	0.00E+00	6.00E-03	5.82E-09	2.22E-04
BATCH-726	11/9/27	55	5.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-02	6.07E+01	3.32E-14	2.11E+00	2.00E+01	6.00E-03	4.47E-13	0.00E+00	3.20E-02	2.56E-07	3.00E-03
BATCH-727	11/12/27	72	7.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.10E-02	8.02E+01	4.10E-14	2.78E+00	2.64E+01	8.00E-03	2.86E-12	0.00E+00	4.30E-02	3.39E-07	4.00E-03
BATCH-728	11/15/27	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.20E-02	5.52E+01	2.20E-14	1.92E+00	1.82E+01	6.00E-03	4.08E-13	0.00E+00	2.90E-02	2.33E-07	3.00E-03
BATCH-729	11/20/27	48	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.73E+01	4.53E-12	1.19E+01	9.33E+00	2.00E-03	5.44E-13	0.00E+00	3.00E-03	2.65E-09	1.01E-04
BATCH-730	11/20/27	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	5.82E+01	1.67E-14	2.02E+00	1.92E+01	6.00E-03	4.29E-13	0.00E+00	3.10E-02	2.46E-07	3.00E-03
BATCH-731	11/25/27	48	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.72E+01	4.53E-12	1.19E+01	9.32E+00	2.00E-03	5.07E-13	0.00E+00	3.00E-03	2.64E-09	1.01E-04
BATCH-732	11/26/27	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	7.86E+01	5.70E-12	6.75E+01	1.61E+01	4.00E-03	3.88E-13	0.00E+00	1.00E-02	5.70E-08	7.54E-04
BATCH-733	12/1/27	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	8.21E+01	5.86E-12	9.07E+01	1.77E+01	5.00E-03	1.36E-12	0.00E+00	1.30E-02	7.93E-08	1.00E-03
BATCH-734	12/6/27	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	5.81E+01	1.67E-14	2.02E+00	1.91E+01	6.00E-03	4.29E-13	0.00E+00	3.10E-02	2.46E-07	3.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-735	12/12/27	17	1.7	0.24	0.00E+00	0.00E+00	1.00E-03	1.81E-04	1.11E-01	2.16E-02	2.43E+01	1.20E-02	4.00E-03	3.03E-01	2.97E-16	1.50E-02	1.64E-05	3.00E-03	1.50E-04
BATCH-736	12/13/27	101	10.5	0.24	0.00E+00	0.00E+00	7.20E-02	4.00E-03	5.50E+00	1.78E+00	4.01E+02	1.75E-01	2.70E-01	8.09E+00	2.69E-15	1.05E+00	2.86E-04	1.19E-01	3.75E-03
BATCH-737	12/14/27	17	1.7	0.24	0.00E+00	0.00E+00	1.00E-03	1.80E-04	1.10E-01	2.16E-02	2.43E+01	1.20E-02	4.00E-03	3.02E-01	2.96E-16	1.50E-02	1.64E-05	3.00E-03	1.50E-04
BATCH-738	12/16/27	49	5.1	0.24	0.00E+00	0.00E+00	1.70E-02	1.00E-03	1.33E+00	3.96E-01	1.34E+02	6.20E-02	6.10E-02	2.27E+00	1.21E-15	2.40E-01	9.36E-05	2.90E-02	1.00E-03
BATCH-739	12/21/27	101	10.5	0.24	0.00E+00	0.00E+00	7.10E-02	4.00E-03	5.48E+00	1.77E+00	3.99E+02	1.75E-01	2.69E-01	8.06E+00	2.68E-15	1.05E+00	2.85E-04	1.18E-01	3.75E-03
BATCH-740	12/24/27	47	4.9	0.24	0.00E+00	0.00E+00	1.90E-02	1.00E-03	1.46E+00	4.46E-01	1.39E+02	6.30E-02	6.90E-02	2.43E+00	1.19E-15	2.68E-01	9.70E-05	3.20E-02	1.25E-03
BATCH-741	12/29/27	92	9.6	0.24	0.00E+00	0.00E+00	1.18E-01	1.80E-02	8.97E+00	1.23E+00	1.84E+03	6.03E-01	1.79E-01	9.16E+00	3.10E-14	1.12E+00	1.00E-03	2.07E-01	7.25E-03
BATCH-742	1/1/28	99	10.4	0.24	0.00E+00	0.00E+00	1.09E-01	1.50E-02	8.25E+00	6.57E-01	1.99E+03	6.51E-01	8.60E-02	9.89E+00	1.83E-14	8.27E-01	1.00E-03	1.95E-01	7.00E-03
BATCH-743	1/8/28	17	1.8	0.24	0.00E+00	0.00E+00	4.00E-03	2.53E-04	3.23E-01	9.72E-02	3.22E+01	1.50E-02	1.40E-02	5.59E-01	1.50E-16	5.60E-02	1.79E-05	7.00E-03	2.50E-04
BATCH-744	1/10/28	49	5.2	0.24	0.00E+00	0.00E+00	3.20E-02	2.00E-03	2.40E+00	7.82E-01	1.72E+02	7.70E-02	1.13E-01	3.56E+00	5.95E-16	4.42E-01	9.81E-05	5.20E-02	1.75E-03
BATCH-745	1/11/28	16	1.7	0.24	0.00E+00	0.00E+00	5.00E-03	2.57E-04	3.44E-01	1.05E-01	3.20E+01	1.50E-02	1.50E-02	5.75E-01	1.42E-16	6.10E-02	1.79E-05	8.00E-03	2.50E-04
BATCH-746	1/13/28	49	5.2	0.24	0.00E+00	0.00E+00	3.10E-02	1.00E-03	2.40E+00	7.80E-01	1.72E+02	7.70E-02	1.13E-01	3.55E+00	5.94E-16	4.40E-01	9.78E-05	5.20E-02	1.75E-03
BATCH-747	1/15/28	77	8.1	0.24	0.00E+00	0.00E+00	8.50E-02	1.20E-02	6.42E+00	5.12E-01	1.55E+03	5.07E-01	6.70E-02	7.70E+00	1.42E-14	6.43E-01	9.01E-04	1.52E-01	5.50E-03
BATCH-748	1/19/28	99	10.3	0.24	0.00E+00	0.00E+00	1.09E-01	1.50E-02	8.24E+00	6.56E-01	1.98E+03	6.50E-01	8.60E-02	9.88E+00	1.82E-14	8.26E-01	1.00E-03	1.95E-01	7.00E-03
BATCH-749	1/23/28	81	8.5	0.24	0.00E+00	0.00E+00	8.90E-02	1.20E-02	6.75E+00	5.38E-01	1.63E+03	5.33E-01	7.00E-02	8.10E+00	1.50E-14	6.77E-01	9.48E-04	1.60E-01	5.75E-03
BATCH-750	1/29/28	18	1.8	0.24	0.00E+00	0.00E+00	8.00E-03	3.87E-04	6.19E-01	2.02E-01	4.44E+01	2.00E-02	2.90E-02	9.18E-01	1.54E-16	1.14E-01	2.53E-05	1.30E-02	5.00E-04
BATCH-751	1/31/28	99	10.3	0.24	0.00E+00	0.00E+00	1.09E-01	1.50E-02	8.22E+00	6.54E-01	1.98E+03	6.49E-01	8.60E-02	9.86E+00	1.82E-14	8.24E-01	1.00E-03	1.94E-01	7.00E-03
BATCH-752	2/1/28	18	1.8	0.24	0.00E+00	0.00E+00	8.00E-03	3.86E-04	6.17E-01	2.01E-01	4.42E+01	2.00E-02	2.90E-02	9.14E-01	1.53E-16	1.13E-01	2.52E-05	1.30E-02	5.00E-04
BATCH-753	2/3/28	32	3.4	0.24	0.00E+00	0.00E+00	5.90E-02	6.00E-03	4.47E+00	8.79E-01	6.46E+02	2.04E-01	3.30E-02	3.22E+00	6.07E-15	2.57E-01	3.76E-04	1.09E-01	2.00E-03
BATCH-754	2/6/28	31	3.2	0.24	0.00E+00	0.00E+00	7.40E-02	6.00E-03	5.60E+00	1.33E+00	6.19E+02	1.89E-01	3.60E-02	3.08E+00	5.90E-15	2.37E-01	3.59E-04	1.37E-01	1.50E-03
BATCH-755	2/10/28	25	2.6	0.24	0.00E+00	0.00E+00	6.10E-02	5.00E-03	4.60E+00	1.09E+00	5.08E+02	1.55E-01	2.90E-02	2.53E+00	4.84E-15	1.94E-01	2.95E-04	1.13E-01	1.25E-03
BATCH-756	2/11/28	38	3.9	0.24	0.00E+00	0.00E+00	9.00E-02	7.00E-03	6.81E+00	1.62E+00	7.52E+02	2.30E-01	4.40E-02	3.75E+00	7.17E-15	2.88E-01	4.37E-04	1.67E-01	2.00E-03
BATCH-757	2/13/28	38	3.9	0.24	0.00E+00	0.00E+00	9.00E-02	7.00E-03	6.81E+00	1.62E+00	7.52E+02	2.29E-01	4.40E-02	3.75E+00	7.17E-15	2.88E-01	4.36E-04	1.67E-01	2.00E-03
BATCH-758	2/15/28	109	11.3	0.24	0.00E+00	0.00E+00	4.70E-02	5.00E-03	3.56E+00	6.40E-01	1.03E+03	2.06E-01	7.60E-02	5.92E+00	5.08E-15	4.21E-01	3.49E-04	8.20E-02	2.50E-03
BATCH-759	2/17/28	80	8.3	0.24	0.00E+00	0.00E+00	2.90E-02	3.00E-03	2.20E+00	3.71E-01	6.31E+02	1.17E-01	1.80E-02	4.13E+00	3.43E-15	1.48E-01	2.14E-04	5.30E-02	1.25E-03
BATCH-760	2/25/28	31	3.2	0.24	0.00E+00	0.00E+00	7.40E-02	6.00E-03	5.59E+00	1.33E+00	6.18E+02	1.89E-01	3.60E-02	3.08E+00	5.89E-15	2.37E-01	3.59E-04	1.37E-01	1.50E-03
BATCH-761	2/26/28	99	10.4	0.24	0.00E+00	0.00E+00	3.60E-02	4.00E-03	2.71E+00	3.74E-01	9.30E+02	1.69E-01	2.40E-02	4.89E+00	4.84E-15	2.14E-01	3.04E-04	6.50E-02	1.75E-03
BATCH-762	2/29/28	27	2.8	0.24	0.00E+00	0.00E+00	6.30E-02	5.00E-03	4.81E+00	1.14E+00	5.32E+02	1.62E-01	3.10E-02	2.65E+00	5.07E-15	2.03E-01	3.08E-04	1.18E-01	1.25E-03
BATCH-763	3/3/28	44	4.6	0.24	0.00E+00	0.00E+00	5.20E-02	1.00E-02	3.95E+00	5.88E-01	8.79E+02	3.37E-01	4.30E-02	4.38E+00	9.66E-15	3.50E-01	6.45E-04	1.37E-01	2.50E-03
BATCH-764	3/7/28	44	4.6	0.24	0.00E+00	0.00E+00	1.40E-02	1.00E-03	1.08E+00	1.83E-01	3.10E+02	5.80E-02	9.00E-03	2.03E+00	1.68E-15	7.30E-02	1.05E-04	2.60E-02	5.00E-04
BATCH-765	3/8/28	51	5.3	0.24	0.00E+00	0.00E+00	2.00E-02	2.00E-03	1.51E+00	2.71E-01	4.36E+02	8.70E-02	3.20E-02	2.51E+00	2.15E-15	1.78E-01	1.48E-04	3.50E-02	1.00E-03
BATCH-766	3/12/28	79	8.3	0.24	0.00E+00	0.00E+00	2.90E-02	3.00E-03	2.19E+00	3.69E-01	6.27E+02	1.17E-01	1.80E-02	4.11E+00	3.40E-15	1.48E-01	2.13E-04	5.30E-02	1.25E-03
BATCH-767	3/14/28	94	9.8	0.24	0.00E+00	0.00E+00	3.50E-02	3.00E-03	2.67E+00	6.35E-01	4.31E+02	9.00E-02	1.70E-02	5.45E+00	2.81E-15	1.13E-01	1.71E-04	6.50E-02	7.50E-04
BATCH-768	3/21/28	104	10.9	0.24	0.00E+00	0.00E+00	3.50E-02	4.00E-03	2.67E+00	5.77E-01	5.06E+02	1.24E-01	2.00E-02	5.39E+00	3.72E-15	1.43E-01	2.36E-04	7.20E-02	1.00E-03
BATCH-769	3/24/28	51	5.3	0.24	0.00E+00	0.00E+00	1.70E-02	2.00E-03	1.27E+00	1.76E-01	4.37E+02	7.90E-02	1.10E-02	2.30E+00	2.27E-15	1.00E-01	1.43E-04	3.00E-02	7.50E-04
BATCH-770	3/29/28	16	1.6	0.24	0.00E+00	0.00E+00	3.00E-03	3.58E-04	2.58E-01	4.32E-02	7.42E+01	1.40E-02	2.00E-03	4.85E-01	4.03E-16	1.70E-02	2.51E-05	6.00E-03	1.37E-04
BATCH-771	3/31/28	19	2.0	0.24	0.00E+00	0.00E+00	6.00E-03	5.86E-04	4.38E-01	7.83E-02	1.27E+02	2.50E-02	9.00E-03	7.28E-01	6.25E-16	5.20E-02	4.30E-05	1.00E-02	2.50E-04
BATCH-772	4/1/28	44	4.6	0.24	0.00E+00	0.00E+00	1.40E-02	1.00E-03	1.08E+00	1.82E-01	3.09E+02	5.70E-02	9.00E-03	2.02E+00	1.68E-15	7.30E-02	1.05E-04	2.60E-02	5.00E-04
BATCH-773	4/2/28	45	4.7	0.24	0.00E+00	0.00E+00	1.50E-02	1.00E-03	1.14E+00	2.70E-01	1.84E+02	3.80E-02	7.00E-03	2.32E+00	1.20E-15	4.80E-02	7.29E-05	2.80E-02	2.50E-04
BATCH-774	4/6/28	20	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	5.95E-04	3.87E-01	5.31E-02	1.33E+02	2.40E-02	3.00E-03	6.99E-01	6.91E-16	3.10E-02	4.34E-05	9.00E-03	2.49E-04
BATCH-775	4/7/28	43	4.5	0.24	0.00E+00	0.00E+00	1.30E-02	1.00E-03	9.68E-01	2.09E-01	1.83E+02	4.50E-02	7.00E-03	1.96E+00	1.35E-15	5.20E-02	8.54E-05	2.80E-02	2.50E-04
BATCH-776	4/8/28	69	7.2	0.24	0.00E+00	0.00E+00	7.50E-02	1.50E-02	5.65E+00	7.47E-01	1.37E+03	5.35E-01	6.70E-02	6.84E+00	1.53E-14	5.49E-01	1.00E-03	2.06E-01	4.00E-03
BATCH-777	4/12/28	69	7.2	0.24	0.00E+00	0.00E+00	7.50E-02	1.50E-02	5.65E+00	7.47E-01	1.37E+03	5.35E-01	6.70E-02	6.83E+00	1.53E-14	5.49E-01	1.00E-03	2.06E-01	4.00E-03
BATCH-778	4/15/28	16	1.6	0.24	0.00E+00	0.00E+00	3.00E-03	3.55E-04	2.56E-01	4.32E-02	7.36E+01	1.40E-02	2.00E-03	4.82E-01	3.99E-16	1.70E-02	2.50E-05	6.00E-03	1.36E-04
BATCH-779	4/17/28	17	1.7	0.24	0.00E+00	0.00E+00	4.00E-03	3.15E-04	3.03E-01	7.20E-02	4.90E+01	1.00E-02	2.00E-03	6.19E-01	3.19E-16	1.30E-02	1.94E-05	7.00E-03	8.45E-05
BATCH-780	4/19/28	69	7.2	0.24	0.00E+00	0.00E+00	7.50E-02	1.50E-02	5.65E+00	7.47E-01	1.37E+03	5.35E-01	6.60E-02	6.83E+00	1.53E-14	5.48E-01	1.00E-03	2.06E-01	4.00E-03
BATCH-781	4/19/28	15	1.6	0.24	0.00E+00	0.00E+00	3.00E-03	3.16E-04	2.28E-01	4.95E-02	4.32E+01	1.10E-02	2.00E-03	4.60E-01	3.17E-16	1.20E-02	2.01E-05	6.00E-03	8.33E-05
BATCH-782	4/21/28	52	5.4	0.24	0.00E+00	0.00E+00	5.60E-02	1.20E-02	4.26E+00	5.63E-01	1.03E+03	4.04E-01	5.00E-02	5.15E+00	1.15E-14	4.14E-01	7.73E-04	1.55E-01	3.00E-03
BATCH-783	4/26/28	68	7.1	0.24	0.00E+00	0.00E+00	7.40E-02	1.50E-02	5.63E+00	7.45E-01	1.37E+03	5.34E-01	6.60E-02	6.82E+00	1.52E-14	5.47E-01	1.00E-03	2.06E-01	4.00E-03

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-735	12/12/27	17	1.7	0.24	1.51E-09	5.01E+01	2.85E+00	3.38E-04	2.30E-02	1.00E-03	1.46E-07	9.93E-08	3.12E-06	1.12E-06	5.84E-06	3.08E-06	1.80E-04	9.45E-04	7.98E-04
BATCH-736	12/13/27	101	10.5	0.24	3.92E-08	3.02E+02	2.25E+01	2.60E-02	1.42E+00	1.92E-01	3.32E-06	7.83E-07	1.76E-05	1.35E-05	4.01E-05	2.74E-05	1.00E-03	7.00E-03	8.00E-03
BATCH-737	12/14/27	17	1.7	0.24	1.51E-09	5.00E+01	2.85E+00	3.38E-04	2.30E-02	1.00E-03	1.46E-07	9.91E-08	3.11E-06	1.11E-06	5.82E-06	3.07E-06	1.79E-04	9.44E-04	7.97E-04
BATCH-738	12/16/27	49	5.1	0.24	1.11E-08	1.46E+02	1.10E+01	6.00E-03	3.28E-01	4.00E-02	9.84E-07	3.82E-07	1.07E-05	5.21E-06	2.13E-05	1.25E-05	6.73E-04	4.00E-03	3.00E-03
BATCH-739	12/21/27	101	10.5	0.24	3.91E-08	3.02E+02	2.24E+01	2.60E-02	1.41E+00	1.91E-01	3.31E-06	7.80E-07	1.76E-05	1.35E-05	3.99E-05	2.73E-05	1.00E-03	7.00E-03	8.00E-03
BATCH-740	12/24/27	47	4.9	0.24	1.19E-08	1.42E+02	1.07E+01	6.00E-03	3.66E-01	4.60E-02	1.04E-06	3.73E-07	1.01E-05	5.25E-06	2.05E-05	1.23E-05	6.52E-04	3.00E-03	3.00E-03
BATCH-741	12/29/27	92	9.6	0.24	6.73E-08	2.76E+02	2.55E+02	9.40E-02	5.24E+00	6.39E-01	2.88E-05	8.83E-06	1.94E-04	1.11E-04	1.51E-04	2.75E-04	1.50E-02	7.70E-02	4.00E-02
BATCH-742	1/1/28	99	10.4	0.24	4.52E-08	2.98E+02	2.97E+02	9.70E-02	5.25E+00	5.96E-01	3.33E-05	1.00E-05	2.05E-04	1.28E-04	1.64E-04	3.20E-04	1.70E-02	9.00E-02	4.50E-02
BATCH-743	1/8/28	17	1.8	0.24	1.95E-09	5.10E+01	2.68E+00	1.00E-03	7.40E-02	9.00E-03	2.42E-07	9.10E-08	2.36E-06	1.28E-06	5.24E-06	3.06E-06	1.64E-04	8.71E-04	8.15E-04
BATCH-744	1/10/28	49	5.2	0.24	1.23E-08	1.48E+02	9.83E+00	1.10E-02	5.75E-01	7.30E-02	1.46E-06	3.34E-07	7.00E-06	5.94E-06	1.76E-05	1.21E-05	5.75E-04	3.00E-03	3.00E-03
BATCH-745	1/11/28	16	1.7	0.24	2.01E-09	4.91E+01	2.52E+00	1.00E-03	8.00E-02	9.00E-03	2.48E-07	8.55E-08	2.16E-06	1.24E-06	4.87E-06	2.90E-06	1.53E-04	8.13E-04	7.77E-04
BATCH-746	1/13/28	49	5.2	0.24	1.23E-08	1.48E+02	9.80E+00	1.10E-02	5.74E-01	7.30E-02	1.46E-06	3.33E-07	6.98E-06	5.92E-06	1.76E-05	1.20E-05	5.74E-04	3.00E-03	3.00E-03
BATCH-747	1/15/28	77	8.1	0.24	3.52E-08	2.32E+02	2.31E+02	7.50E-02	4.08E+00	4.64E-01	2.59E-05	7.79E-06	1.60E-04	9.97E-05	1.28E-04	2.49E-04	1.30E-02	7.00E-02	3.50E-02
BATCH-748	1/19/28	99	10.3	0.24	4.51E-08	2.96E+02	2.96E+02	9.70E-02	5.24E+00	5.95E-01	3.33E-05	1.00E-05	2.05E-04	1.28E-04	1.64E-04	3.20E-04	1.70E-02	8.90E-02	4.50E-02
BATCH-749	1/23/28	81	8.5	0.24	3.70E-08	2.44E+02	2.43E+02	7.90E-02	4.30E+00	4.88E-01	2.73E-05	8.21E-06	1.68E-04	1.05E-04	1.34E-04	2.63E-04	1.40E-02	7.30E-02	3.70E-02
BATCH-750	1/29/28	18	1.8	0.24	3.18E-09	5.28E+01	2.54E+00	3.00E-03	1.48E-01	1.90E-02	3.76E-07	8.61E-08	1.81E-06	1.53E-06	4.55E-06	3.11E-06	1.48E-04	7.69E-04	8.57E-04
BATCH-751	1/31/28	99	10.3	0.24	4.50E-08	2.97E+02	2.96E+02	9.60E-02	5.23E+00	5.93E-01	3.32E-05	9.98E-06	2.04E-04	1.28E-04	1.64E-04	3.19E-04	1.70E-02	8.90E-02	4.50E-02
BATCH-752	2/1/28	18	1.8	0.24	3.17E-09	5.26E+01	2.53E+00	3.00E-03	1.48E-01	1.90E-02	3.75E-07	8.57E-08	1.80E-06	1.53E-06	4.53E-06	3.10E-06	1.48E-04	7.86E-04	8.53E-04
BATCH-753	2/3/28	32	3.4	0.24	1.66E-08	9.70E+01	9.91E+01	1.47E-01	7.86E+00	1.02E+00	1.48E-05	3.36E-06	5.48E-05	6.28E-05	5.01E-05	1.04E-04	6.00E-03	3.10E-02	4.20E-02
BATCH-754	2/6/28	31	3.2	0.24	1.79E-08	9.28E+01	9.68E+01	2.25E-01	1.21E+01	1.58E+00	1.71E-05	3.30E-06	4.36E-05	7.56E-05	4.56E-05	9.85E-05	6.00E-03	3.10E-02	6.00E-02
BATCH-755	2/10/28	25	2.6	0.24	1.42E-08	7.61E+01	7.94E+01	1.85E-01	9.89E+00	1.29E+00	1.40E-05	2.71E-06	3.58E-05	6.20E-05	3.74E-05	8.08E-05	5.00E-03	2.50E-02	4.90E-02
BATCH-756	2/11/28	38	3.9	0.24	2.11E-08	1.13E+02	1.18E+02	2.74E-01	1.47E+01	1.92E+00	2.08E-05	4.01E-06	5.30E-05	9.20E-05	5.54E-05	1.20E-04	7.00E-03	3.80E-02	7.30E-02
BATCH-757	2/13/28	38	3.9	0.24	2.11E-08	1.13E+02	1.18E+02	2.74E-01	1.47E+01	1.92E+00	2.07E-05	4.01E-06	5.30E-05	9.19E-05	5.54E-05	1.20E-04	7.00E-03	3.80E-02	7.30E-02
BATCH-758	2/15/28	109	11.3	0.24	1.79E-08	3.25E+02	8.28E+01	4.80E-02	2.59E+00	3.16E-01	1.00E-05	2.80E-06	5.52E-05	3.96E-05	5.08E-05	8.95E-05	5.00E-03	2.50E-02	1.80E-02
BATCH-759	2/17/28	80	8.3	0.24	9.08E-09	2.39E+02	5.59E+01	6.10E-02	3.28E+00	4.19E-01	7.65E-06	1.89E-06	3.35E-05	3.16E-05	2.91E-05	5.90E-05	3.00E-03	1.70E-02	1.90E-02
BATCH-760	2/25/28	31	3.2	0.24	1.73E-08	9.27E+01	9.66E+01	2.25E-01	1.20E+01	1.58E+00	1.70E-05	3.29E-06	4.36E-05	7.55E-05	4.55E-05	9.83E-05	6.00E-03	3.10E-02	6.00E-02
BATCH-761	2/26/28	99	10.4	0.24	1.25E-08	2.98E+02	7.88E+01	6.00E-02	3.24E+00	4.05E-01	9.95E-06	2.67E-06	5.03E-05	4.01E-05	4.22E-05	8.40E-05	5.00E-03	2.40E-02	2.00E-02
BATCH-762	2/29/28	27	2.8	0.24	1.49E-08	7.97E+01	8.31E+01	1.94E-01	1.04E+01	1.36E+00	1.47E-05	2.83E-06	3.74E-05	6.50E-05	3.91E-05	8.45E-05	5.00E-03	2.70E-02	5.20E-02
BATCH-763	3/3/28	44	4.6	0.24	2.47E-08	1.32E+02	1.77E+02	9.80E-02	5.24E+00	6.38E-01	8.05E-06	5.89E-06	8.03E-05	7.61E-05	8.12E-05	1.71E-04	1.00E-02	5.20E-02	2.50E-02
BATCH-764	3/7/28	44	4.6	0.24	4.47E-09	1.33E+02	2.75E+01	3.00E-02	1.61E+00	2.06E-01	3.76E-06	9.31E-07	1.65E-05	1.56E-05	1.43E-05	2.90E-05	2.00E-03	8.00E-03	9.00E-03
BATCH-765	3/8/28	51	5.3	0.24	7.58E-09	1.52E+02	3.50E+01	2.00E-02	1.09E+00	1.34E-01	4.24E-06	1.18E-06	2.34E-05	1.68E-05	2.15E-05	3.79E-05	2.00E-03	1.10E-02	7.00E-03
BATCH-766	3/12/28	79	8.3	0.24	9.03E-09	2.38E+02	5.55E+01	6.10E-02	3.26E+00	4.16E-01	7.60E-06	1.88E-05	3.33E-05	3.14E-05	2.90E-05	5.87E-05	3.00E-03	1.70E-02	1.90E-02
BATCH-767	3/14/28	94	9.8	0.24	8.25E-09	2.82E+02	4.61E+01	1.07E-01	5.74E+00	7.52E-01	8.13E-06	1.57E-06	2.08E-05	3.60E-05	2.17E-05	4.69E-05	3.00E-03	1.50E-02	2.90E-02
BATCH-768	3/21/28	104	10.9	0.24	1.03E-08	3.12E+02	6.41E+01	9.70E-02	5.21E+00	6.75E-01	7.48E-06	2.16E-06	2.90E-05	3.98E-05	2.98E-05	6.36E-05	4.00E-03	2.00E-02	2.60E-02
BATCH-769	3/24/28	51	5.3	0.24	5.85E-09	1.53E+02	3.70E+01	2.80E-02	1.52E+00	1.90E-01	4.67E-06	1.25E-06	2.36E-05	1.88E-05	1.98E-05	3.94E-05	2.00E-03	1.10E-02	9.00E-03
BATCH-770	3/29/28	16	1.6	0.24	1.07E-09	4.73E+01	6.57E+00	7.00E-03	3.85E-01	4.90E-02	2.23E-07	3.93E-06	3.72E-06	3.43E-06	6.94E-06	3.81E-04	2.00E-03	2.00E-03	2.00E-03
BATCH-771	3/31/28	19	2.0	0.24	2.20E-09	5.72E+01	1.02E+01	6.00E-03	3.18E-01	3.90E-02	1.23E-06	3.44E-07	6.79E-06	4.87E-06	6.24E-06	1.10E-05	5.82E-04	3.00E-03	2.00E-03
BATCH-772	4/1/28	44	4.6	0.24	4.44E-09	1.33E+02	2.73E+01	3.00E-02	1.60E+00	2.05E-01	3.74E-06	9.26E-07	1.64E-05	1.55E-05	1.43E-05	2.89E-05	2.00E-03	8.00E-03	9.00E-03
BATCH-773	4/2/28	45	4.7	0.24	3.52E-09	1.35E+02	1.96E+01	4.60E-02	2.45E+00	3.21E-01	3.47E-06	6.69E-07	8.85E-06	1.54E-05	9.25E-06	2.00E-05	1.00E-03	6.00E-03	1.20E-02
BATCH-774	4/6/28	20	2.1	0.24	1.78E-09	5.92E+01	1.13E+01	9.00E-03	4.62E-01	5.80E-02	1.42E-06	3.81E-07	7.18E-06	5.72E-06	6.02E-06	1.20E-05	6.47E-04	3.00E-03	3.00E-03
BATCH-775	4/7/28	43	4.5	0.24	3.74E-09	1.29E+02	2.32E+01	3.50E-02	1.89E+00	2.45E-01	2.71E-06	7.83E-07	1.05E-05	1.44E-05	1.08E-05	2.31E-05	1.00E-03	7.00E-03	9.00E-03
BATCH-776	4/8/28	69	7.2	0.24	3.86E-08	2.06E+02	2.82E+02	1.24E-01	6.63E+00	7.86E-01	1.05E-05	9.36E-06	1.28E-04	1.15E-04	1.29E-04	2.71E-04	1.50E-02	8.20E-02	3.20E-02
BATCH-777	4/12/28	69	7.2	0.24	3.86E-08	2.06E+02	2.82E+02	1.23E-01	6.62E+00	7.86E-01	1.05E-05	9.36E-06	1.28E-04	1.15E-04	1.29E-04	2.71E-04	1.50E-02	8.20E-02	3.20E-02
BATCH-778	4/15/28	16	1.6	0.24	1.06E-09	4.72E+01	6.52E+00	7.00E-03	3.82E-01	4.90E-02	8.92E-07	2.21E-07	3.90E-06	3.69E-06	3.40E-06	6.88E-06	3.78E-04	2.00E-03	2.00E-03
BATCH-779	4/17/28	17	1.7	0.24	9.37E-10	5.02E+01	5.23E+00	1.20E-02	6.52E-01	8.50E-02	9.23E-07	1.78E-07	2.36E-06	4.09E-06	2.47E-06	5.32E-06	3.15E-04	2.00E-03	3.00E-03
BATCH-780	4/19/28	69	7.2	0.24	3.86E-08	2.06E+02	2.82E+02	1.23E-01	6.62E+00	7.86E-01	1.05E-05	9.35E-06	1.28E-04	1.15E-04	1.29E-04	2.71E-04	1.50E-02	8.20E-02	3.20E-02
BATCH-781	4/19/28	15	1.6	0.24	8.81E-10	4.61E+01	5.47E+00	8.00E-03	4.45E-01	5.80E-02	6.39E-07	1.84E-07	2.47E-06	3.40E-06	2.54E-06	5.43E-06	3.16E-04	2.00E-03	2.00E-03
BATCH-782	4/21/28	52	5.4	0.24	2.92E-08	1.55E+02	2.13E+02	9.30E-02	5.00E+00	5.93E-01	7.89E-06	7.06E-06	9.64E-05	8.66E-05	9.72E-05	2.04E-04	1.20E-02	6.20E-02	2.40E-02
BATCH-783	4/26/28	68	7.1	0.24	3.85E-08	2.05E+02	2.81E+02	1.23E-01	6.61E+00	7.84E-01	1.04E-05	9.33E-06	1.28E-04	1.15E-04	1.29E-04	2.70E-04	1.50E-02	8.20E-02	3.20E-02

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-735	12/12/27	17	1.7	0.24	3.40E-05	1.63E-05	3.03E-04	8.63E-04	8.29E-04	4.70E-02	7.00E-03	2.67E-01	1.50E-02	4.17E-26	4.15E-07	3.49E-06	1.89E-05	2.83E-04	1.86E-11
BATCH-736	12/13/27	101	10.5	0.24	2.64E-04	1.37E-04	3.00E-03	5.00E-02	8.00E-03	1.80E+00	3.29E-01	2.55E+01	9.41E-01	1.95E-24	2.62E-05	3.55E-04	1.00E-03	2.80E-02	3.72E-09
BATCH-737	12/14/27	17	1.7	0.24	3.39E-05	1.62E-05	3.02E-04	8.62E-04	8.27E-04	4.70E-02	7.00E-03	2.67E-01	1.50E-02	4.16E-26	4.15E-07	3.49E-06	1.89E-05	2.82E-04	1.85E-11
BATCH-738	12/16/27	49	5.1	0.24	1.30E-04	6.44E-05	1.00E-03	1.20E-02	3.00E-03	4.60E-01	8.00E-02	5.57E+00	2.18E-01	4.75E-25	6.05E-06	7.72E-05	2.83E-04	6.00E-03	7.66E-10
BATCH-739	12/21/27	101	10.5	0.24	2.63E-04	1.37E-04	3.00E-03	5.00E-02	8.00E-03	1.80E+00	3.28E-01	2.54E+01	9.38E-01	1.94E-24	2.61E-05	3.54E-04	1.00E-03	2.80E-02	3.71E-09
BATCH-740	12/24/27	47	4.9	0.24	1.27E-04	6.30E-05	1.00E-03	1.30E-02	3.00E-03	5.02E-01	8.80E-02	6.29E+00	2.43E-01	5.23E-25	6.75E-06	8.74E-05	3.16E-04	7.00E-03	8.79E-10
BATCH-741	12/29/27	92	9.6	0.24	2.00E-03	8.89E-04	2.80E-02	5.50E-02	4.40E-02	2.25E+00	3.87E-01	1.67E+01	9.81E-01	1.25E-24	2.48E-05	4.84E-04	7.61E-04	1.30E-02	6.04E-09
BATCH-742	1/1/28	99	10.4	0.24	2.00E-03	1.00E-03	3.30E-02	4.30E-02	4.90E-02	1.88E+00	3.15E-01	8.39E+00	7.15E-01	1.28E-25	1.78E-05	4.21E-04	3.39E-04	3.00E-03	5.59E-09
BATCH-743	1/8/28	17	1.8	0.24	3.20E-05	1.58E-05	3.02E-04	3.00E-03	8.49E-04	1.13E-01	2.00E-02	1.37E+00	5.10E-02	2.48E-26	1.49E-06	1.90E-05	6.79E-05	1.00E-03	1.88E-10
BATCH-744	1/10/28	49	5.2	0.24	1.16E-04	6.04E-05	1.00E-03	2.20E-02	3.00E-03	7.94E-01	1.45E-01	1.12E+01	3.95E-01	1.82E-25	1.15E-05	1.56E-04	5.29E-04	1.20E-02	1.64E-09
BATCH-745	1/11/28	16	1.7	0.24	3.00E-05	1.49E-05	2.86E-04	3.00E-03	8.09E-04	1.19E-01	2.10E-02	1.49E+00	5.50E-02	2.63E-26	1.60E-06	2.07E-05	7.31E-05	2.00E-03	2.08E-10
BATCH-746	1/13/28	49	5.2	0.24	1.16E-04	6.02E-05	1.00E-03	2.20E-02	3.00E-03	7.92E-01	1.45E-01	1.12E+01	3.94E-01	1.82E-25	1.15E-05	1.56E-04	5.28E-04	1.20E-02	1.63E-09
BATCH-747	1/15/28	77	8.1	0.24	1.00E-03	7.89E-04	2.60E-02	3.30E-02	3.80E-02	1.46E+00	2.45E-01	6.53E+00	5.56E-01	1.00E-25	1.39E-05	3.28E-04	2.64E-04	2.00E-03	4.35E-09
BATCH-748	1/19/28	99	10.3	0.24	2.00E-03	1.00E-03	3.30E-02	4.30E-02	4.90E-02	1.88E+00	3.15E-01	8.38E+00	7.14E-01	1.28E-25	1.78E-05	4.21E-04	3.38E-04	3.00E-03	5.58E-09
BATCH-749	1/23/28	81	8.5	0.24	1.00E-03	8.30E-04	2.70E-02	3.50E-02	4.00E-02	1.54E+00	2.58E-01	6.87E+00	5.85E-01	1.05E-25	1.46E-05	3.45E-04	2.77E-04	2.00E-03	4.58E-09
BATCH-750	1/29/28	18	1.8	0.24	3.00E-05	1.56E-05	3.07E-04	6.00E-03	8.95E-04	2.05E-01	3.70E-02	2.88E+00	1.02E-01	4.69E-26	2.97E-06	4.03E-05	1.36E-04	3.00E-03	4.22E-10
BATCH-751	1/31/28	99	10.3	0.24	2.00E-03	1.00E-03	3.30E-02	4.20E-02	4.90E-02	1.87E+00	3.14E-01	8.36E+00	7.12E-01	1.28E-25	1.77E-05	4.19E-04	3.37E-04	3.00E-03	5.57E-09
BATCH-752	2/1/28	18	1.8	0.24	2.98E-05	1.55E-05	3.06E-04	6.00E-03	8.91E-04	2.04E-01	3.70E-02	2.87E+00	1.01E-01	4.67E-26	2.96E-06	4.02E-05	1.36E-04	3.00E-03	4.21E-10
BATCH-753	2/3/28	32	3.4	0.24	1.00E-03	5.88E-04	1.10E-02	2.60E-02	4.40E-02	9.98E-01	1.73E-01	1.28E+01	4.10E-01	7.84E-26	7.27E-06	6.84E-04	2.58E-04	3.00E-03	2.98E-09
BATCH-754	2/6/28	31	3.2	0.24	2.00E-03	7.52E-04	1.10E-02	3.30E-02	6.20E-02	1.24E+00	2.17E-01	1.97E+01	5.23E-01	1.02E-25	8.04E-06	1.00E-03	3.56E-04	4.00E-03	3.70E-09
BATCH-755	2/10/28	25	2.6	0.24	2.00E-03	6.17E-04	9.00E-03	2.70E-02	5.10E-02	1.02E+00	1.78E-01	1.61E+01	4.29E-01	8.36E-26	6.60E-06	8.67E-04	2.92E-04	4.00E-03	3.04E-09
BATCH-756	2/11/28	38	3.9	0.24	3.00E-03	9.15E-04	1.30E-02	4.10E-02	7.60E-02	1.51E+00	2.64E-01	2.39E+01	6.37E-01	1.24E-25	9.78E-06	1.00E-03	4.33E-04	5.00E-03	4.50E-09
BATCH-757	2/13/28	38	3.9	0.24	3.00E-03	9.15E-04	1.30E-02	4.10E-02	7.60E-02	1.51E+00	2.63E-01	2.39E+01	6.36E-01	1.24E-25	9.77E-06	1.00E-03	4.33E-04	5.00E-03	4.50E-09
BATCH-758	2/15/28	109	11.3	0.24	6.45E-04	3.33E-04	9.00E-03	2.30E-02	1.90E-02	9.23E-01	1.61E-01	8.98E+00	3.99E-01	1.24E-25	1.03E-05	2.67E-04	3.59E-04	7.00E-03	2.41E-09
BATCH-759	2/17/28	80	8.3	0.24	6.62E-04	2.84E-04	6.00E-03	1.20E-02	2.00E-02	4.93E-01	8.50E-02	5.33E+00	1.99E-01	3.75E-26	3.85E-06	2.83E-04	1.18E-04	1.00E-03	1.47E-09
BATCH-760	2/25/28	31	3.2	0.24	2.00E-03	7.51E-04	1.10E-02	3.30E-02	6.20E-02	1.24E+00	2.16E-01	1.96E+01	5.22E-01	1.02E-25	8.03E-06	1.00E-03	3.55E-04	4.00E-03	3.69E-09
BATCH-761	2/26/28	99	10.4	0.24	7.29E-04	3.44E-04	9.00E-03	1.50E-02	2.10E-02	6.11E-01	1.04E-01	5.25E+00	2.42E-01	4.48E-26	5.13E-06	2.76E-04	1.34E-04	1.00E-03	1.82E-09
BATCH-762	2/29/28	27	2.8	0.24	2.00E-03	6.47E-04	9.00E-03	2.90E-02	5.30E-02	1.07E+00	1.86E-01	1.69E+01	4.50E-01	8.76E-26	6.91E-06	9.08E-04	3.06E-04	4.00E-03	3.18E-09
BATCH-763	3/3/28	44	4.6	0.24	8.55E-04	5.41E-04	1.70E-02	2.90E-02	2.80E-02	1.22E+00	2.09E-01	8.29E+00	4.90E-01	8.66E-26	1.13E-05	4.36E-04	2.58E-04	2.00E-03	5.56E-10
BATCH-764	3/7/28	44	4.6	0.24	3.25E-04	1.40E-04	3.00E-03	6.00E-03	1.00E-02	2.42E-01	4.20E-02	2.62E+00	9.80E-02	1.84E-26	1.89E-06	1.39E-04	5.81E-05	6.22E-04	7.22E-10
BATCH-765	3/8/28	51	5.3	0.24	2.73E-04	1.41E-04	4.00E-03	1.00E-02	8.00E-03	3.91E-01	6.80E-02	3.80E+00	1.69E-01	5.27E-26	4.36E-06	1.13E-04	1.52E-04	3.00E-03	1.02E-09
BATCH-766	3/12/28	79	8.3	0.24	6.58E-04	2.83E-04	6.00E-03	1.20E-02	1.90E-02	4.90E-01	8.40E-02	5.30E+00	1.98E-01	3.73E-26	3.83E-06	2.81E-04	1.17E-04	1.00E-03	1.46E-09
BATCH-767	3/14/28	94	9.8	0.24	9.94E-04	3.58E-04	5.00E-03	1.60E-02	3.00E-02	5.90E-01	1.03E-01	9.37E+00	2.49E-01	4.86E-26	3.83E-06	5.04E-04	1.70E-04	2.00E-03	1.76E-09
BATCH-768	3/21/28	104	10.9	0.24	8.93E-04	3.61E-04	7.00E-03	1.70E-02	2.70E-02	6.48E-01	1.13E-01	8.47E+00	2.70E-01	5.10E-26	4.76E-06	4.53E-04	1.71E-04	2.00E-03	1.43E-09
BATCH-769	3/24/28	51	5.3	0.24	3.42E-04	1.62E-04	4.00E-03	7.00E-03	1.00E-02	2.87E-01	4.90E-02	2.46E+00	1.13E-01	2.10E-26	2.41E-06	1.29E-04	6.28E-05	6.23E-04	8.54E-10
BATCH-770	3/29/28	16	1.6	0.24	7.78E-05	3.34E-05	7.27E-04	1.00E-03	2.00E-03	5.80E-02	1.00E-02	6.27E-01	2.30E-02	4.41E-27	4.52E-07	3.33E-05	1.39E-05	1.49E-04	1.73E-10
BATCH-771	3/31/28	19	2.0	0.24	7.94E-05	4.10E-05	1.00E-03	3.00E-03	2.00E-03	1.14E-01	2.00E-02	1.10E+00	4.90E-02	1.53E-26	1.27E-06	3.29E-05	4.42E-05	8.14E-04	2.96E-10
BATCH-772	4/1/28	44	4.6	0.24	3.24E-04	1.39E-04	3.00E-03	6.00E-03	1.00E-02	2.41E-01	4.10E-02	2.61E+00	9.70E-02	1.83E-26	1.88E-06	1.38E-04	5.78E-05	6.19E-04	7.18E-10
BATCH-773	4/2/28	45	4.7	0.24	4.24E-04	1.53E-04	2.00E-03	7.00E-03	1.30E-02	2.52E-01	4.40E-02	4.00E+00	1.06E-01	2.07E-26	1.63E-06	2.15E-04	7.23E-05	8.72E-04	7.52E-10
BATCH-774	4/6/28	20	2.1	0.24	1.04E-04	4.92E-05	1.00E-03	2.00E-03	3.00E-03	8.70E-02	1.50E-02	7.49E-01	3.40E-02	6.40E-27	7.32E-07	3.94E-05	1.91E-05	1.89E-04	2.60E-10
BATCH-775	4/7/28	43	4.5	0.24	3.24E-04	1.31E-04	2.00E-03	6.00E-03	1.00E-02	2.35E-01	4.10E-02	3.07E+00	9.80E-02	1.85E-26	1.73E-06	1.64E-04	6.20E-05	6.89E-04	5.17E-10
BATCH-776	4/8/28	69	7.2	0.24	1.00E-03	7.75E-04	2.70E-02	4.20E-02	3.50E-02	1.84E+00	3.14E-01	1.04E+01	7.33E-01	1.28E-25	1.76E-05	5.41E-04	3.71E-04	3.00E-03	2.53E-10
BATCH-777	4/12/28	69	7.2	0.24	1.00E-03	7.75E-04	2.70E-02	4.20E-02	3.50E-02	1.84E+00	3.14E-01	1.04E+01	7.32E-01	1.28E-25	1.76E-05	5.41E-04	3.71E-04	3.00E-03	2.53E-10
BATCH-778	4/15/28	16	1.6	0.24	7.71E-05	3.32E-05	7.21E-04	1.00E-03	2.00E-03	5.70E-02	1.00E-02	6.22E-01	2.30E-02	4.37E-27	4.49E-07	3.30E-05	1.38E-05	1.48E-04	1.71E-10
BATCH-779	4/17/28	17	1.7	0.24	1.13E-04	4.07E-05	5.76E-04	2.00E-03	3.00E-03	6.70E-02	1.20E-02	1.07E+00	2.80E-02	5.52E-27	4.35E-07	5.72E-05	1.93E-05	2.32E-04	2.00E-10
BATCH-780	4/19/28	69	7.2	0.24	1.00E-03	7.74E-04	2.70E-02	4.20E-02	3.50E-02	1.83E+00	3.14E-01	1.04E+01	7.32E-01	1.28E-25	1.76E-05	5.41E-04	3.71E-04	3.00E-03	2.53E-10
BATCH-781	4/19/28	15	1.6	0.24	7.62E-05	3.08E-05	5.70E-04	1.00E-03	2.00E-03	5.50E-02	1.00E-02	7.22E-01	2.30E-02	4.36E-27	4.06E-07	3.87E-05	1.46E-05	1.62E-04	1.22E-10
BATCH-782	4/21/28	52	5.4	0.24	7.98E-04	5.84E-04	2.10E-02	3.20E-02	2.70E-02	1.38E+00	2.37E-01	7.82E+00	5.52E-01	9.63E-26	1.33E-05	4.08E-04	2.80E-04	2.00E-03	1.91E-10
BATCH-783	4/26/28	68	7.1	0.24	1.00E-03	7.73E-04	2.70E-02	4.20E-02	3.50E-02	1.83E+00	3.13E-01	1.03E+01	7.30E-01	1.27E-25	1.76E-05	5.39E-04	3.70E-04	3.00E-03	2.52E-10

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
Units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-735	12/12/27	17		0.24	3.25E+01	0.00E+00	3.04E-10	1.20E-08	5.31E-10	4.16E-09	4.00E-03	1.02E-01	3.36E-09	3.31E-04	1.09E+00	0.00E+00	2.31E+00	0.00E+00	5.29E-07
BATCH-736	12/13/27	101	10.5	0.24	2.85E+02	0.00E+00	8.25E-12	1.64E-07	2.22E-11	5.46E-18	5.30E-02	1.24E+00	4.40E-10	4.00E-03	1.09E+01	0.00E+00	1.42E+01	0.00E+00	4.22E-06
BATCH-737	12/14/27	17	1.7	0.24	3.24E+01	0.00E+00	3.04E-10	1.19E-08	5.30E-10	4.15E-09	4.00E-03	1.02E-01	3.35E-09	3.31E-04	1.09E+00	0.00E+00	2.31E+00	0.00E+00	5.28E-07
BATCH-738	12/16/27	49	5.1	0.24	1.31E+02	0.00E+00	7.07E-10	5.96E-08	1.24E-09	9.65E-09	2.00E-02	4.79E-01	7.87E-09	2.00E-03	4.63E+00	0.00E+00	8.13E+00	0.00E+00	2.05E-06
BATCH-739	12/21/27	101	10.5	0.24	2.84E+02	0.00E+00	8.23E-12	1.63E-07	2.21E-11	6.19E-14	5.30E-02	1.24E+00	4.39E-10	4.00E-03	1.08E+01	0.00E+00	1.42E+01	0.00E+00	4.21E-06
BATCH-740	12/24/27	47	4.9	0.24	1.17E+02	0.00E+00	6.00E-10	6.06E-08	1.05E-09	8.18E-09	1.80E-02	4.76E-01	6.70E-09	2.00E-03	4.60E+00	0.00E+00	6.58E+00	0.00E+00	2.00E-06
BATCH-741	12/29/27	92	9.6	0.24	3.00E-03	1.23E+02	7.09E-09	1.18E-06	4.12E-09	3.70E-13	1.03E-01	9.06E-01	6.27E-09	1.50E-02	2.38E+01	0.00E+00	2.05E-04	7.97E+00	5.39E-05
BATCH-742	1/1/28	99	10.4	0.24	4.00E-03	1.38E+02	8.59E-09	1.35E-06	4.98E-09	5.74E-13	1.15E-01	1.03E+00	7.39E-09	1.60E-02	2.37E+01	0.00E+00	3.19E-04	9.09E+00	5.39E-05
BATCH-743	1/8/28	17	1.8	0.24	3.21E+01	0.00E+00	1.74E-10	1.46E-08	3.04E-10	2.37E-09	5.00E-03	1.18E-01	1.94E-09	3.69E-04	1.14E+00	0.00E+00	2.00E+00	0.00E+00	5.03E-07
BATCH-744	1/10/28	49	5.2	0.24	1.25E+02	0.00E+00	3.63E-12	7.21E-08	9.77E-12	2.40E-18	2.30E-02	5.47E-01	1.94E-10	2.00E-03	4.78E+00	0.00E+00	6.25E+00	0.00E+00	1.86E-06
BATCH-745	1/11/28	16	1.7	0.24	2.77E+01	0.00E+00	1.42E-10	1.44E-08	2.48E-10	1.94E-09	4.00E-03	1.13E-01	1.59E-09	3.57E-04	1.09E+00	0.00E+00	1.56E+00	0.00E+00	4.73E-07
BATCH-746	1/13/28	49	5.2	0.24	1.25E+02	0.00E+00	3.62E-12	7.19E-08	9.75E-12	2.73E-14	2.30E-02	5.46E-01	1.93E-10	2.00E-03	4.77E+00	0.00E+00	6.24E+00	0.00E+00	1.85E-06
BATCH-747	1/15/28	77	8.1	0.24	1.56E-06	1.07E+02	6.68E-09	1.05E-06	3.87E-09	1.99E-16	9.00E-02	8.01E-01	5.75E-09	1.30E-02	1.85E+01	0.00E+00	1.11E-07	7.07E+00	5.39E-05
BATCH-748	1/19/28	99	10.3	0.24	5.00E-03	1.38E+02	8.58E-09	1.35E-06	4.97E-09	3.41E-13	1.15E-01	1.03E+00	7.38E-09	1.60E-02	2.37E+01	0.00E+00	2.88E-04	9.08E+00	5.39E-05
BATCH-749	1/23/28	81	8.5	0.24	2.29E-06	1.13E+02	7.03E-09	1.11E-06	4.08E-09	2.94E-16	9.40E-02	8.43E-01	6.05E-09	1.30E-02	1.94E+01	0.00E+00	1.63E-07	7.45E+00	5.39E-05
BATCH-750	1/29/28	18	1.8	0.24	3.23E+01	0.00E+00	9.36E-13	1.86E-08	2.52E-12	6.20E-19	6.00E-03	1.41E-01	5.00E-11	4.30E-04	1.23E+00	0.00E+00	1.61E+00	0.00E+00	4.79E-07
BATCH-751	1/31/28	99	10.3	0.24	4.00E-03	1.38E+02	8.56E-09	1.35E-06	4.96E-09	2.65E-13	1.15E-01	1.03E+00	7.36E-09	1.60E-02	2.37E+01	0.00E+00	2.13E-04	9.06E+00	5.39E-05
BATCH-752	2/1/28	18	1.8	0.24	3.23E+01	0.00E+00	9.33E-13	1.85E-08	2.51E-12	7.02E-15	6.00E-03	1.41E-01	4.98E-11	4.28E-04	1.23E+00	0.00E+00	1.61E+00	0.00E+00	4.77E-07
BATCH-753	2/3/28	32	3.4	0.24	7.43E-10	4.05E+01	2.78E-09	3.70E-07	1.92E-09	9.52E-20	1.70E-02	5.46E-01	8.75E-09	3.00E-03	7.32E+00	0.00E+00	5.29E-11	3.11E+00	1.90E-05
BATCH-754	2/6/28	31	3.2	0.24	2.07E-06	3.55E+01	2.65E-09	3.01E-07	2.07E-09	1.52E-16	1.00E-03	6.78E-01	1.31E-08	2.00E-03	6.70E+00	0.00E+00	1.29E-07	3.09E+00	1.84E-05
BATCH-755	2/10/28	25	2.6	0.24	1.25E-09	2.91E+01	2.17E-09	2.47E-07	1.69E-09	1.60E-19	1.00E-03	5.56E-01	1.07E-08	1.00E-03	5.50E+00	0.00E+00	8.88E-11	2.54E+00	1.51E-05
BATCH-756	2/11/28	38	3.9	0.24	4.00E-03	4.32E+01	3.22E-09	3.68E-07	2.51E-09	8.31E-23	2.00E-03	8.25E-01	1.59E-08	2.00E-03	8.15E+00	0.00E+00	2.16E-04	3.76E+00	2.24E-05
BATCH-757	2/13/28	38	3.9	0.24	4.00E-03	4.31E+01	3.22E-09	3.66E-07	2.51E-09	9.41E-19	2.00E-03	8.25E-01	1.59E-08	2.00E-03	8.14E+00	0.00E+00	2.15E-04	3.76E+00	2.24E-05
BATCH-758	2/15/28	109	11.3	0.24	2.86E+02	0.00E+00	2.25E-09	3.78E-07	1.36E-09	1.98E-13	9.50E-02	1.62E+00	3.00E-09	5.00E-03	8.40E+00	0.00E+00	1.34E+01	0.00E+00	1.60E-05
BATCH-759	2/17/28	80	8.3	0.24	2.37E+02	0.00E+00	1.58E-09	2.24E-07	1.04E-09	3.97E-14	5.40E-02	1.52E+00	3.75E-09	2.00E-03	4.24E+00	0.00E+00	8.75E+00	0.00E+00	1.07E-05
BATCH-760	2/25/28	31	3.2	0.24	1.69E-06	3.55E+01	2.64E-09	3.01E-07	2.06E-09	1.18E-16	1.00E-03	6.77E-01	1.30E-08	2.00E-03	6.69E+00	0.00E+00	9.52E-08	3.09E+00	1.84E-05
BATCH-761	2/26/28	99	10.4	0.24	2.82E+02	0.00E+00	2.25E-09	3.35E-07	1.40E-09	6.56E-14	8.50E-02	1.70E+00	3.86E-09	4.00E-03	6.12E+00	0.00E+00	1.23E+01	0.00E+00	1.52E-05
BATCH-762	2/29/28	27	2.8	0.24	2.25E-06	3.05E+01	2.27E-09	2.59E-07	1.77E-09	4.31E-26	1.00E-03	5.83E-01	1.12E-08	1.00E-03	5.75E+00	0.00E+00	1.12E-07	2.65E+00	1.58E-05
BATCH-763	3/3/28	44	4.6	0.24	1.48E-06	6.76E+01	7.67E-10	1.12E-07	6.18E-10	3.22E-22	2.00E-03	2.24E-01	4.68E-09	4.00E-03	1.03E+01	0.00E+00	7.37E-08	5.51E+00	2.70E-05
BATCH-764	3/7/28	44	4.6	0.24	1.17E+02	0.00E+00	7.78E-10	1.10E-07	5.09E-10	1.95E-14	2.70E-02	7.45E-01	1.84E-09	1.00E-03	2.09E+00	0.00E+00	4.30E+00	0.00E+00	5.28E-06
BATCH-765	3/8/28	51	5.3	0.24	1.21E+02	0.00E+00	9.52E-10	1.60E-07	5.74E-10	8.36E-14	4.00E-02	6.86E-01	1.27E-09	2.00E-03	3.56E+00	0.00E+00	5.69E+00	0.00E+00	6.75E-06
BATCH-766	3/12/28	79	8.3	0.24	2.37E+02	0.00E+00	1.57E-09	2.23E-07	1.03E-09	3.07E-14	5.40E-02	1.51E+00	3.73E-09	2.00E-03	4.22E+00	0.00E+00	8.72E+00	0.00E+00	1.07E-05
BATCH-767	3/14/28	94	9.8	0.24	3.12E+02	0.00E+00	1.26E-09	1.43E-07	9.83E-10	1.91E-23	2.50E-02	2.21E+00	6.22E-09	7.32E-04	3.19E+00	0.00E+00	7.41E+00	0.00E+00	8.77E-06
BATCH-768	3/21/28	104	10.9	0.24	3.84E+02	0.00E+00	1.08E-09	1.27E-07	8.47E-10	2.32E-19	2.80E-02	1.70E+00	5.48E-09	1.00E-03	4.11E+00	0.00E+00	1.09E+01	0.00E+00	1.20E-05
BATCH-769	3/24/28	51	5.3	0.24	1.32E+02	0.00E+00	1.06E-09	1.57E-07	6.57E-10	3.08E-14	4.00E-02	7.99E-01	1.81E-09	2.00E-03	2.87E+00	0.00E+00	5.76E+00	0.00E+00	7.13E-06
BATCH-770	3/29/28	16	1.6	0.24	2.79E+01	0.00E+00	1.86E-10	2.63E-08	1.22E-10	4.67E-15	6.00E-03	1.78E-01	4.41E-10	2.61E-04	4.98E-01	0.00E+00	1.03E+00	0.00E+00	1.26E-06
BATCH-771	3/31/28	19	2.0	0.24	3.52E+01	0.00E+00	2.77E-10	4.65E-08	1.67E-10	2.43E-14	1.20E-02	1.99E-01	3.69E-10	5.78E-04	1.03E+00	0.00E+00	1.65E+00	0.00E+00	1.96E-06
BATCH-772	4/1/28	44	4.6	0.24	1.16E+02	0.00E+00	7.74E-10	1.10E-07	5.06E-10	1.51E-14	2.70E-02	7.44E-01	1.83E-09	1.00E-03	2.07E+00	0.00E+00	4.29E+00	0.00E+00	5.25E-06
BATCH-773	4/2/28	45	4.7	0.24	1.33E+02	0.00E+00	5.37E-10	6.11E-08	4.19E-10	8.16E-24	1.10E-02	9.44E-01	2.65E-09	3.12E-04	1.36E+00	0.00E+00	3.16E+00	0.00E+00	3.74E-06
BATCH-774	4/6/28	20	2.1	0.24	4.03E+01	0.00E+00	3.22E-10	4.77E-08	2.00E-10	9.36E-15	1.20E-02	2.43E-01	5.51E-10	5.18E-04	8.74E-01	0.00E+00	1.75E+00	0.00E+00	2.17E-06
BATCH-775	4/7/28	43	4.5	0.24	1.39E+02	0.00E+00	3.92E-10	4.61E-08	3.07E-10	8.41E-20	1.00E-02	6.17E-01	1.99E-09	4.67E-04	1.49E+00	0.00E+00	3.95E+00	0.00E+00	4.36E-06
BATCH-776	4/8/28	69	7.2	0.24	4.00E-03	1.08E+02	8.06E-10	1.34E-07	6.61E-10	5.97E-19	3.00E-03	2.52E-01	5.50E-09	7.00E-03	1.61E+01	0.00E+00	1.32E-04	8.75E+00	5.39E-05
BATCH-777	4/12/28	69	7.2	0.24	6.00E-03	1.08E+02	8.06E-10	1.34E-07	6.61E-10	4.13E-18	3.00E-03	2.52E-01	5.49E-09	7.00E-03	1.61E+01	0.00E+00	2.81E-04	8.75E+00	5.39E-05
BATCH-778	4/15/28	16	1.6	0.24	2.78E+01	0.00E+00	1.85E-10	2.61E-08	1.21E-10	3.60E-15	6.00E-03	1.77E-01	4.37E-10	2.59E-04	4.95E-01	0.00E+00	1.02E+00	0.00E+00	1.25E-06
BATCH-779	4/17/28	17	1.7	0.24	3.55E+01	0.00E+00	1.43E-10	1.63E-08	1.12E-10	2.17E-24	3.00E-03	2.51E-01	7.07E-10	8.31E-05	3.62E-01	0.00E+00	8.41E-01	0.00E+00	9.96E-07
BATCH-780	4/19/28	69	7.2	0.24	7.00E-03	1.08E+02	8.05E-10	1.34E-07	6.61E-10	1.70E-18	3.00E-03	2.52E-01	5.49E-09	7.00E-03	1.61E+01	0.00E+00	3.19E-04	8.74E+00	5.39E-05
BATCH-781	4/19/28	15	1.6	0.24	3.27E+01	0.00E+00	9.22E-11	1.09E-08	7.22E-11	1.98E-20	2.00E-03	1.45E-01	4.68E-10	1.10E-04	3.50E-01	0.00E+00	9.29E-01	0.00E+00	1.03E-06
BATCH-782	4/21/28	52	5.4	0.24	1.84E-06	8.13E+01	6.08E-10	1.01E-07	4.99E-10	3.08E-22	2.00E-03	1.90E-01	4.14E-09	5.00E-03	1.22E+01	0.00E+00	6.78E-08	6.60E+00	2.70E-05
BATCH-783	4/26/28	68	7.1	0.24	4.00E-03	1.08E+02	8.03E-10	1.34E-07	6.59E-10	4.59E-19	3.00E-03	2.52E-01	5.48E-09	7.00E-03	1.61E+01	0.00E+00	1.31E-04	8.72E+00	5.39E-05

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-735	12/12/27	17	1.7	0.24	6.65E-14	1.87E+00	1.55E-01	0.00E+00	0.00E+00	5.76E-05	1.46E-01	1.61E-06	1.44E-12	2.48E-12	5.00E-03	1.14E-10	2.85E+02	0.00E+00	3.10E-04
BATCH-735	12/12/27	101	10.5	0.24	3.04E-13	7.85E+00	9.06E-01	0.00E+00	0.00E+00	4.40E-03	2.40E+00	2.86E-04	1.83E-10	5.74E-11	7.90E-02	2.27E-08	1.72E+03	0.00E+00	1.90E-02
BATCH-736	12/13/27	17	1.7	0.24	6.63E-14	1.87E+00	1.55E-01	0.00E+00	0.00E+00	5.75E-05	1.45E-01	1.61E-06	1.42E-12	2.27E-12	5.00E-03	1.14E-10	2.85E+02	0.00E+00	3.09E-04
BATCH-737	12/14/27	49	5.1	0.24	2.11E-13	5.87E+00	5.36E-01	0.00E+00	0.00E+00	1.00E-03	8.04E-01	5.93E-05	3.85E-11	1.12E-11	2.80E-02	4.68E-09	8.33E+02	0.00E+00	4.00E-03
BATCH-738	12/15/27	101	10.5	0.24	3.03E-13	7.83E+00	9.04E-01	0.00E+00	0.00E+00	4.40E-03	2.39E+00	2.85E-04	1.82E-10	5.84E-11	7.80E-02	2.26E-08	1.72E+03	0.00E+00	1.90E-02
BATCH-739	12/21/27	47	4.9	0.24	2.01E-13	5.46E+00	4.98E-01	0.00E+00	0.00E+00	1.20E-03	8.30E-01	6.80E-05	4.44E-11	2.01E-11	2.80E-02	5.37E-09	8.08E+02	0.00E+00	5.00E-03
BATCH-740	12/24/27	92	9.6	0.24	4.87E-11	3.80E+01	8.82E-01	0.00E+00	0.00E+00	2.20E-03	6.69E+00	4.00E-03	2.34E-09	1.74E-07	2.39E-01	1.84E-08	1.57E+03	0.00E+00	3.18E-01
BATCH-741	12/29/27	99	10.4	0.24	5.88E-11	4.24E+01	1.05E+00	0.00E+00	0.00E+00	6.00E-04	6.99E+00	4.00E-03	2.75E-09	2.11E-07	2.52E-01	1.17E-08	1.70E+03	0.00E+00	3.77E-01
BATCH-742	1/1/28	99	10.4	0.24	5.88E-11	4.24E+01	1.05E+00	0.00E+00	0.00E+00	2.00E-04	1.98E-01	1.46E-05	9.46E-12	2.75E-12	7.00E-03	1.15E-09	2.91E+02	0.00E+00	1.00E-03
BATCH-743	1/8/28	17	1.8	0.24	5.20E-14	1.44E+00	1.32E-01	0.00E+00	0.00E+00	2.00E-04	1.06E+00	1.26E-04	8.03E-11	2.53E-11	3.50E-02	1.00E-08	8.45E+02	0.00E+00	8.00E-03
BATCH-744	1/10/28	49	5.2	0.24	1.34E-13	3.46E+00	3.99E-01	0.00E+00	0.00E+00	2.00E-03	1.06E+00	1.61E-05	1.05E-11	4.76E-12	7.00E-03	1.27E-09	2.80E+02	0.00E+00	1.00E-03
BATCH-745	1/11/28	16	1.7	0.24	4.76E-14	1.29E+00	1.18E-01	0.00E+00	0.00E+00	2.00E-04	1.97E-01	1.26E-04	8.01E-11	2.57E-11	3.50E-02	9.97E-09	8.44E+02	0.00E+00	8.00E-03
BATCH-746	1/13/28	49	5.2	0.24	1.34E-13	3.45E+00	3.98E-01	0.00E+00	0.00E+00	2.00E-03	1.05E+00	1.26E-04	8.01E-11	2.57E-11	3.50E-02	9.97E-09	8.44E+02	0.00E+00	8.00E-03
BATCH-747	1/15/28	77	8.1	0.24	4.58E-11	3.30E+01	8.13E-01	0.00E+00	0.00E+00	6.00E-04	5.44E+00	3.00E-03	2.14E-09	1.64E-07	1.96E-01	9.09E-09	1.32E+03	0.00E+00	2.93E-01
BATCH-748	1/19/28	99	10.3	0.24	5.88E-11	4.23E+01	1.04E+00	0.00E+00	0.00E+00	6.00E-04	6.98E+00	4.00E-03	2.75E-09	2.11E-07	2.52E-01	1.17E-08	1.70E+03	0.00E+00	3.76E-01
BATCH-749	1/23/28	81	8.5	0.24	4.82E-11	3.47E+01	8.56E-01	0.00E+00	0.00E+00	6.00E-04	5.72E+00	4.00E-03	2.25E-09	1.73E-07	2.07E-01	9.57E-09	1.39E+03	0.00E+00	3.09E-01
BATCH-750	1/29/28	18	1.8	0.24	3.45E-14	8.91E-01	1.03E-01	0.00E+00	0.00E+00	4.00E-04	2.73E-01	3.25E-05	2.07E-11	6.52E-12	9.00E-03	2.58E-09	3.01E+02	0.00E+00	2.00E-03
BATCH-751	1/31/28	99	10.3	0.24	5.86E-11	4.22E+01	1.04E+00	0.00E+00	0.00E+00	6.00E-04	6.96E+00	4.00E-03	2.74E-09	2.10E-07	2.52E-01	1.16E-08	1.69E+03	0.00E+00	3.75E-01
BATCH-752	2/1/28	18	1.8	0.24	3.44E-14	8.88E-01	1.03E-01	0.00E+00	0.00E+00	4.00E-04	2.71E-01	3.23E-05	2.06E-11	6.62E-12	9.00E-03	2.57E-09	3.01E+02	0.00E+00	2.00E-03
BATCH-753	2/3/28	32	3.4	0.24	1.27E-10	3.17E+01	9.07E-01	0.00E+00	0.00E+00	6.00E-04	2.09E+00	7.11E-04	1.59E-08	6.99E-08	1.54E-01	1.24E-08	5.29E+02	0.00E+00	5.15E-01
BATCH-754	2/6/28	31	3.2	0.24	2.01E-10	4.35E+01	1.29E+00	0.00E+00	0.00E+00	8.00E-04	1.86E+00	1.75E-04	2.63E-08	6.79E-08	1.54E-01	1.02E-08	4.34E+02	0.00E+00	7.82E-01
BATCH-755	2/10/28	25	2.6	0.24	1.65E-10	3.57E+01	1.06E+00	0.00E+00	0.00E+00	8.00E-04	1.53E+00	1.44E-04	2.16E-08	5.57E-08	1.27E-01	1.51E-08	6.43E+02	0.00E+00	6.41E-01
BATCH-756	2/11/28	38	3.9	0.24	2.45E-10	5.30E+01	1.57E+00	0.00E+00	0.00E+00	1.00E-03	2.26E+00	2.11E-04	3.20E-08	8.25E-08	1.88E-01	1.51E-08	6.43E+02	0.00E+00	9.52E-01
BATCH-757	2/13/28	38	3.9	0.24	2.45E-10	5.29E+01	1.56E+00	0.00E+00	0.00E+00	1.00E-03	2.26E+00	2.11E-04	3.20E-08	8.25E-08	1.88E-01	1.51E-08	6.43E+02	0.00E+00	9.51E-01
BATCH-758	2/15/28	109	11.3	0.24	3.20E-11	1.55E+01	1.17E+00	0.00E+00	0.00E+00	1.20E-03	2.30E+00	1.00E-03	3.06E-09	5.55E-08	8.90E-02	8.53E-09	1.85E+03	0.00E+00	1.63E-01
BATCH-759	2/17/28	80	8.3	0.24	5.14E-11	1.46E+01	1.06E+00	0.00E+00	0.00E+00	2.00E-04	1.22E+00	5.37E-04	6.15E-09	3.95E-08	6.40E-02	4.10E-09	1.36E+03	0.00E+00	2.17E-01
BATCH-760	2/25/28	31	3.2	0.24	2.01E-10	4.35E+01	1.28E+00	0.00E+00	0.00E+00	8.00E-04	1.86E+00	1.75E-04	2.63E-08	6.77E-08	1.54E-01	1.24E-08	5.28E+02	0.00E+00	7.80E-01
BATCH-761	2/26/28	99	10.4	0.24	4.81E-11	1.66E+01	1.23E+00	0.00E+00	0.00E+00	2.00E-04	1.78E+00	9.21E-04	5.26E-09	5.59E-08	8.00E-02	4.63E-09	1.70E+03	0.00E+00	2.18E-01
BATCH-762	2/29/28	27	2.8	0.24	1.73E-10	3.74E+01	1.11E+00	0.00E+00	0.00E+00	8.00E-04	1.60E+00	1.49E-04	2.26E-08	5.83E-08	1.33E-01	1.07E-08	4.54E+02	0.00E+00	6.72E-01
BATCH-763	3/3/28	44	4.6	0.24	6.60E-11	5.75E+01	1.97E-01	0.00E+00	0.00E+00	1.80E-03	2.36E+00	9.65E-05	6.32E-09	2.14E-08	3.10E-01	1.37E-09	7.51E+02	0.00E+00	1.26E-01
BATCH-764	3/7/28	44	4.6	0.24	2.53E-11	7.16E+00	5.22E-01	0.00E+00	0.00E+00	1.32E-04	6.01E-01	2.64E-04	3.02E-09	1.94E-08	3.10E-02	2.02E-09	7.60E+02	0.00E+00	1.07E-01
BATCH-765	3/8/28	51	5.3	0.24	1.36E-11	6.55E+00	4.93E-01	0.00E+00	0.00E+00	4.00E-04	9.72E-01	4.58E-04	1.29E-09	2.35E-08	3.80E-02	3.61E-09	8.64E+02	0.00E+00	6.90E-02
BATCH-766	3/12/28	79	8.3	0.24	5.11E-11	1.45E+01	1.06E+00	0.00E+00	0.00E+00	2.00E-04	1.22E+00	5.34E-04	6.11E-09	3.93E-08	6.30E-02	4.08E-09	1.35E+03	0.00E+00	2.16E-01
BATCH-767	3/14/28	94	9.8	0.24	9.59E-11	2.07E+01	1.46E+00	0.00E+00	0.00E+00	4.00E-04	8.86E-01	8.26E-05	1.25E-08	3.23E-08	7.40E-02	5.91E-09	1.61E+03	0.00E+00	3.73E-01
BATCH-768	3/21/28	104	10.9	0.24	8.35E-11	2.52E+01	1.25E+00	0.00E+00	0.00E+00	6.00E-04	1.06E+00	7.84E-05	1.05E-08	2.80E-08	1.07E-01	4.70E-09	1.78E+03	0.00E+00	3.03E-01
BATCH-769	3/24/28	51	5.3	0.24	2.26E-11	7.77E+00	5.78E-01	0.00E+00	0.00E+00	1.38E-04	8.36E-01	4.32E-04	2.47E-09	2.62E-08	3.80E-02	2.18E-09	8.74E+02	0.00E+00	1.02E-01
BATCH-770	3/29/28	16	1.6	0.24	6.04E-12	1.71E+00	1.25E-01	0.00E+00	0.00E+00	3.16E-05	1.44E-01	6.31E-05	7.23E-10	4.65E-09	7.00E-03	4.82E-10	2.70E+02	0.00E+00	2.50E-02
BATCH-771	3/31/28	19	2.0	0.24	3.94E-12	1.90E+00	1.43E-01	0.00E+00	0.00E+00	1.40E-04	2.83E-01	1.33E-04	3.76E-10	6.83E-09	1.10E-02	1.05E-09	3.26E+02	0.00E+00	2.00E-02
BATCH-772	4/1/28	44	4.6	0.24	2.51E-11	7.12E+00	5.20E-01	0.00E+00	0.00E+00	1.31E-04	5.98E-01	2.63E-04	3.01E-09	1.93E-08	3.10E-02	2.01E-09	7.59E+02	0.00E+00	1.06E-01
BATCH-773	4/2/28	45	4.7	0.24	4.09E-11	8.84E+00	6.23E-01	0.00E+00	0.00E+00	1.74E-04	3.78E-01	3.52E-05	5.35E-09	1.38E-08	3.10E-02	2.52E-09	7.70E+02	0.00E+00	1.59E-01
BATCH-774	4/6/28	20	2.1	0.24	6.86E-12	2.36E+00	1.76E-01	0.00E+00	0.00E+00	4.20E-05	2.54E-01	1.32E-04	7.51E-10	7.98E-09	1.10E-02	6.62E-10	3.38E+02	0.00E+00	3.10E-02
BATCH-775	4/7/28	43	4.5	0.24	3.03E-11	9.13E+00	4.52E-01	0.00E+00	0.00E+00	2.00E-04	3.84E-01	2.84E-05	3.82E-09	1.02E-08	3.90E-02	1.70E-09	7.38E+02	0.00E+00	1.10E-01
BATCH-776	4/8/28	69	7.2	0.24	7.42E-11	8.93E+01	9.40E-02	0.00E+00	0.00E+00	3.00E-03	3.65E+00	1.31E-04	5.80E-09	2.36E-08	4.97E-01	8.52E-12	1.17E+03	0.00E+00	6.90E-02
BATCH-777	4/12/28	69	7.2	0.24	7.42E-11	8.92E+01	9.40E-02	0.00E+00	0.00E+00	3.00E-03	3.64E+00	1.31E-04	5.80E-09	2.36E-08	4.97E-01	8.64E-12	1.17E+03	0.00E+00	6.90E-02
BATCH-778	4/15/28	16	1.6	0.24	5.99E-12	1.70E+00	1.24E-01	0.00E+00	0.00E+00	3.13E-05	1.43E-01	6.26E-05	7.17E-10	4.61E-09	7.00E-03	4.78E-10	2.69E+02	0.00E+00	2.50E-02
BATCH-779	4/17/28	17	1.7	0.24	1.09E-11	2.36E+00	1.66E-01	0.00E+00	0.00E+00	4.63E-05	1.01E-01	9.38E-06	1.31E-04	5.80E-09	2.36E-08	4.96E-01	8.57E-12	1.17E+03	0.00E+00	4.20E-02
BATCH-780	4/19/28	69	7.2	0.24	7.42E-11	8.92E+01	9.40E-02	0.00E+00	0.00E+00	3.00E-03	3.64E+00	1.31E-04	5.80E-09	2.36E-08	4.96E-01	8.57E-12	1.17E+03	0.00E+00	6.80E-02
BATCH-781	4/19/28	15	1.6	0.24	7.12E-12	2.15E+00	1.06E-01	0.00E+00	0.00E+00	5.18E-05	9.00E-02	6.69E-06	8.99E-10	2.39E-09	9.00E-03	4.01E-10	2.63E+02	0.00E+00	2.60E-02
BATCH-782	4/21/28	52	5.4	0.24	5.60E-11	6.73E+01	7.10E-02	0.00E+00	0.00E+00	2.20E-03	2.75E+00	9.89E-05	4.38E-09	1.78E-08	3.74E-01	6.38E-12	8.85E+02	0.00E+00	5.20E-02
BATCH-783	4/26/28	68	7.1	0.24	7.40E-11	8.90E+01	9.40E-02	0.00E+00	0.00E+00	3.00E-03	3.63E+00	1.31E-04	5.79E-09	2.36E-08	4.95E-01	8.50E-12	1.17E+03	0.00E+00	6.80E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-735	12/12/27	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.07E-04	8.88E+00	1.08E-12	2.84E+00	2.22E+00	5.60E-04	1.30E-13	0.00E+00	5.97E-04	6.31E-10	2.40E-05
BATCH-736	12/13/27	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	7.18E+01	1.16E-14	7.90E+01	9.96E+00	3.00E-03	6.34E-13	0.00E+00	1.60E-02	1.22E-07	1.00E-03
BATCH-737	12/14/27	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.06E-04	8.87E+00	1.08E-12	2.84E+00	2.22E+00	5.59E-04	1.21E-13	0.00E+00	5.96E-04	6.30E-10	2.40E-05
BATCH-738	12/16/27	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.46E+01	2.50E-12	2.97E+01	7.10E+00	2.00E-03	1.71E-13	0.00E+00	4.00E-03	2.51E-08	3.32E-04
BATCH-739	12/21/27	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-02	7.16E+01	1.19E-14	7.89E+01	9.95E+00	3.00E-03	6.82E-13	0.00E+00	1.60E-02	1.21E-07	1.00E-03
BATCH-740	12/24/27	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	2.98E+01	2.13E-12	3.29E+01	6.43E+00	2.00E-03	4.95E-13	0.00E+00	5.00E-03	2.88E-08	3.69E-04
BATCH-741	12/29/27	92	9.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	6.04E+01	3.98E-10	7.87E+00	3.81E+01	2.90E-02	9.50E-14	0.00E+00	1.50E-01	4.33E-07	1.40E-02
BATCH-742	1/1/28	99	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.98E+01	4.82E-10	9.08E+00	4.17E+01	3.30E-02	1.63E-14	0.00E+00	1.74E-01	4.69E-07	1.60E-02
BATCH-743	1/8/28	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	8.49E+00	6.15E-13	7.29E+00	1.74E+00	4.59E-04	4.20E-14	0.00E+00	1.00E-03	6.16E-09	8.15E-05
BATCH-744	1/10/28	49	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.16E+01	5.09E-15	3.48E+01	4.39E+00	1.00E-03	2.79E-13	0.00E+00	7.00E-03	5.35E-08	6.25E-04
BATCH-745	1/11/28	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	7.06E+00	5.04E-13	7.80E+00	1.52E+00	4.18E-04	1.17E-13	0.00E+00	1.00E-03	6.82E-09	8.74E-05
BATCH-746	1/13/28	49	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.15E+01	5.26E-15	3.47E+01	4.38E+00	1.00E-03	3.00E-13	0.00E+00	7.00E-03	5.34E-08	6.24E-04
BATCH-747	1/15/28	77	8.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	4.66E+01	3.75E-10	7.06E+00	3.25E+01	2.60E-02	1.27E-14	0.00E+00	1.36E-01	3.65E-07	1.20E-02
BATCH-748	1/19/28	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.98E+01	4.82E-10	9.07E+00	4.17E+01	3.30E-02	1.63E-14	0.00E+00	1.74E-01	4.68E-07	1.60E-02
BATCH-749	1/23/28	81	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.90E+01	3.95E-10	7.44E+00	3.42E+01	2.70E-02	1.34E-14	0.00E+00	1.43E-01	3.84E-07	1.30E-02
BATCH-750	1/29/28	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.15E+00	1.31E-15	8.97E+00	1.13E+00	3.33E-04	7.19E-14	0.00E+00	2.00E-03	1.38E-08	1.61E-04
BATCH-751	1/31/28	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.96E+01	4.81E-10	9.04E+00	4.16E+01	3.30E-02	1.63E-14	0.00E+00	1.74E-01	4.67E-07	1.60E-02
BATCH-752	2/1/28	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.12E+00	1.35E-15	8.94E+00	1.13E+00	3.31E-04	7.73E-14	0.00E+00	2.00E-03	1.37E-08	1.61E-04
BATCH-753	2/3/28	32	3.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-02	3.68E+01	1.52E-10	2.86E+00	1.42E+01	6.00E-03	9.71E-11	0.00E+00	5.30E-02	1.64E-07	5.90E-02
BATCH-754	2/6/28	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	4.79E+01	1.42E-10	2.67E+00	1.40E+01	3.00E-03	1.64E-10	0.00E+00	4.70E-02	1.65E-07	9.70E-02
BATCH-755	2/10/28	25	2.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	3.93E+01	1.16E-10	2.19E+00	1.15E+01	2.00E-03	1.35E-10	0.00E+00	3.90E-02	1.36E-07	7.90E-02
BATCH-756	2/11/28	38	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.83E+01	1.72E-10	3.24E+00	1.70E+01	3.00E-03	2.00E-10	0.00E+00	5.70E-02	2.01E-07	1.18E-01
BATCH-757	2/13/28	38	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.83E+01	1.72E-10	3.24E+00	1.70E+01	3.00E-03	2.00E-10	0.00E+00	5.70E-02	2.01E-07	1.18E-01
BATCH-758	2/15/28	109	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	9.45E+01	1.26E-10	3.48E+01	1.36E+01	9.00E-03	1.49E-11	0.00E+00	5.00E-02	1.50E-07	1.30E-02
BATCH-759	2/17/28	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.48E+01	8.74E-11	1.82E+01	8.35E+00	4.00E-03	3.64E-11	0.00E+00	3.20E-02	9.10E-08	2.30E-02
BATCH-760	2/25/28	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	4.79E+01	1.42E-10	2.66E+00	1.40E+01	3.00E-03	1.64E-10	0.00E+00	4.70E-02	1.65E-07	9.60E-02
BATCH-761	2/26/28	99	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	9.29E+01	1.25E-10	2.33E+01	1.17E+01	7.00E-03	2.93E-11	0.00E+00	4.70E-02	1.27E-07	2.10E-02
BATCH-762	2/29/28	27	2.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	4.12E+01	1.22E-10	2.29E+00	1.20E+01	2.00E-03	1.41E-10	0.00E+00	4.10E-02	6.42E-07	8.30E-02
BATCH-763	3/3/28	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.59E+01	6.85E-11	4.06E+00	1.85E+01	3.00E-03	1.81E-11	0.00E+00	2.00E-02	6.42E-07	2.05E-01
BATCH-764	3/7/28	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.68E+01	4.30E-11	8.94E+00	4.10E+00	2.00E-03	1.79E-11	0.00E+00	1.60E-02	4.47E-08	1.10E-02
BATCH-765	3/8/28	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.00E+01	5.32E-11	1.47E+01	5.74E+00	4.00E-03	6.31E-12	0.00E+00	2.10E-02	6.33E-08	5.00E-03
BATCH-766	3/12/28	79	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.45E+01	8.69E-11	1.81E+01	8.30E+00	4.00E-03	3.62E-11	0.00E+00	3.20E-02	9.04E-08	2.30E-02
BATCH-767	3/14/28	94	9.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	8.95E+01	6.75E-11	2.01E+01	7.03E+00	1.00E-03	7.83E-11	0.00E+00	2.40E-02	7.86E-08	4.60E-02
BATCH-768	3/21/28	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	8.32E+01	6.24E-11	2.05E+01	8.62E+00	1.00E-03	6.23E-11	0.00E+00	2.20E-02	1.65E-07	6.90E-02
BATCH-769	3/24/28	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.36E+01	5.89E-11	1.09E+01	5.50E+00	3.00E-03	1.38E-11	0.00E+00	2.20E-02	5.94E-08	1.00E-02
BATCH-770	3/29/28	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	8.79E+00	1.03E-11	2.14E+00	9.81E-01	5.19E-04	4.28E-12	0.00E+00	4.00E-03	1.07E-08	3.00E-03
BATCH-771	3/31/28	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.16E+01	1.55E-11	4.28E+00	1.67E+00	1.00E-03	1.83E-12	0.00E+00	6.00E-03	1.84E-08	2.00E-03
BATCH-772	4/1/28	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.67E+01	4.28E-11	8.92E+00	4.08E+00	2.00E-03	1.78E-11	0.00E+00	1.60E-02	4.45E-08	1.10E-02
BATCH-773	4/2/28	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.82E+01	2.88E-11	8.58E+00	3.00E+00	5.07E-04	3.34E-11	0.00E+00	1.00E-02	3.35E-08	2.00E-02
BATCH-774	4/6/28	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.33E+01	1.79E-11	3.33E+00	1.67E+00	1.00E-03	4.19E-12	0.00E+00	7.00E-03	1.81E-08	3.00E-03
BATCH-775	4/7/28	43	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.02E+01	2.26E-11	7.44E+00	3.13E+00	5.18E-04	2.26E-11	0.00E+00	8.00E-03	5.99E-08	2.50E-02
BATCH-776	4/8/28	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	5.19E+01	8.95E-11	6.38E+00	2.87E+01	5.00E-03	2.74E-15	0.00E+00	2.50E-02	1.06E-06	3.30E-01
BATCH-777	4/12/28	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	5.19E+01	8.95E-11	6.38E+00	2.87E+01	5.00E-03	2.74E-15	0.00E+00	2.50E-02	1.06E-06	3.30E-01
BATCH-778	4/15/28	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	8.74E+00	1.02E-11	2.13E+00	9.74E-01	5.15E-04	4.25E-12	0.00E+00	4.00E-03	1.06E-08	3.00E-03
BATCH-779	4/17/28	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.02E+01	7.67E-12	2.29E+00	7.99E-01	1.35E-04	8.90E-12	0.00E+00	3.00E-03	8.93E-09	5.00E-03
BATCH-780	4/19/28	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	5.18E+01	8.95E-11	6.37E+00	2.87E+01	5.00E-03	3.19E-15	0.00E+00	2.50E-02	1.06E-06	3.29E-01
BATCH-781	4/19/28	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	7.10E+00	5.33E-12	1.75E+00	7.36E-01	1.22E-04	5.32E-12	0.00E+00	2.00E-03	1.41E-08	6.00E-03
BATCH-782	4/21/28	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.91E+01	6.75E-11	4.81E+00	2.16E+01	4.00E-03	1.83E-15	0.00E+00	1.90E-02	7.96E-07	2.49E-01
BATCH-783	4/26/28	68	7.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	5.17E+01	8.93E-11	6.36E+00	2.86E+01	5.00E-03	2.97E-15	0.00E+00	2.50E-02	1.05E-06	3.29E-01

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-784	4/26/28	97	10.1	0.24	0.00E+00	0.00E+00	4.60E-02	6.00E-03	3.45E+00	4.45E-01	1.53E+03	2.84E-01	2.90E-02	7.34E+00	6.53E-15	6.71E-01	4.43E-04	6.50E-02	6.75E-03
BATCH-785	5/3/28	166	17.3	0.24	0.00E+00	0.00E+00	6.00E-02	7.00E-03	4.54E+00	5.77E-01	2.36E+03	3.45E-01	3.10E-02	1.01E+01	6.69E-15	1.11E+00	4.57E-04	4.40E-02	1.18E-02
BATCH-786	5/7/28	165	17.3	0.24	0.00E+00	0.00E+00	6.00E-02	7.00E-03	4.54E+00	5.76E-01	2.36E+03	3.44E-01	3.10E-02	1.01E+01	6.69E-15	1.11E+00	4.57E-04	4.40E-02	1.18E-02
BATCH-787	5/21/28	117	12.2	0.24	0.00E+00	0.00E+00	2.80E-02	6.00E-03	2.10E+00	2.78E-01	6.24E+02	1.99E-01	2.50E-02	4.06E+00	5.69E-15	2.04E-01	3.82E-04	7.70E-02	1.50E-03
BATCH-788	5/24/28	125	13.0	0.24	0.00E+00	0.00E+00	4.50E-02	5.00E-03	3.43E+00	4.36E-01	1.78E+03	2.60E-01	2.30E-02	7.64E+00	5.05E-15	8.40E-01	3.45E-04	3.30E-02	8.75E-03
BATCH-789	6/2/28	125	13.0	0.24	0.00E+00	0.00E+00	4.50E-02	5.00E-03	3.43E+00	4.36E-01	1.78E+03	2.60E-01	2.30E-02	7.64E+00	5.05E-15	8.40E-01	3.45E-04	3.30E-02	8.75E-03
BATCH-790	6/7/28	95	9.9	0.24	0.00E+00	0.00E+00	3.40E-02	4.00E-03	2.61E+00	3.32E-01	1.36E+03	1.98E-01	1.80E-02	5.82E+00	3.85E-15	6.40E-01	2.63E-04	2.50E-02	6.75E-03
BATCH-791	6/16/28	138	14.4	0.24	0.00E+00	0.00E+00	5.00E-02	5.00E-03	3.78E+00	4.80E-01	1.96E+03	2.87E-01	2.60E-02	8.42E+00	5.57E-15	9.26E-01	3.80E-04	3.60E-02	9.75E-03
BATCH-792	6/17/28	79	8.2	0.24	0.00E+00	0.00E+00	6.40E-02	1.30E-02	4.88E+00	2.34E-01	1.57E+03	4.59E-01	5.50E-02	7.85E+00	1.26E-14	5.94E-01	8.49E-04	1.36E-01	4.75E-03
BATCH-793	6/25/28	35	3.7	0.24	0.00E+00	0.00E+00	7.00E-03	2.00E-03	5.58E-01	7.38E-02	1.65E+02	5.30E-02	7.00E-03	1.08E+00	1.51E-15	5.40E-02	1.01E-04	2.00E-02	5.00E-04
BATCH-794	6/29/28	51	5.3	0.24	0.00E+00	0.00E+00	5.20E-02	1.10E-02	3.94E+00	1.38E-01	1.01E+03	3.82E-01	4.70E-02	5.03E+00	1.09E-14	4.00E-01	7.32E-04	1.22E-01	2.75E-03
BATCH-795	6/30/28	51	5.3	0.24	0.00E+00	0.00E+00	5.20E-02	1.10E-02	3.95E+00	1.39E-01	1.01E+03	3.83E-01	4.70E-02	5.03E+00	1.09E-14	4.00E-01	7.33E-04	1.22E-01	2.75E-03
BATCH-796	7/5/28	141	14.7	0.24	0.00E+00	0.00E+00	3.00E-02	5.00E-03	2.25E+00	2.95E-01	7.83E+02	2.04E-01	2.40E-02	4.50E+00	5.45E-15	2.95E-01	3.67E-04	6.80E-02	2.50E-03
BATCH-797	7/6/28	52	5.4	0.24	0.00E+00	0.00E+00	5.30E-02	1.10E-02	4.02E+00	1.40E-01	1.03E+03	3.90E-01	4.80E-02	5.13E+00	1.11E-14	4.08E-01	7.48E-04	1.24E-01	2.75E-03
BATCH-798	7/11/28	13	1.3	0.24	0.00E+00	0.00E+00	2.00E-03	3.60E-04	1.32E-01	1.71E-02	3.92E+01	1.30E-02	2.00E-03	2.55E-01	3.58E-16	1.30E-02	2.40E-05	5.00E-03	9.25E-05
BATCH-799	7/13/28	56	5.8	0.24	0.00E+00	0.00E+00	5.80E-02	1.20E-02	4.36E+00	1.53E-01	1.12E+03	4.23E-01	5.20E-02	5.57E+00	1.20E-14	4.42E-01	8.10E-04	1.35E-01	3.00E-03
BATCH-800	7/19/28	144	15.0	0.24	0.00E+00	0.00E+00	3.10E-02	6.00E-03	2.33E+00	2.33E-01	7.80E+02	2.15E-01	2.60E-02	4.44E+00	5.83E-15	2.92E-01	3.93E-04	7.00E-02	2.50E-03
BATCH-801	7/20/28	144	15.0	0.24	0.00E+00	0.00E+00	3.10E-02	6.00E-03	2.33E+00	2.32E-01	7.78E+02	2.14E-01	2.50E-02	4.42E+00	5.81E-15	2.91E-01	3.92E-04	6.90E-02	2.50E-03
BATCH-802	8/3/28	148	15.4	0.24	0.00E+00	0.00E+00	2.90E-02	5.00E-03	2.17E+00	1.51E-01	8.16E+02	1.94E-01	2.20E-02	4.09E+00	4.94E-15	3.38E-01	3.34E-04	5.00E-02	3.00E-03
BATCH-803	8/4/28	80	8.3	0.24	0.00E+00	0.00E+00	8.20E-02	1.70E-02	6.23E+00	2.18E-01	1.59E+03	6.04E-01	7.40E-02	7.94E+00	1.72E-14	6.31E-01	1.00E-03	1.92E-01	4.50E-03
BATCH-804	8/12/28	131	13.7	0.24	0.00E+00	0.00E+00	2.30E-02	4.00E-03	1.73E+00	1.49E-01	7.21E+02	1.48E-01	1.60E-02	3.43E+00	3.55E-15	3.13E-01	2.41E-04	3.30E-02	3.00E-03
BATCH-805	8/19/28	48	5.0	0.24	0.00E+00	0.00E+00	9.00E-03	2.00E-03	6.81E-01	8.91E-02	2.37E+02	6.20E-02	7.00E-03	1.36E+00	1.65E-15	8.90E-02	1.11E-04	2.10E-02	7.50E-04
BATCH-806	8/24/28	48	5.0	0.24	0.00E+00	0.00E+00	9.00E-03	2.00E-03	6.91E-01	6.93E-02	2.31E+02	6.40E-02	8.00E-03	1.31E+00	1.73E-15	8.60E-02	1.16E-04	2.10E-02	7.50E-04
BATCH-807	8/26/28	48	5.0	0.24	0.00E+00	0.00E+00	9.00E-03	2.00E-03	6.88E-01	6.84E-02	2.30E+02	6.30E-02	8.00E-03	1.31E+00	1.72E-15	8.60E-02	1.16E-04	2.10E-02	7.50E-04
BATCH-808	8/29/28	61	6.4	0.24	0.00E+00	0.00E+00	6.30E-02	1.30E-02	4.79E+00	1.67E-01	1.23E+03	4.65E-01	5.70E-02	6.11E+00	1.32E-14	4.85E-01	8.90E-04	1.48E-01	3.25E-03
BATCH-809	8/31/28	50	5.2	0.24	0.00E+00	0.00E+00	9.00E-03	1.00E-03	6.49E-01	4.50E-02	2.44E+02	5.80E-02	6.00E-03	1.22E+00	1.47E-15	1.01E-01	9.98E-05	1.50E-02	1.00E-03
BATCH-810	9/5/28	17	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	3.88E-04	1.60E-01	2.07E-02	5.56E+01	1.40E-02	2.00E-03	3.19E-01	3.87E-16	2.10E-02	2.60E-05	5.00E-03	1.81E-04
BATCH-811	9/5/28	53	5.5	0.24	0.00E+00	0.00E+00	8.00E-03	1.00E-03	6.31E-01	5.40E-02	2.63E+02	5.40E-02	6.00E-03	1.25E+00	1.29E-15	1.14E-01	8.77E-05	1.20E-02	1.00E-03
BATCH-812	9/7/28	17	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	4.07E-04	1.62E-01	1.62E-02	5.42E+01	1.50E-02	2.00E-03	3.08E-01	4.05E-16	2.00E-02	2.73E-05	5.00E-03	1.69E-04
BATCH-813	9/9/28	17	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	4.06E-04	1.62E-01	1.62E-02	5.41E+01	1.50E-02	2.00E-03	3.07E-01	4.04E-16	2.00E-02	2.72E-05	5.00E-03	1.68E-04
BATCH-814	9/11/28	17	1.8	0.24	0.00E+00	0.00E+00	2.00E-03	3.49E-04	1.53E-01	1.08E-02	5.76E+01	1.40E-02	2.00E-03	2.89E-01	3.48E-16	2.40E-02	2.36E-05	4.00E-03	2.17E-04
BATCH-815	9/11/28	41	4.3	0.24	0.00E+00	0.00E+00	4.20E-02	9.00E-03	3.19E+00	1.12E-01	8.20E+02	3.09E-01	3.80E-02	4.09E+00	8.76E-15	3.24E-01	5.91E-04	9.80E-02	2.25E-03
BATCH-816	9/13/28	157	16.4	0.24	0.00E+00	0.00E+00	7.70E-02	1.00E-02	5.85E+00	3.65E-01	2.68E+03	4.80E-01	4.80E-02	1.15E+01	1.09E-14	1.23E+00	7.20E-04	7.30E-02	1.23E-02
BATCH-817	9/16/28	157	16.4	0.24	0.00E+00	0.00E+00	7.70E-02	1.00E-02	5.85E+00	3.65E-01	2.68E+03	4.80E-01	4.80E-02	1.15E+01	1.08E-14	1.23E+00	7.19E-04	7.30E-02	1.23E-02
BATCH-818	9/29/28	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	3.08E-04	1.51E-01	1.26E-02	6.27E+01	1.30E-02	1.00E-03	2.98E-01	3.09E-16	2.70E-02	2.09E-05	3.00E-03	2.50E-04
BATCH-819	10/1/28	157	16.4	0.24	0.00E+00	0.00E+00	7.70E-02	1.00E-02	5.85E+00	3.65E-01	2.68E+03	4.79E-01	4.80E-02	1.15E+01	1.08E-14	1.23E+00	7.19E-04	7.30E-02	1.23E-02
BATCH-820	10/2/28	157	16.4	0.24	0.00E+00	0.00E+00	7.70E-02	1.00E-02	5.84E+00	3.64E-01	2.68E+03	4.79E-01	4.80E-02	1.15E+01	1.08E-14	1.23E+00	7.18E-04	7.30E-02	1.23E-02
BATCH-821	10/18/28	174	18.1	0.24	0.00E+00	0.00E+00	4.50E-02	9.00E-03	3.41E+00	1.20E-01	9.85E+02	3.31E-01	4.10E-02	5.71E+00	9.39E-15	3.45E-01	6.34E-04	1.05E-01	2.50E-03
BATCH-822	10/19/28	132	13.8	0.24	0.00E+00	0.00E+00	6.50E-02	9.00E-03	4.91E+00	3.06E-01	2.25E+03	4.02E-01	4.00E-02	9.63E+00	9.09E-15	1.03E+00	6.03E-04	6.10E-02	1.03E-02
BATCH-823	11/2/28	120	12.5	0.24	0.00E+00	0.00E+00	6.00E-02	8.00E-03	4.55E+00	2.80E-01	2.07E+03	3.75E-01	3.80E-02	8.89E+00	8.52E-15	9.46E-01	5.67E-04	5.90E-02	9.50E-03
BATCH-824	11/5/28	143	14.9	0.24	0.00E+00	0.00E+00	8.00E-02	1.20E-02	6.04E+00	3.47E-01	2.61E+03	5.16E-01	5.40E-02	1.15E+01	1.22E-14	1.15E+00	8.22E-04	9.70E-02	1.10E-02
BATCH-825	11/15/28	120	12.5	0.24	0.00E+00	0.00E+00	6.70E-02	1.00E-02	5.08E+00	2.91E-01	2.19E+03	4.34E-01	4.50E-02	9.68E+00	1.03E-14	9.67E-01	6.91E-04	8.20E-02	9.25E-03
BATCH-826	11/20/28	120	12.5	0.24	0.00E+00	0.00E+00	6.70E-02	1.00E-02	5.08E+00	2.91E-01	2.19E+03	4.34E-01	4.50E-02	9.67E+00	1.03E-14	9.67E-01	6.90E-04	8.20E-02	9.25E-03
BATCH-827	11/27/28	101	10.5	0.24	0.00E+00	0.00E+00	5.60E-02	8.00E-03	4.27E+00	2.45E-01	1.84E+03	3.65E-01	3.80E-02	8.13E+00	8.62E-15	8.12E-01	5.80E-04	6.90E-02	7.75E-03
BATCH-828	12/3/28	42	4.3	0.24	0.00E+00	0.00E+00	1.00E-02	2.00E-03	7.22E-01	2.52E-02	2.08E+02	7.00E-02	9.00E-03	1.21E+00	1.99E-15	7.30E-02	1.34E-04	2.20E-02	5.00E-04
BATCH-829	12/8/28	93	9.7	0.24	0.00E+00	0.00E+00	5.20E-02	8.00E-03	3.94E+00	2.25E-01	1.70E+03	3.36E-01	3.50E-02	7.49E+00	7.94E-15	7.49E-01	5.35E-04	6.30E-02	7.25E-03
BATCH-830	12/8/28	118	12.3	0.24	0.00E+00	0.00E+00	6.60E-02	1.00E-02	4.99E+00	2.86E-01	2.16E+03	4.27E-01	4.50E-02	9.51E+00	1.01E-14	9.50E-01	6.79E-04	8.10E-02	9.25E-03
BATCH-831	12/18/28	86	9.0	0.24	0.00E+00	0.00E+00	4.80E-02	7.00E-03	3.62E+00	2.43E-01	1.62E+03	3.11E-01	3.20E-02	7.13E+00	1.06E-14	6.70E-01	4.80E-04	6.20E-02	6.50E-03
BATCH-832	12/21/28	49	5.1	0.24	0.00E+00	0.00E+00	2.30E-02	2.00E-03	1.71E+00	4.95E-01	9.81E+02	1.59E-01	8.00E-03	4.89E+00	3.99E-14	1.09E-01	9.95E-05	7.20E-02	2.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization			Losses																
BATCH-784	4/26/28	97	10.1	0.24	3.84E-08	2.91E+02	7.62E+01	5.10E-02	2.73E+00	3.38E-01	6.04E-06	2.54E-06	1.80E-04	5.67E-05	5.38E-05	1.33E-04	4.00E-03	2.30E-02	1.10E-02
BATCH-784		166	17.3	0.24	6.06E-08	4.96E+02	3.46E+01	5.00E-02	2.69E+00	3.47E-01	7.72E-06	1.18E-06	3.06E-04	6.54E-05	5.37E-05	1.53E-04	2.00E-03	1.20E-02	8.00E-03
BATCH-785	5/3/28	166	17.3	0.24	6.06E-08	4.96E+02	3.46E+01	5.00E-02	2.68E+00	3.47E-01	7.72E-06	1.18E-06	3.06E-04	6.53E-05	5.36E-05	1.53E-04	2.00E-03	1.20E-02	8.00E-03
BATCH-786	5/7/28	165	17.3	0.24	6.06E-08	4.96E+02	3.46E+01	5.00E-02	2.68E+00	3.47E-01	7.72E-06	1.18E-06	3.06E-04	6.53E-05	5.36E-05	1.01E-04	6.00E-03	3.10E-02	1.20E-02
BATCH-787	5/21/28	117	12.2	0.24	1.44E-08	3.51E+02	1.05E+02	4.60E-02	2.47E+00	2.93E-01	3.90E-06	3.49E-06	4.76E-05	4.28E-05	4.80E-05	1.16E-04	2.00E-03	9.00E-03	6.00E-03
BATCH-788	5/24/28	125	13.0	0.24	4.57E-08	3.74E+02	2.63E+01	3.80E-02	2.03E+00	2.62E-01	5.83E-06	8.92E-07	2.31E-04	4.94E-05	4.05E-05	1.16E-04	2.00E-03	9.00E-03	6.00E-03
BATCH-789	6/2/28	125	13.0	0.24	4.57E-08	3.74E+02	2.63E+01	3.80E-02	2.03E+00	2.62E-01	5.83E-06	8.92E-07	2.31E-04	4.94E-05	4.05E-05	1.16E-04	2.00E-03	9.00E-03	6.00E-03
BATCH-790	6/7/28	95	9.9	0.24	3.48E-08	2.85E+02	2.00E+01	2.90E-02	1.55E+00	2.00E-01	4.44E-06	6.77E-07	1.76E-04	3.76E-05	3.09E-05	8.80E-05	1.00E-03	7.00E-03	5.00E-03
BATCH-791	6/16/28	138	14.4	0.24	5.04E-08	4.13E+02	2.88E+01	4.20E-02	2.23E+00	2.89E-01	6.42E-06	9.78E-07	2.54E-04	5.44E-05	4.47E-05	1.27E-04	2.00E-03	1.00E-02	7.00E-03
BATCH-792	6/17/28	79	8.2	0.24	3.71E-08	2.36E+02	2.19E+02	2.50E-02	1.34E+00	1.02E-01	6.60E-06	7.24E-06	1.41E-04	8.15E-05	1.06E-04	2.28E-04	1.20E-02	6.20E-02	2.00E-02
BATCH-793	6/25/28	35	3.7	0.24	3.82E-09	1.05E+02	2.78E+01	1.20E-02	6.54E-01	7.80E-02	1.03E-06	9.24E-07	1.26E-05	1.13E-05	1.27E-05	2.68E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-794	6/29/28	51	5.3	0.24	2.63E-08	1.52E+02	2.01E+02	1.60E-02	8.81E-01	4.70E-02	5.11E-06	6.64E-06	8.87E-05	6.72E-05	9.18E-05	1.93E-04	1.10E-02	5.70E-02	1.70E-02
BATCH-795	6/30/28	51	5.3	0.24	2.63E-08	1.52E+02	2.01E+02	1.60E-02	8.81E-01	4.70E-02	5.11E-06	6.64E-06	8.87E-05	6.73E-05	9.18E-05	1.93E-04	1.10E-02	5.70E-02	1.70E-02
BATCH-796	7/5/28	141	14.7	0.24	1.88E-08	4.22E+02	9.05E+01	4.40E-02	2.34E+00	2.81E-01	4.09E-06	3.01E-06	7.41E-05	4.27E-05	4.57E-05	1.01E-04	5.00E-03	2.60E-02	1.10E-02
BATCH-796		141	14.7	0.24	1.88E-08	4.22E+02	9.05E+01	1.60E-02	8.98E-01	4.80E-02	5.21E-06	6.78E-06	9.04E-05	6.86E-05	9.37E-05	1.97E-04	1.10E-02	5.80E-02	1.80E-02
BATCH-797	7/6/28	52	5.4	0.24	2.68E-08	1.55E+02	2.05E+02	3.00E-03	1.55E-01	1.80E-02	2.45E-07	2.19E-07	3.00E-06	2.69E-06	3.02E-06	6.35E-06	3.60E-04	2.00E-03	7.40E-04
BATCH-798	7/11/28	13	1.3	0.24	9.05E-10	3.80E+01	6.61E+00	3.00E-03	1.55E-01	1.80E-02	2.45E-07	2.19E-07	3.00E-06	2.69E-06	3.02E-06	2.13E-04	1.20E-02	6.30E-02	1.90E-02
BATCH-799	7/13/28	56	5.8	0.24	2.91E-08	1.68E+02	2.22E+02	1.80E-02	9.74E-01	5.20E-02	5.65E-06	7.34E-06	9.81E-05	7.44E-05	1.02E-04	2.13E-04	1.07E-04	5.00E-03	2.90E-02
BATCH-800	7/19/28	144	15.0	0.24	1.86E-08	4.32E+02	9.96E+01	3.30E-02	1.78E+00	2.03E-01	3.84E-06	3.30E-06	7.15E-05	4.25E-05	4.90E-05	1.06E-04	5.00E-03	2.90E-02	1.10E-02
BATCH-800		144	15.0	0.24	1.85E-08	4.31E+02	9.92E+01	3.30E-02	1.77E+00	2.02E-01	3.83E-06	3.29E-06	7.13E-05	4.24E-05	4.89E-05	1.06E-04	5.00E-03	2.90E-02	1.10E-02
BATCH-801	7/20/28	148	15.4	0.24	1.99E-08	4.44E+02	7.52E+01	1.50E-02	7.86E-01	7.90E-02	3.15E-06	2.49E-06	8.55E-05	3.49E-05	4.12E-05	9.38E-05	4.00E-03	1.70E-02	8.90E-02
BATCH-802	8/3/28	80	8.3	0.24	4.15E-08	2.39E+02	3.17E+02	2.50E-02	1.39E+00	7.40E-02	8.07E-06	1.05E-05	1.40E-04	1.06E-04	1.45E-04	7.02E-05	3.00E-03	1.40E-02	5.00E-03
BATCH-803	8/4/28	131	13.7	0.24	1.79E-08	3.93E+02	4.69E+01	1.40E-02	7.38E-01	8.20E-02	2.63E-06	1.56E-06	8.18E-05	2.70E-05	2.94E-05	7.02E-05	3.00E-03	8.00E-03	3.00E-03
BATCH-804	8/12/28	48	5.0	0.24	5.68E-09	1.44E+02	2.74E+01	1.30E-02	7.08E-01	8.50E-02	1.24E-06	9.10E-07	2.24E-05	1.29E-05	1.38E-05	3.05E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-805	8/19/28	48	5.0	0.24	5.68E-09	1.44E+02	2.74E+01	1.30E-02	7.08E-01	8.50E-02	1.14E-06	9.77E-07	2.12E-05	1.26E-05	1.45E-05	3.16E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-806	8/24/28	48	5.0	0.24	5.49E-09	1.44E+02	2.95E+01	1.00E-02	5.24E-01	6.00E-02	1.13E-06	9.73E-07	2.11E-05	1.25E-05	1.45E-05	3.15E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-807	8/26/28	48	5.0	0.24	5.48E-09	1.44E+02	2.94E+01	1.00E-02	5.24E-01	6.00E-02	1.08E-06	8.07E-06	1.08E-04	8.17E-05	1.12E-04	2.34E-04	1.30E-02	6.90E-02	2.10E-02
BATCH-808	8/29/28	61	6.4	0.24	3.19E-08	1.84E+02	2.44E+02	2.00E-02	1.07E+00	5.70E-02	6.21E-06	8.07E-06	2.56E-06	1.04E-05	1.23E-05	2.80E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-808	8/31/28	50	5.2	0.24	5.96E-09	1.49E+02	2.25E+01	4.00E-03	2.35E-01	2.30E-02	2.90E-07	2.14E-07	5.26E-06	3.03E-06	3.24E-06	7.15E-06	3.53E-04	2.00E-03	7.55E-04
BATCH-809	9/5/28	17	1.7	0.24	1.33E-09	4.95E+01	6.43E+00	3.00E-03	1.66E-01	2.00E-02	9.59E-07	5.67E-07	2.98E-05	9.85E-06	1.07E-05	2.56E-05	9.33E-04	5.00E-03	2.00E-03
BATCH-810	9/5/28	53	5.5	0.24	6.54E-09	1.59E+02	1.71E+01	5.00E-03	2.69E-01	3.00E-02	2.67E-07	2.29E-07	4.97E-06	2.95E-06	3.41E-06	7.41E-06	3.75E-04	2.00E-03	7.34E-04
BATCH-811	9/7/28	17	1.7	0.24	1.29E-09	4.96E+01	6.92E+00	2.00E-03	1.24E-01	1.40E-02	2.67E-07	2.29E-07	4.96E-06	2.94E-06	3.40E-06	7.39E-06	3.74E-04	2.00E-03	7.32E-04
BATCH-812	9/9/28	17	1.7	0.24	1.29E-09	4.96E+01	6.90E+00	2.00E-03	1.23E-01	1.40E-02	2.66E-07	2.22E-07	1.76E-07	6.03E-06	2.46E-06	6.62E-06	2.86E-04	2.00E-03	5.24E-04
BATCH-813	9/11/28	17	1.8	0.24	1.41E-09	5.10E+01	5.31E+00	1.00E-03	5.50E-02	6.00E-03	2.22E-07	1.76E-07	7.21E-05	5.43E-05	7.40E-05	1.56E-04	9.00E-03	4.60E-02	1.40E-02
BATCH-814		41	4.3	0.24	2.13E-08	1.23E+02	1.62E+02	1.30E-02	7.09E-01	3.80E-02	4.13E-06	5.35E-06	3.26E-04	7.91E-05	8.60E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-815	9/11/28	157	16.4	0.24	8.31E-08	4.72E+02	1.09E+02	9.00E-03	4.77E-01	2.50E-02	8.77E-06	3.60E-06	3.26E-04	7.91E-05	8.60E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-816	9/13/28	157	16.4	0.24	8.31E-08	4.72E+02	1.09E+02	9.00E-03	4.77E-01	2.50E-02	8.76E-06	3.60E-06	3.26E-04	7.91E-05	8.60E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-817	9/16/28	18	1.9	0.24	1.56E-09	5.34E+01	4.08E+00	1.00E-03	6.40E-02	7.00E-03	2.29E-07	1.35E-07	7.11E-06	2.35E-06	2.56E-06	6.10E-06	2.23E-04	1.00E-03	4.47E-04
BATCH-818	9/29/28	157	16.4	0.24	8.30E-08	4.71E+02	1.09E+02	9.00E-03	4.76E-01	2.50E-02	8.76E-06	3.60E-06	3.26E-04	7.90E-05	8.60E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-819	10/1/28	157	16.4	0.24	8.30E-08	4.71E+02	1.09E+02	9.00E-03	4.76E-01	2.50E-02	8.75E-06	3.59E-06	3.26E-04	7.90E-05	8.59E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-820	10/2/28	157	16.4	0.24	8.30E-08	4.71E+02	1.09E+02	9.00E-03	4.76E-01	2.50E-02	8.75E-06	3.59E-06	3.26E-04	7.90E-05	8.59E-05	2.18E-04	6.00E-03	3.30E-02	1.10E-02
BATCH-821	10/18/28	174	18.1	0.24	2.27E-08	5.21E+02	1.74E+02	1.40E-02	7.61E-01	4.00E-02	4.42E-06	5.74E-06	7.66E-05	5.82E-05	7.94E-05	1.83E-04	5.00E-03	2.70E-02	9.00E-03
BATCH-821		174	18.1	0.24	2.27E-08	5.21E+02	1.74E+02	1.40E-02	7.61E-01	4.00E-02	7.35E-06	3.02E-06	2.74E-04	6.63E-05	7.21E-05	1.71E-04	5.00E-03	2.60E-02	8.00E-03
BATCH-822	10/19/28	132	13.8	0.24	6.97E-08	3.96E+02	9.13E+01	7.00E-03	4.00E-01	2.10E-02	6.85E-06	2.92E-06	2.50E-04	6.19E-05	6.79E-05	1.71E-04	5.00E-03	2.60E-02	8.00E-03
BATCH-823	11/2/28	120	12.5	0.24	6.38E-08	3.61E+02	8.83E+01	7.00E-03	3.87E-01	2.00E-02	9.49E-06	5.01E-06	2.97E-04	8.61E-05	9.94E-05	2.40E-04	8.00E-03	4.50E-02	1.40E-02
BATCH-824	11/5/28	143	14.9	0.24	7.75E-08	4.28E+02	1.52E+02	1.20E-02	6.64E-01	3.50E-02	7.98E-06	4.21E-06	2.49E-04	7.24E-05	8.36E-05	2.02E-04	7.00E-03	3.80E-02	1.20E-02
BATCH-825	11/15/28	120	12.5	0.24	6.51E-08	3.60E+02	1.27E+02	1.00E-02	5.58E-01	2.90E-02	7.98E-06	4.21E-06	2.49E-04	7.24E-05	8.35E-05	2.02E-04	7.00E-03	3.80E-02	1.20E-02
BATCH-826	11/20/28	120	12.5	0.24	6.51E-08	3.60E+02	1.27E+02	1.00E-02	5.58E-01	2.90E-02	6.70E-06	3.54E-06	2.09E-04	6.08E-05	7.02E-05	1.69E-04	6.00E-03	3.20E-02	1.00E-02
BATCH-827	11/27/28	101	10.5	0.24	5.47E-08	3.02E+02	1.07E+02	8.00E-03	4.69E-01	2.50E-02	6.70E-06	1.22E-06	1.62E-05	1.23E-05	1.68E-05	3.53E-05	2.00E-03	1.00E-02	3.00E-03
BATCH-828	12/3/28	42	4.3	0.24	4.81E-09	1.25E+02	3.68E+01	3.00E-03	1.61E-01	9.00E-03	9.35E-07	1.22E-06	1.93E-04	5.61E-05	6.47E-05	1.56E-04	5.00E-03	2.90E-02	9.00E-03
BATCH-829	12/8/28	93	9.7	0.24	5.04E-08	2.79E+02	9.86E+01	8.00E-03	4.32E-01	2.30E-02	6.18E-06	3.26E-06	2.45E-04	7.12E-05	8.21E-05	1.98E-04	7.00E-03	3.70E-02	1.20E-02
BATCH-830	12/8/28	118	12.3	0.24	6.40E-08	3.54E+02	1.25E+02	1.00E-02	5.49E-01	2.90E-02	7.84E-06	4.14E-06	1.72E-04	5.03E-05	5.84E-05	1.40E-04	5.00E-03	2.60E-02	9.00E-03
BATCH-831	12/18/28	86	9.0	0.24	4.77E-08	2.59E+02	8.89E+01	7.00E-03	3.90E-01	2.00E-02	7.80E-05	2.94E-06	1.72E-04	5.03E-05	5.84E-05	1.40E-04	5.00E-03	2.60E-02	9.00E-03
BATCH-832	12/21/28	49	5.1	0.24	3.60E-08	1.47E+02	2.19E+01	2.00E-03	9.60E-02	5.00E-03	8.02E-04	7.25E-07	2.48E-05	9.73E-06	1.46E-05	2.73E-05	1.00E-03	7.00E-03	7.00E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-784	4/26/28	97	10.1	0.24	3.37E-04	2.24E-04	1.50E-02	1.40E-02	1.20E-02	6.40E-01	1.08E-01	4.34E+00	2.50E-01	6.52E-26	5.67E-06	2.30E-04	1.98E-04	1.00E-03	9.69E-11
BATCH-785	5/3/28	166	17.3	0.24	2.32E-04	1.25E-04	1.80E-02	1.10E-02	9.00E-03	5.14E-01	8.60E-02	4.35E+00	1.93E-01	7.70E-26	3.98E-06	2.34E-04	2.42E-04	2.00E-03	8.82E-11
BATCH-786	5/7/28	165	17.3	0.24	2.32E-04	1.25E-04	1.80E-02	1.10E-02	9.00E-03	5.14E-01	8.60E-02	4.34E+00	1.93E-01	7.70E-26	3.98E-06	2.34E-04	2.41E-04	2.00E-03	8.81E-11
BATCH-787	5/21/28	117	12.2	0.24	3.94E-04	2.89E-04	1.00E-02	1.60E-02	1.30E-02	6.84E-01	1.17E-01	3.87E+00	2.73E-01	4.76E-26	6.56E-06	2.02E-04	1.38E-04	1.00E-03	9.42E-11
BATCH-788	5/24/28	125	13.0	0.24	1.75E-04	9.48E-05	1.40E-02	8.00E-03	7.00E-03	3.89E-01	6.50E-02	3.28E+00	1.46E-01	5.82E-26	3.01E-06	1.77E-04	1.82E-04	1.00E-03	6.66E-11
BATCH-789	6/2/28	125	13.0	0.24	1.75E-04	9.48E-05	1.40E-02	8.00E-03	7.00E-03	3.89E-01	6.50E-02	3.28E+00	1.46E-01	5.82E-26	3.01E-06	1.77E-04	1.82E-04	1.00E-03	6.66E-11
BATCH-790	6/7/28	95	9.9	0.24	1.33E-04	7.21E-05	1.10E-02	6.00E-03	5.00E-03	2.96E-01	4.90E-02	2.50E+00	1.11E-01	4.43E-26	2.29E-06	1.35E-04	1.39E-04	9.23E-04	5.07E-11
BATCH-791	6/16/28	138	14.4	0.24	1.93E-04	1.04E-04	1.50E-02	9.00E-03	7.00E-03	4.28E-01	7.10E-02	3.62E+00	1.61E-01	6.41E-26	3.31E-06	1.95E-04	2.01E-04	1.00E-03	7.34E-11
BATCH-792	6/17/28	79	8.2	0.24	7.86E-04	5.89E-04	2.30E-02	2.80E-02	2.30E-02	1.26E+00	2.13E-01	1.93E+00	4.89E-01	7.53E-26	1.36E-05	8.29E-05	2.21E-04	1.00E-03	1.88E-11
BATCH-793	6/25/28	35	3.7	0.24	1.05E-04	7.65E-05	3.00E-03	4.00E-03	3.00E-03	1.81E-01	3.10E-02	1.03E+00	7.20E-02	1.26E-26	1.74E-06	5.34E-05	3.66E-05	2.78E-04	2.50E-11
BATCH-794	6/29/28	51	5.3	0.24	7.05E-04	5.35E-04	1.90E-02	2.50E-02	2.00E-02	1.11E+00	1.88E-01	1.19E+00	4.32E-01	5.98E-26	1.22E-05	4.45E-05	1.74E-04	1.00E-03	5.08E-12
BATCH-795	6/30/28	51	5.3	0.24	7.06E-04	5.36E-04	1.90E-02	2.50E-02	2.00E-02	1.11E+00	1.89E-01	1.19E+00	4.32E-01	5.98E-26	1.22E-05	4.45E-05	1.74E-04	1.00E-03	5.08E-12
BATCH-796	7/5/28	141	14.7	0.24	3.51E-04	2.52E-04	1.00E-02	1.40E-02	1.20E-02	6.22E-01	1.06E-01	3.68E+00	2.47E-01	4.80E-26	5.86E-06	1.93E-04	1.41E-04	1.00E-03	8.77E-11
BATCH-797	7/6/28	52	5.4	0.24	7.20E-04	5.47E-04	2.00E-02	2.60E-02	2.00E-02	1.13E+00	1.92E-01	1.22E+00	4.41E-01	6.10E-26	1.24E-05	4.54E-05	1.77E-04	1.00E-03	5.15E-12
BATCH-798	7/11/28	13	1.3	0.24	2.48E-05	1.82E-05	6.38E-04	9.89E-04	8.26E-04	4.30E-02	7.00E-03	2.43E-01	1.70E-02	2.99E-27	4.13E-07	1.27E-05	8.69E-06	6.59E-05	5.92E-12
BATCH-799	7/13/28	56	5.8	0.24	7.80E-04	5.92E-04	2.10E-02	2.80E-02	2.20E-02	1.23E+00	2.08E-01	1.32E+00	4.78E-01	6.61E-26	1.35E-05	4.92E-05	1.92E-04	1.00E-03	5.61E-12
BATCH-800	7/19/28	144	15.0	0.24	3.74E-04	2.73E-04	1.10E-02	1.50E-02	1.20E-02	6.37E-01	1.09E-01	2.77E+00	2.51E-01	4.48E-26	6.32E-06	1.42E-04	1.32E-04	9.32E-04	6.12E-11
BATCH-801	7/20/28	144	15.0	0.24	3.73E-04	2.72E-04	1.10E-02	1.40E-02	1.20E-02	6.35E-01	1.08E-01	2.75E+00	2.50E-01	4.47E-26	6.29E-06	1.41E-04	1.31E-04	9.28E-04	6.09E-11
BATCH-802	8/3/28	148	15.4	0.24	2.84E-04	2.07E-04	1.00E-02	1.10E-02	8.00E-03	4.74E-01	8.00E-02	1.19E+00	1.83E-01	3.44E-26	4.90E-06	5.75E-05	1.03E-04	6.56E-04	1.76E-11
BATCH-803	8/4/28	80	8.3	0.24	1.00E-03	8.46E-04	3.10E-02	4.00E-02	3.20E-02	1.76E+00	2.98E-01	1.88E+00	6.82E-01	9.45E-26	1.93E-05	7.02E-05	2.74E-04	2.00E-03	7.96E-12
BATCH-804	8/12/28	131	13.7	0.24	1.88E-04	1.32E-04	8.00E-03	7.00E-03	6.00E-03	3.27E-01	5.50E-02	1.15E+00	1.26E-01	2.80E-26	3.24E-06	5.81E-05	8.50E-05	5.48E-04	1.96E-11
BATCH-805	8/19/28	48	5.0	0.24	1.06E-04	7.63E-05	3.00E-03	4.00E-03	4.00E-03	1.88E-01	3.20E-02	1.11E+00	7.50E-02	1.45E-26	1.77E-06	5.83E-05	4.28E-05	3.17E-04	2.65E-11
BATCH-806	8/24/28	48	5.0	0.24	1.11E-04	8.08E-05	3.00E-03	4.00E-03	4.00E-03	1.88E-01	3.20E-02	8.18E-01	7.40E-02	1.33E-26	1.87E-06	4.19E-05	3.90E-05	2.76E-04	1.81E-11
BATCH-807	8/26/28	48	5.0	0.24	1.10E-04	8.05E-05	3.00E-03	4.00E-03	4.00E-03	1.88E-01	3.20E-02	8.14E-01	7.40E-02	1.32E-26	1.86E-06	4.17E-05	3.89E-05	2.75E-04	1.80E-11
BATCH-808	8/29/28	61	6.4	0.24	8.58E-04	6.51E-04	2.40E-02	3.10E-02	2.40E-02	1.35E+00	2.29E-01	1.45E+00	5.25E-01	7.27E-26	1.48E-05	5.40E-05	2.11E-04	1.00E-03	6.12E-12
BATCH-809	8/31/28	50	5.2	0.24	8.49E-05	6.17E-05	3.00E-03	3.00E-03	3.00E-03	1.42E-01	2.40E-02	3.56E-01	5.50E-02	1.03E-26	1.47E-06	1.72E-05	3.08E-05	1.96E-04	5.26E-12
BATCH-810	9/5/28	17	1.7	0.24	2.49E-05	1.79E-05	7.43E-04	1.00E-03	8.38E-04	4.40E-02	8.00E-03	2.61E-01	1.80E-02	3.41E-27	4.16E-07	1.37E-05	1.00E-05	7.43E-05	6.22E-12
BATCH-811	9/5/28	53	5.5	0.24	6.85E-05	4.81E-05	3.00E-03	3.00E-03	2.00E-03	1.19E-01	2.00E-02	4.19E-01	4.60E-02	1.02E-26	1.18E-06	2.12E-05	3.10E-05	2.00E-04	7.13E-12
BATCH-812	9/7/28	17	1.7	0.24	2.60E-05	1.90E-05	7.64E-04	1.00E-03	8.25E-04	4.40E-02	8.00E-03	1.92E-01	1.70E-02	3.11E-27	4.39E-07	9.83E-06	9.16E-06	6.47E-05	4.25E-12
BATCH-813	9/9/28	17	1.7	0.24	2.59E-05	1.89E-05	7.62E-04	1.00E-03	8.23E-04	4.40E-02	8.00E-03	1.91E-01	1.70E-02	3.10E-27	4.38E-07	9.79E-06	9.13E-06	6.45E-05	4.23E-12
BATCH-814	9/11/28	17	1.8	0.24	2.00E-05	1.46E-05	7.03E-04	7.52E-04	5.96E-04	3.30E-02	6.00E-03	8.40E-02	1.30E-02	2.43E-27	3.46E-07	4.06E-06	7.28E-06	4.63E-05	1.24E-12
BATCH-815	9/11/28	41	4.3	0.24	5.68E-04	4.31E-04	1.60E-02	2.00E-02	1.60E-02	8.95E-01	1.52E-01	9.58E-01	3.48E-01	4.83E-26	9.82E-06	3.58E-05	1.40E-04	8.64E-04	4.17E-12
BATCH-816	9/13/28	157	16.4	0.24	4.31E-04	3.11E-04	2.50E-02	1.70E-02	1.20E-02	8.02E-01	1.33E-01	7.10E-01	2.96E-01	8.84E-26	8.35E-06	2.65E-05	2.71E-04	2.00E-03	4.32E-11
BATCH-817	9/16/28	157	16.4	0.24	4.31E-04	3.11E-04	2.50E-02	1.70E-02	1.20E-02	8.01E-01	1.33E-01	7.10E-01	2.96E-01	8.83E-26	8.34E-06	2.64E-05	2.71E-04	2.00E-03	4.32E-11
BATCH-818	9/29/28	18	1.9	0.24	1.63E-05	1.15E-05	6.69E-04	6.36E-04	5.02E-04	2.80E-02	5.00E-03	1.00E-01	1.10E-02	2.43E-27	2.82E-07	5.05E-06	7.40E-06	4.77E-05	1.70E-12
BATCH-819	10/1/28	157	16.4	0.24	4.31E-04	3.10E-04	2.50E-02	1.70E-02	1.20E-02	8.01E-01	1.33E-01	7.09E-01	2.96E-01	8.83E-26	8.34E-06	2.64E-05	2.71E-04	2.00E-03	4.32E-11
BATCH-820	10/2/28	157	16.4	0.24	4.30E-04	3.10E-04	2.50E-02	1.70E-02	1.20E-02	8.00E-01	1.33E-01	7.09E-01	2.96E-01	8.82E-26	8.33E-06	2.64E-05	2.71E-04	2.00E-03	4.31E-11
BATCH-821	10/18/28	174	18.1	0.24	6.10E-04	4.63E-04	1.70E-02	2.20E-02	1.70E-02	9.61E-01	1.63E-01	1.03E+00	3.74E-01	5.17E-26	1.05E-05	3.84E-05	1.50E-04	9.24E-04	4.36E-12
BATCH-822	10/19/28	132	13.8	0.24	3.62E-04	2.60E-04	2.10E-02	1.50E-02	1.00E-02	6.72E-01	1.11E-01	5.95E-01	2.49E-01	7.41E-26	7.00E-06	2.22E-05	2.27E-04	1.00E-03	3.62E-11
BATCH-823	11/2/28	120	12.5	0.24	3.47E-04	2.51E-04	2.00E-02	1.40E-02	1.00E-02	6.40E-01	1.06E-01	5.73E-01	2.37E-01	6.88E-26	6.68E-06	2.13E-05	2.11E-04	1.00E-03	4.09E-11
BATCH-824	11/5/28	143	14.9	0.24	5.75E-04	4.23E-04	2.70E-02	2.20E-02	1.60E-02	1.01E+00	1.69E-01	9.52E-01	3.79E-01	9.26E-26	1.07E-05	3.55E-05	2.81E-04	2.00E-03	1.21E-10
BATCH-825	11/15/28	120	12.5	0.24	4.83E-04	3.56E-04	2.20E-02	1.90E-02	1.40E-02	8.49E-01	1.42E-01	8.00E-01	3.19E-01	7.78E-26	8.98E-06	2.99E-05	2.36E-04	1.00E-03	1.01E-10
BATCH-826	11/20/28	120	12.5	0.24	4.83E-04	3.56E-04	2.20E-02	1.90E-02	1.40E-02	8.49E-01	1.42E-01	8.00E-01	3.19E-01	7.78E-26	8.98E-06	2.98E-05	2.36E-04	1.00E-03	1.01E-10
BATCH-827	11/27/28	101	10.5	0.24	4.06E-04	2.99E-04	1.90E-02	1.60E-02	1.10E-02	7.13E-01	1.19E-01	6.72E-01	2.68E-01	6.54E-26	7.54E-06	2.51E-05	1.98E-04	1.00E-03	8.51E-11
BATCH-828	12/3/28	42	4.3	0.24	1.29E-04	9.80E-05	4.00E-03	5.00E-03	4.00E-03	2.03E-01	3.40E-02	2.18E-01	7.90E-02	1.09E-26	2.23E-06	8.13E-06	3.18E-05	1.96E-04	9.22E-13
BATCH-829	12/8/28	93	9.7	0.24	3.74E-04	2.76E-04	1.70E-02	1.40E-02	1.00E-02	6.58E-01	1.10E-01	6.20E-01	2.47E-01	6.03E-26	6.96E-06	2.31E-05	1.83E-04	1.00E-03	7.85E-11
BATCH-830	12/8/28	118	12.3	0.24	4.75E-04	3.50E-04	2.20E-02	1.80E-02	1.30E-02	8.35E-01	1.39E-01	7.87E-01	3.13E-01	7.65E-26	8.83E-06	2.93E-05	2.32E-04	1.00E-03	9.96E-11
BATCH-831	12/18/28	86	9.0	0.24	3.55E-04	2.67E-04	1.60E-02	1.30E-02	1.00E-02	5.92E-01	9.90E-02	6.11E-01	2.22E-01	5.50E-26	6.27E-06	2.30E-05	1.66E-04	1.00E-03	1.32E-08
BATCH-832	12/21/28	49	5.1	0.24	2.82E-04	2.66E-04	4.00E-03	3.00E-03	7.00E-03	1.41E-01	2.40E-02	7.13E-01	5.30E-02	2.03E-26	1.49E-06	2.91E-05	5.46E-05	5.49E-04	1.45E-07

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-784	4/26/28	97	10.1	0.24	2.35E-06	1.13E+02	1.83E-10	3.39E-08	2.26E-10	1.63E-21	4.00E-03	3.48E-01	1.78E-09	2.60E-02	2.62E+01	0.00E+00	1.11E-07	3.06E+00	1.40E-05
BATCH-785	5/3/28	166	17.3	0.24	6.00E-03	1.81E+02	2.95E-11	1.18E-08	1.76E-10	3.54E-28	7.00E-03	5.90E-01	1.26E-09	4.80E-02	4.56E+01	0.00E+00	1.37E-04	2.47E+00	6.34E-06
BATCH-786	5/7/28	165	17.3	0.24	4.00E-03	1.81E+02	2.95E-11	1.17E-08	1.75E-10	2.72E-24	7.00E-03	5.90E-01	1.26E-09	4.80E-02	4.56E+01	0.00E+00	1.28E-04	2.47E+00	6.34E-06
BATCH-787	5/21/28	117	12.2	0.24	5.40E+02	0.00E+00	3.00E-10	5.00E-08	2.46E-10	1.27E-19	3.20E-02	3.31E-01	2.05E-09	3.00E-03	6.01E+00	0.00E+00	1.88E+01	0.00E+00	1.93E-05
BATCH-788	5/24/28	125	13.0	0.24	4.15E-06	1.37E+02	2.27E-11	8.93E-09	1.33E-10	9.63E-22	5.00E-03	4.45E-01	9.54E-10	3.70E-02	3.44E+01	0.00E+00	1.80E-07	1.87E+00	4.81E-06
BATCH-789	6/2/28	125	13.0	0.24	2.00E-06	1.37E+02	2.27E-11	8.93E-09	1.33E-10	2.60E-22	5.00E-03	4.45E-01	9.54E-10	3.70E-02	3.44E+01	0.00E+00	7.38E-08	1.87E+00	4.81E-06
BATCH-790	6/7/28	95	9.9	0.24	1.74E-09	1.04E+02	1.71E-11	6.77E-09	1.01E-10	1.20E-24	4.00E-03	3.40E-01	7.26E-10	2.80E-02	2.62E+01	0.00E+00	8.19E-11	1.42E+00	3.65E-06
BATCH-791	6/16/28	138	14.4	0.24	2.96E-06	1.51E+02	2.45E-11	9.77E-09	1.46E-10	1.81E-31	6.00E-03	4.91E-01	1.05E-09	4.00E-02	3.79E+01	0.00E+00	7.01E-08	2.05E+00	5.28E-06
BATCH-792	6/17/28	79	8.2	0.24	1.76E-06	1.07E+02	1.79E-11	2.71E-04	3.90E-11	1.06E-27	2.00E-03	2.22E-01	3.20E-10	1.40E-02	1.96E+01	0.00E+00	4.99E-08	6.83E+00	2.70E-05
BATCH-793	6/25/28	35	3.7	0.24	1.43E+02	0.00E+00	7.96E-11	1.33E-08	6.53E-11	3.36E-20	8.00E-03	8.80E-02	5.42E-10	7.17E-04	1.59E+00	0.00E+00	4.99E+00	0.00E+00	5.13E-06
BATCH-794	6/29/28	51	5.3	0.24	2.60E-09	7.48E+01	1.26E-11	2.54E-04	1.17E-11	6.03E-25	6.36E-04	1.24E-01	1.21E-10	6.00E-03	1.20E+01	0.00E+00	1.13E-10	6.06E+00	2.70E-05
BATCH-795	6/30/28	51	5.3	0.24	1.25E-09	7.48E+01	1.26E-11	2.55E-04	1.17E-11	1.63E-25	6.37E-04	1.24E-01	1.21E-10	6.00E-03	1.20E+01	0.00E+00	4.62E-11	6.07E+00	2.70E-05
BATCH-796	7/5/28	141	14.7	0.24	5.36E+02	0.00E+00	2.51E-10	4.25E-08	2.23E-10	8.46E-19	3.50E-02	4.06E-01	1.83E-09	8.00E-03	1.02E+01	0.00E+00	1.87E+01	0.00E+00	1.67E-05
BATCH-797	7/6/28	52	5.4	0.24	1.08E-09	7.63E+01	1.29E-11	2.60E-04	1.19E-11	6.53E-31	6.47E-04	1.27E-01	1.23E-10	6.00E-03	1.22E+01	0.00E+00	3.06E-11	6.19E+00	2.70E-05
BATCH-798	7/11/28	13	1.3	0.24	3.39E+01	0.00E+00	1.89E-11	3.14E-09	1.55E-11	7.97E-21	2.00E-03	2.10E-02	1.29E-10	1.70E-04	3.78E-01	0.00E+00	1.18E+00	0.00E+00	1.22E-06
BATCH-799	7/13/28	56	5.8	0.24	1.67E-09	8.27E+01	1.39E-11	2.82E-04	1.29E-11	1.03E-34	7.04E-04	1.38E-01	1.34E-10	7.00E-03	1.32E+01	0.00E+00	3.97E-11	6.71E+00	5.39E-05
BATCH-800	7/19/28	144	15.0	0.24	6.03E+02	0.00E+00	1.71E-10	4.86E-05	1.55E-10	3.50E-19	3.60E-02	3.81E-01	1.27E-09	7.00E-03	9.82E+00	0.00E+00	2.12E+01	0.00E+00	1.83E-05
BATCH-801	7/20/28	144	15.0	0.24	6.02E+02	0.00E+00	1.70E-10	4.86E-05	1.54E-10	9.42E-20	3.60E-02	3.81E-01	1.26E-09	7.00E-03	9.79E+00	0.00E+00	2.12E+01	0.00E+00	1.83E-05
BATCH-802	8/3/28	148	15.4	0.24	5.69E+02	0.00E+00	9.64E-12	8.75E-05	3.56E-11	3.34E-25	3.30E-02	3.62E-01	2.69E-10	1.10E-02	1.23E+01	0.00E+00	2.00E+01	0.00E+00	1.38E-05
BATCH-803	8/4/28	80	8.3	0.24	5.00E-03	1.18E+02	1.99E-11	4.02E-04	1.84E-11	1.16E-24	1.00E-03	1.96E-01	1.90E-10	9.00E-03	1.89E+01	0.00E+00	1.71E-04	9.58E+00	5.39E-05
BATCH-804	8/12/28	131	13.7	0.24	4.55E+02	0.00E+00	8.69E-12	5.02E-05	3.92E-11	4.08E-29	3.00E-02	3.58E-01	2.89E-10	1.10E-02	1.19E+01	0.00E+00	1.56E+01	0.00E+00	8.61E-06
BATCH-805	8/19/28	48	5.0	0.24	1.62E+02	0.00E+00	7.58E-11	1.29E-08	6.74E-11	2.56E-19	1.00E-02	1.23E-01	5.54E-10	2.00E-03	3.07E+00	0.00E+00	5.66E+00	0.00E+00	5.04E-06
BATCH-806	8/24/28	48	5.0	0.24	1.78E+02	0.00E+00	5.06E-11	1.44E-05	4.57E-11	1.04E-19	1.10E-02	1.13E-01	3.76E-10	2.00E-03	2.90E+00	0.00E+00	6.27E+00	0.00E+00	5.42E-06
BATCH-807	8/26/28	48	5.0	0.24	1.78E+02	0.00E+00	5.03E-11	1.44E-05	4.55E-11	2.79E-20	1.10E-02	1.13E-01	3.74E-10	2.00E-03	2.90E+00	0.00E+00	6.27E+00	0.00E+00	5.40E-06
BATCH-808	8/29/28	61	6.4	0.24	2.53E-06	9.09E+01	1.53E-11	3.10E-04	1.41E-11	5.94E-28	7.70E-04	1.51E-01	1.46E-10	7.00E-03	1.45E+01	0.00E+00	8.82E-08	7.37E+00	5.39E-05
BATCH-809	8/31/28	50	5.2	0.24	1.70E+02	0.00E+00	2.88E-12	2.61E-05	1.06E-11	9.96E-26	1.00E-02	1.08E-01	8.02E-11	3.00E-03	3.68E+00	0.00E+00	5.98E+00	0.00E+00	4.13E-06
BATCH-810	9/5/28	17	1.7	0.24	3.81E+01	0.00E+00	1.78E-11	3.02E-09	1.58E-11	6.01E-20	2.00E-03	2.90E-02	1.30E-10	5.50E-04	7.21E-01	0.00E+00	1.33E+00	0.00E+00	1.18E-06
BATCH-811	9/5/28	53	5.5	0.24	1.66E+02	0.00E+00	3.17E-12	1.83E-05	1.43E-11	1.49E-29	1.10E-02	1.31E-01	1.05E-10	4.00E-03	4.36E+00	0.00E+00	5.75E+00	0.00E+00	3.14E-06
BATCH-812	9/7/28	17	1.7	0.24	4.19E+01	0.00E+00	1.19E-11	3.37E-06	1.07E-11	2.43E-20	2.00E-03	2.60E-02	8.82E-11	4.94E-04	6.82E-01	0.00E+00	1.47E+00	0.00E+00	1.27E-06
BATCH-813	9/9/28	17	1.7	0.24	4.19E+01	0.00E+00	1.18E-11	3.38E-06	1.07E-11	6.55E-21	2.00E-03	2.60E-02	8.78E-11	4.93E-04	6.81E-01	0.00E+00	1.47E+00	0.00E+00	1.27E-06
BATCH-814	9/11/28	17	1.8	0.24	4.02E+01	0.00E+00	6.80E-13	6.17E-06	2.51E-12	2.35E-26	2.00E-03	2.60E-02	1.89E-11	7.59E-04	8.69E-01	0.00E+00	1.41E+00	0.00E+00	9.75E-07
BATCH-815	9/11/28	41	4.3	0.24	1.46E-09	6.06E+01	1.02E-11	2.05E-04	9.54E-12	3.43E-31	5.18E-04	1.01E-01	9.87E-11	5.00E-03	9.71E+00	0.00E+00	5.10E-11	4.89E+00	2.70E-05
BATCH-816	9/13/28	157	16.4	0.24	5.00E-03	1.81E+02	2.03E-11	1.64E-05	7.05E-11	8.13E-24	3.00E-03	5.64E-01	7.03E-10	4.90E-02	4.23E+01	0.00E+00	1.80E-04	4.51E+00	1.98E-05
BATCH-817	9/16/28	157	16.4	0.24	6.00E-03	1.81E+02	2.03E-11	1.64E-05	7.05E-11	3.29E-24	3.00E-03	5.64E-01	7.02E-10	4.90E-02	4.23E+01	0.00E+00	1.99E-04	4.51E+00	1.98E-05
BATCH-818	9/29/28	18	1.9	0.24	3.96E+01	0.00E+00	7.56E-13	4.36E-06	3.41E-12	3.55E-30	3.00E-03	3.10E-02	2.51E-11	9.88E-04	1.04E+00	0.00E+00	1.37E+00	0.00E+00	7.49E-07
BATCH-819	10/1/28	157	16.4	0.24	6.00E-03	1.81E+02	2.03E-11	1.64E-05	7.05E-11	8.83E-25	3.00E-03	5.64E-01	7.02E-10	4.90E-02	4.22E+01	0.00E+00	1.98E-04	4.50E+00	1.98E-05
BATCH-820	10/2/28	157	16.4	0.24	5.00E-03	1.80E+02	2.03E-11	1.64E-05	7.04E-11	3.16E-30	3.00E-03	5.63E-01	7.01E-10	4.90E-02	4.22E+01	0.00E+00	1.90E-04	4.50E+00	1.98E-05
BATCH-821	10/18/28	174	18.1	0.24	7.85E+02	0.00E+00	1.09E-11	2.20E-04	1.01E-11	2.38E-25	3.90E-02	3.16E-01	1.04E-10	5.00E-03	1.03E+01	0.00E+00	2.92E+01	0.00E+00	2.70E-05
BATCH-822	10/19/28	132	13.8	0.24	2.63E-06	1.52E+02	1.70E-11	1.38E-05	5.91E-11	4.15E-27	3.00E-03	4.73E-01	5.89E-10	4.10E-02	3.55E+01	0.00E+00	9.18E-08	3.78E+00	1.66E-05
BATCH-823	11/2/28	120	12.5	0.24	2.60E-06	1.39E+02	1.84E-11	1.12E-05	6.92E-11	1.51E-27	3.00E-03	4.34E-01	6.30E-10	3.80E-02	3.23E+01	0.00E+00	9.14E-08	3.60E+00	1.61E-05
BATCH-824	11/5/28	143	14.9	0.24	6.00E-03	1.76E+02	4.85E-11	4.43E-07	2.22E-10	5.01E-34	4.00E-03	5.35E-01	1.59E-09	5.40E-02	3.81E+01	0.00E+00	1.94E-04	5.66E+00	2.70E-05
BATCH-825	11/15/28	120	12.5	0.24	2.85E-06	1.48E+02	4.07E-11	3.80E-07	1.87E-10	4.45E-28	3.00E-03	4.50E-01	1.34E-09	4.50E-02	3.20E+01	0.00E+00	1.00E-07	4.76E+00	2.33E-05
BATCH-826	11/20/28	120	12.5	0.24	2.72E-06	1.48E+02	4.07E-11	3.80E-07	1.86E-10	1.59E-33	3.00E-03	4.50E-01	1.34E-09	4.50E-02	3.20E+01	0.00E+00	9.58E-08	4.76E+00	2.33E-05
BATCH-827	11/27/28	101	10.5	0.24	1.58E-09	1.24E+02	3.42E-11	3.20E-07	1.57E-10	2.49E-30	3.00E-03	3.78E-01	1.13E-09	3.80E-02	2.69E+01	0.00E+00	5.51E-11	4.00E+00	1.96E-05
BATCH-828	12/3/28	42	4.3	0.24	1.66E+02	0.00E+00	2.30E-12	4.66E-05	2.13E-12	5.03E-26	8.00E-03	6.70E-02	2.21E-11	1.00E-03	2.19E+00	0.00E+00	6.19E+00	0.00E+00	6.76E-06
BATCH-829	12/8/28	93	9.7	0.24	1.69E-09	1.14E+02	3.15E-11	2.95E-07	1.44E-10	9.81E-31	2.00E-03	3.48E-01	1.04E-09	3.50E-02	2.48E+01	0.00E+00	5.94E-11	3.69E+00	1.80E-05
BATCH-830	12/8/28	118	12.3	0.24	2.86E-06	1.45E+02	4.00E-11	3.66E-07	1.83E-10	2.56E-37	3.00E-03	4.42E-01	1.32E-09	4.40E-02	3.15E+01	0.00E+00	9.91E-08	4.68E+00	2.29E-05
BATCH-831	12/18/28	86	9.0	0.24	1.54E-09	1.05E+02	1.03E-08	4.80E-07	3.98E-09	2.41E-31	2.00E-03	3.37E-01	1.01E-08	3.10E-02	2.29E+01	0.00E+00	5.41E-11	4.34E+00	1.64E-05
BATCH-832	12/21/28	49	5.1	0.24	1.43E-09	4.28E+01	1.14E-07	2.50E-06	4.26E-08	8.34E-37	3.00E-03	3.36E-01	1.01E-07	4.00E-03	1.18E+01	0.00E+00	5.01E-11	1.20E+01	5.13E-06

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-784	4/26/28	97	10.1	0.24	6.24E-11	4.43E+01	3.98E-01	0.00E+00	0.00E+00	1.00E-03	7.16E+00	1.11E-04	2.07E-09	5.31E-09	1.26E-01	4.02E-10	1.66E+03	0.00E+00	7.40E-02
BATCH-785	5/3/28	166	17.3	0.24	9.38E-11	5.13E+01	7.56E-01	0.00E+00	0.00E+00	6.00E-04	1.28E+01	1.67E-04	1.72E-09	7.61E-10	4.40E-02	8.00E-10	2.83E+03	0.00E+00	1.19E-01
BATCH-786	5/7/28	165	17.3	0.24	9.38E-11	5.13E+01	7.55E-01	0.00E+00	0.00E+00	6.00E-04	1.28E+01	1.67E-04	1.72E-09	7.60E-10	4.40E-02	7.99E-10	2.83E+03	0.00E+00	1.19E-01
BATCH-787	5/21/28	117	12.2	0.24	2.76E-11	3.32E+01	5.21E-01	0.00E+00	0.00E+00	1.00E-03	1.36E+00	4.88E-05	2.16E-09	8.80E-09	1.85E-01	3.16E-12	2.00E+03	0.00E+00	2.60E-02
BATCH-788	5/24/28	125	13.0	0.24	7.08E-11	3.87E+01	5.70E-01	0.00E+00	0.00E+00	4.00E-04	9.65E+00	1.26E-04	1.30E-09	5.86E-10	3.30E-02	6.03E-10	2.13E+03	0.00E+00	9.00E-02
BATCH-789	6/2/28	125	13.0	0.24	7.08E-11	3.87E+01	5.70E-01	0.00E+00	0.00E+00	4.00E-04	9.65E+00	1.26E-04	1.30E-09	5.86E-10	3.30E-02	6.03E-10	2.13E+03	0.00E+00	9.00E-02
BATCH-790	6/7/28	95	9.9	0.24	5.40E-11	2.95E+01	4.35E-01	0.00E+00	0.00E+00	4.00E-04	7.36E+00	9.58E-05	9.91E-10	4.41E-10	2.50E-02	4.60E-10	1.63E+03	0.00E+00	6.80E-02
BATCH-791	6/16/28	138	14.4	0.24	7.81E-11	4.27E+01	6.29E-01	0.00E+00	0.00E+00	6.00E-04	1.07E+01	1.39E-04	1.43E-09	6.32E-10	3.60E-02	6.65E-10	2.35E+03	0.00E+00	9.90E-02
BATCH-792	6/17/28	79	8.2	0.24	1.66E-11	7.04E+01	1.41E-01	0.00E+00	0.00E+00	2.40E-03	4.60E+00	2.78E-05	3.90E-10	6.07E-10	3.87E-01	1.36E-10	1.35E+03	0.00E+00	4.80E-02
BATCH-793	6/25/28	35	3.7	0.24	7.33E-12	8.81E+00	1.38E-01	0.00E+00	0.00E+00	2.00E-04	3.60E-01	1.30E-05	5.73E-10	2.33E-09	4.90E-02	8.39E-13	6.01E+02	0.00E+00	7.00E-03
BATCH-794	6/29/28	51	5.3	0.24	2.28E-12	5.88E+01	2.50E-02	0.00E+00	0.00E+00	2.20E-03	2.50E+00	2.45E-06	1.22E-10	4.62E-10	3.57E-01	1.35E-11	8.63E+02	0.00E+00	2.80E-02
BATCH-795	6/30/28	51	5.3	0.24	2.28E-12	5.88E+01	2.50E-02	0.00E+00	0.00E+00	2.20E-03	2.51E+00	2.45E-06	1.22E-10	4.62E-10	3.57E-01	1.35E-11	8.64E+02	0.00E+00	2.80E-02
BATCH-796	7/5/28	141	14.7	0.24	3.35E-11	3.32E+01	5.96E-01	0.00E+00	0.00E+00	1.00E-03	2.58E+00	5.92E-05	1.98E-09	7.34E-09	1.57E-01	9.38E-11	2.40E+03	0.00E+00	3.50E-02
BATCH-797	7/6/28	52	5.4	0.24	2.29E-12	6.00E+01	2.50E-02	0.00E+00	0.00E+00	2.20E-03	2.55E+00	2.43E-06	1.23E-10	4.72E-10	3.65E-01	1.35E-11	8.81E+02	0.00E+00	2.90E-02
BATCH-798	7/11/28	13	1.3	0.24	1.74E-12	2.09E+00	3.30E-02	0.00E+00	0.00E+00	6.83E-05	8.50E-02	3.07E-05	1.36E-10	5.53E-10	1.20E-02	1.99E-13	2.17E+02	0.00E+00	2.00E-03
BATCH-799	7/13/28	56	5.8	0.24	2.52E-12	6.51E+01	2.70E-02	0.00E+00	0.00E+00	2.40E-03	2.77E+00	2.70E-06	1.34E-10	5.11E-10	3.95E-01	1.49E-11	9.55E+02	0.00E+00	3.10E-02
BATCH-800	7/19/28	144	15.0	0.24	2.44E-11	3.43E+01	5.71E-01	0.00E+00	0.00E+00	1.00E-03	2.41E+00	4.29E-05	1.38E-09	5.02E-09	1.74E-01	7.83E-11	2.46E+03	0.00E+00	3.10E-02
BATCH-801	7/20/28	144	15.0	0.24	2.43E-11	3.42E+01	5.70E-01	0.00E+00	0.00E+00	1.00E-03	2.41E+00	4.27E-05	1.37E-09	4.99E-09	1.74E-01	7.82E-11	2.46E+03	0.00E+00	3.00E-02
BATCH-802	8/3/28	148	15.4	0.24	1.77E-11	2.94E+01	5.21E-01	0.00E+00	0.00E+00	8.00E-04	3.16E+00	3.08E-05	3.52E-10	2.96E-10	1.31E-01	1.49E-10	2.53E+03	0.00E+00	3.10E-02
BATCH-803	8/4/28	80	8.3	0.24	3.53E-12	9.29E+01	3.80E-02	0.00E+00	0.00E+00	3.40E-03	3.95E+00	3.74E-06	1.91E-10	7.30E-10	5.64E-01	2.08E-11	1.36E+03	0.00E+00	4.50E-02
BATCH-804	8/12/28	131	13.7	0.24	2.02E-11	2.24E+01	5.05E-01	0.00E+00	0.00E+00	6.00E-04	3.19E+00	3.55E-05	3.86E-10	2.51E-10	8.00E-02	1.71E-10	2.24E+03	0.00E+00	3.10E-02
BATCH-805	8/19/28	48	5.0	0.24	1.01E-11	1.01E+01	1.80E-01	0.00E+00	0.00E+00	2.00E-04	7.80E-01	1.79E-05	5.98E-10	2.22E-09	4.80E-02	2.84E-11	8.19E+02	0.00E+00	1.00E-02
BATCH-806	8/24/28	48	5.0	0.24	7.21E-12	1.02E+01	1.69E-01	0.00E+00	0.00E+00	4.00E-04	7.13E-01	1.27E-05	4.07E-10	1.49E-09	5.20E-02	2.32E-11	8.20E+02	0.00E+00	9.00E-03
BATCH-807	8/26/28	48	5.0	0.24	7.18E-12	1.01E+01	1.69E-01	0.00E+00	0.00E+00	4.00E-04	7.12E-01	1.26E-05	4.05E-10	1.48E-09	5.10E-02	2.31E-11	8.19E+02	0.00E+00	9.00E-03
BATCH-808	8/29/28	61	6.4	0.24	2.72E-12	7.15E+01	3.00E-02	0.00E+00	0.00E+00	2.60E-03	3.04E+00	2.88E-06	1.47E-10	5.62E-10	4.34E-01	1.60E-11	1.05E+03	0.00E+00	3.40E-02
BATCH-809	8/31/28	50	5.2	0.24	5.28E-12	8.80E+00	1.56E-01	0.00E+00	0.00E+00	2.00E-04	9.45E-01	9.21E-06	1.05E-10	8.83E-11	3.90E-02	4.44E-11	8.48E+02	0.00E+00	9.00E-03
BATCH-810	9/5/28	17	1.7	0.24	2.36E-12	4.20E-02	4.20E-02	0.00E+00	0.00E+00	6.87E-05	1.83E-01	4.21E-06	1.40E-10	5.21E-10	1.10E-02	6.66E-12	2.82E+02	0.00E+00	2.00E-03
BATCH-811	9/5/28	53	5.5	0.24	7.36E-12	8.16E+00	1.84E-01	0.00E+00	0.00E+00	2.00E-04	1.16E+00	1.30E-05	1.41E-10	9.15E-11	2.90E-02	6.23E-11	9.09E+02	0.00E+00	1.10E-02
BATCH-812	9/7/28	17	1.7	0.24	1.69E-12	2.39E+00	4.00E-02	0.00E+00	0.00E+00	7.48E-05	1.68E-01	2.98E-06	9.56E-11	3.49E-10	1.20E-02	5.44E-12	2.83E+02	0.00E+00	2.00E-03
BATCH-813	9/9/28	17	1.7	0.24	1.69E-12	2.38E+00	4.00E-02	0.00E+00	0.00E+00	7.46E-05	1.67E-01	2.97E-06	9.52E-11	3.47E-10	1.20E-02	5.44E-12	2.83E+02	0.00E+00	2.00E-03
BATCH-814	9/11/28	17	1.8	0.24	1.25E-12	2.08E+00	3.70E-02	0.00E+00	0.00E+00	6.11E-05	2.23E-01	2.17E-06	2.48E-11	2.09E-11	9.00E-03	1.05E-11	2.91E+02	0.00E+00	2.00E-03
BATCH-815	9/11/28	41	4.3	0.24	1.91E-12	4.75E+01	2.20E-02	0.00E+00	0.00E+00	1.80E-03	2.04E+00	1.92E-06	9.93E-11	3.74E-10	2.88E-01	1.14E-11	7.01E+02	0.00E+00	2.30E-02
BATCH-816	9/13/28	157	16.4	0.24	3.99E-11	6.57E+01	7.28E-01	0.00E+00	0.00E+00	1.20E-03	1.20E+01	5.01E-06	8.16E-10	1.04E-09	1.85E-01	3.24E-10	2.69E+03	0.00E+00	1.03E-01
BATCH-817	9/16/28	157	16.4	0.24	3.99E-11	6.57E+01	7.28E-01	0.00E+00	0.00E+00	1.20E-03	1.20E+01	5.01E-06	8.15E-10	1.04E-09	1.85E-01	3.23E-10	2.69E+03	0.00E+00	1.03E-01
BATCH-818	9/29/28	18	1.9	0.24	1.76E-12	1.95E+00	4.40E-02	0.00E+00	0.00E+00	4.92E-05	2.77E-01	3.09E-06	3.36E-11	2.18E-11	7.00E-03	1.49E-11	3.04E+02	0.00E+00	3.00E-03
BATCH-819	10/1/28	157	16.4	0.24	3.98E-11	6.56E+01	7.28E-01	0.00E+00	0.00E+00	1.20E-03	1.20E+01	5.00E-06	8.15E-10	1.04E-09	1.85E-01	3.23E-10	2.69E+03	0.00E+00	1.03E-01
BATCH-820	10/2/28	157	16.4	0.24	3.98E-11	6.56E+01	7.27E-01	0.00E+00	0.00E+00	1.20E-03	1.20E+01	5.00E-06	8.14E-10	1.04E-09	1.85E-01	3.23E-10	2.68E+03	0.00E+00	1.03E-01
BATCH-821	10/18/28	174	18.1	0.24	1.93E-12	5.09E+01	4.52E-01	0.00E+00	0.00E+00	1.80E-03	2.16E+00	2.05E-06	1.05E-10	4.00E-10	3.09E-01	1.14E-11	2.97E+03	0.00E+00	2.50E-02
BATCH-822	10/19/28	132	13.8	0.24	3.34E-11	5.51E+01	6.11E-01	0.00E+00	0.00E+00	1.00E-03	1.01E+01	4.20E-06	6.84E-10	8.71E-10	1.55E-01	2.71E-10	2.25E+03	0.00E+00	8.60E-02
BATCH-823	11/2/28	120	12.5	0.24	3.86E-11	5.62E+01	6.11E-01	0.00E+00	0.00E+00	1.00E-03	9.19E+00	3.55E-06	7.72E-10	8.19E-10	1.51E-01	3.17E-10	2.06E+03	0.00E+00	7.90E-02
BATCH-824	11/5/28	143	14.9	0.24	1.21E-10	7.38E+01	7.13E-01	0.00E+00	0.00E+00	1.60E-03	1.08E+01	1.59E-06	2.27E-09	1.20E-09	2.63E-01	1.02E-09	2.44E+03	0.00E+00	9.60E-02
BATCH-825	11/15/28	120	12.5	0.24	1.01E-10	6.21E+01	5.99E-01	0.00E+00	0.00E+00	1.40E-03	9.05E+00	1.34E-06	1.91E-09	1.01E-09	2.21E-01	8.56E-10	2.05E+03	0.00E+00	8.10E-02
BATCH-826	11/20/28	120	12.5	0.24	1.01E-10	6.21E+01	5.99E-01	0.00E+00	0.00E+00	1.40E-03	9.04E+00	1.34E-06	1.91E-09	1.01E-09	2.21E-01	8.55E-10	2.05E+03	0.00E+00	8.10E-02
BATCH-827	11/27/28	101	10.5	0.24	8.51E-11	5.21E+01	5.03E-01	0.00E+00	0.00E+00	1.20E-03	7.60E+00	1.12E-06	1.61E-09	8.44E-10	1.86E-01	7.18E-10	1.72E+03	0.00E+00	6.80E-02
BATCH-828	12/3/28	42	4.3	0.24	4.09E-13	1.08E+01	9.60E-02	0.00E+00	0.00E+00	4.00E-04	4.57E-01	4.34E-07	2.21E-11	8.46E-11	6.50E-02	2.41E-12	7.12E+02	0.00E+00	5.00E-03
BATCH-829	12/8/28	93	9.7	0.24	7.85E-11	4.81E+01	4.64E-01	0.00E+00	0.00E+00	1.00E-03	7.01E+00	1.04E-06	1.48E-09	7.79E-10	1.71E-01	6.63E-10	1.59E+03	0.00E+00	6.30E-02
BATCH-830	12/8/28	118	12.3	0.24	9.96E-11	6.10E+01	5.89E-01	0.00E+00	0.00E+00	1.40E-03	8.89E+00	1.31E-06	1.88E-09	9.88E-10	2.17E-01	8.41E-10	2.02E+03	0.00E+00	7.90E-02
BATCH-831	12/18/28	86	9.0	0.24	9.31E-11	4.30E+01	4.14E-01	0.00E+00	0.00E+00	1.00E-03	6.37E+00	1.18E-05	4.99E-09	1.33E-07	1.54E-01	2.28E-09	1.48E+03	0.00E+00	5.80E-02
BATCH-832	12/21/28	49	5.1	0.24	2.65E-10	6.94E+00	5.80E-02	0.00E+00	0.00E+00	1.33E-04	2.11E+00	1.21E-04	4.07E-08	1.46E-06	3.70E-02	1.87E-08	8.39E+02	0.00E+00	3.20E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Tl+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-784	4/26/28	97	10.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	3.53E+01	1.96E-11	2.09E+00	3.20E+01	2.30E-02	4.21E-11	0.00E+00	1.30E-02	2.36E-07	8.60E-02
BATCH-785	5/3/28	166	17.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.90E+01	1.91E-12	1.51E+00	5.21E+01	4.30E-02	8.41E-11	0.00E+00	1.60E-02	3.19E-08	3.30E-02
BATCH-786	5/7/28	165	17.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	4.90E+01	1.91E-12	1.51E+00	5.20E+01	4.30E-02	8.41E-11	0.00E+00	1.60E-02	3.19E-08	3.30E-02
BATCH-787	5/21/28	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	6.09E+01	3.33E-11	2.06E+01	1.16E+01	2.00E-03	1.02E-15	0.00E+00	1.10E-02	3.93E-07	1.23E-01
BATCH-788	5/24/28	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.70E+01	1.49E-12	1.15E+00	3.93E+01	3.30E-02	6.34E-11	0.00E+00	1.20E-02	2.46E-08	2.50E-02
BATCH-789	6/2/28	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.70E+01	1.49E-12	1.15E+00	3.93E+01	3.30E-02	6.34E-11	0.00E+00	1.20E-02	2.46E-08	2.50E-02
BATCH-790	6/7/28	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	2.82E+01	1.11E-12	8.71E-01	2.99E+01	2.50E-02	4.84E-11	0.00E+00	9.00E-03	1.85E-08	1.90E-02
BATCH-791	6/16/28	138	14.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	4.08E+01	1.59E-12	1.26E+00	4.33E+01	3.60E-02	7.00E-11	0.00E+00	1.30E-02	2.65E-08	2.80E-02
BATCH-792	6/17/28	79	8.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.25E+01	1.75E-12	4.79E+00	3.01E+01	7.00E-03	1.47E-11	0.00E+00	4.00E-03	3.91E-06	2.62E-01
BATCH-793	6/25/28	35	3.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.61E+01	8.84E-12	5.46E+00	3.08E+00	4.91E-04	2.71E-16	0.00E+00	3.00E-03	1.04E-07	3.30E-02
BATCH-794	6/29/28	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.30E+01	1.37E-12	4.29E+00	2.09E+01	6.77E-04	1.79E-12	0.00E+00	1.00E-03	3.67E-06	2.41E-01
BATCH-795	6/30/28	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.30E+01	1.38E-12	4.29E+00	2.09E+01	6.78E-04	1.80E-12	0.00E+00	1.00E-03	3.67E-06	2.41E-01
BATCH-796	7/5/28	141	14.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	6.35E+01	2.77E-11	2.00E+01	1.59E+01	6.00E-03	9.59E-12	0.00E+00	1.10E-02	3.28E-07	1.05E-01
BATCH-797	7/6/28	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.36E+01	1.40E-12	4.38E+00	2.13E+01	6.75E-04	1.80E-12	0.00E+00	1.00E-03	3.75E-06	2.46E-01
BATCH-798	7/11/28	13	1.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.89E-04	3.83E+00	2.10E-12	1.30E+00	7.30E-01	1.17E-04	6.43E-17	0.00E+00	7.15E-04	2.47E-08	8.00E-03
BATCH-799	7/13/28	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.65E+01	1.52E-12	4.74E+00	2.31E+01	7.47E-04	1.98E-12	0.00E+00	2.00E-03	4.06E-06	2.67E-01
BATCH-800	7/19/28	144	15.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	6.74E+01	1.89E-11	2.16E+01	1.60E+01	5.00E-03	8.12E-12	0.00E+00	9.00E-03	9.21E-07	1.17E-01
BATCH-801	7/20/28	144	15.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	6.73E+01	1.88E-11	2.16E+01	1.59E+01	5.00E-03	8.12E-12	0.00E+00	9.00E-03	9.19E-07	1.17E-01
BATCH-802	8/3/28	148	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	6.24E+01	8.16E-13	1.89E+01	1.79E+01	8.00E-03	1.58E-11	0.00E+00	5.00E-03	1.27E-06	8.90E-02
BATCH-803	8/4/28	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	5.21E+01	2.17E-12	6.78E+00	3.30E+01	1.00E-03	2.77E-12	0.00E+00	2.00E-03	5.80E-06	3.81E-01
BATCH-804	8/12/28	131	13.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.20E+01	6.72E-13	1.53E+01	1.63E+01	9.00E-03	1.81E-11	0.00E+00	5.00E-03	7.31E-07	5.50E-02
BATCH-805	8/19/28	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.92E+01	8.38E-12	6.04E+00	4.81E+00	2.00E-03	2.90E-12	0.00E+00	3.00E-03	9.91E-08	3.20E-02
BATCH-806	8/24/28	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.99E+01	5.58E-12	6.40E+00	4.72E+00	2.00E-03	2.40E-12	0.00E+00	3.00E-03	2.72E-07	3.50E-02
BATCH-807	8/26/28	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.99E+01	5.55E-12	6.39E+00	4.71E+00	2.00E-03	2.40E-12	0.00E+00	3.00E-03	2.72E-07	3.40E-02
BATCH-808	8/29/28	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.01E+01	1.67E-12	5.21E+00	2.54E+01	7.99E-04	2.13E-12	0.00E+00	2.00E-03	4.47E-06	2.93E-01
BATCH-809	8/31/28	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.86E+01	2.44E-13	5.65E+00	5.35E+00	2.00E-03	4.71E-12	0.00E+00	1.00E-03	3.79E-07	2.70E-02
BATCH-810	9/5/28	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.48E-04	4.51E+00	1.97E-12	1.42E+00	1.13E+00	4.59E-04	6.81E-13	0.00E+00	7.89E-04	2.33E-08	7.00E-03
BATCH-811	9/5/28	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.90E+01	2.45E-13	5.58E+00	5.95E+00	3.00E-03	5.64E-13	0.00E+00	2.00E-03	2.66E-07	2.00E-02
BATCH-812	9/7/28	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.05E-04	4.68E+00	1.31E-12	1.50E+00	1.11E+00	3.58E-04	5.64E-13	0.00E+00	6.12E-04	6.40E-08	8.00E-03
BATCH-813	9/9/28	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.03E-04	4.68E+00	1.30E-12	1.50E+00	1.11E+00	3.58E-04	5.64E-13	0.00E+00	6.10E-04	6.39E-08	8.00E-03
BATCH-814	9/11/28	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.78E-04	4.40E+00	5.76E-14	1.33E+00	1.26E+00	5.66E-04	1.11E-12	0.00E+00	3.44E-04	8.94E-08	6.00E-03
BATCH-815	9/11/28	41	4.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.66E+01	1.11E-12	3.46E+00	1.69E+01	6.56E-04	1.50E-12	0.00E+00	1.00E-03	2.95E-06	1.94E-01
BATCH-816	9/13/28	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.42E+01	1.25E-12	2.78E+00	4.50E+01	4.70E-02	3.29E-11	0.00E+00	2.00E-03	2.41E-07	1.35E-01
BATCH-817	9/16/28	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.42E+01	1.25E-12	2.78E+00	4.49E+01	4.70E-02	3.29E-11	0.00E+00	2.00E-03	2.40E-07	1.35E-01
BATCH-818	9/29/28	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.12E-04	4.53E+00	5.85E-14	1.33E+00	1.42E+00	8.04E-04	1.57E-12	0.00E+00	3.98E-04	6.36E-08	5.00E-03
BATCH-819	10/1/28	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.42E+01	1.25E-12	2.78E+00	4.49E+01	4.70E-02	3.29E-11	0.00E+00	2.00E-03	2.40E-07	1.35E-01
BATCH-820	10/2/28	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.41E+01	1.25E-12	2.77E+00	4.49E+01	4.70E-02	3.29E-11	0.00E+00	2.00E-03	2.40E-07	1.35E-01
BATCH-821	10/18/28	174	18.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.37E+01	1.19E-12	2.65E+01	1.96E+01	5.69E-04	1.52E-12	0.00E+00	4.00E-03	3.18E-06	2.09E-01
BATCH-822	10/19/28	132	13.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.55E+01	1.05E-12	2.33E+00	3.77E+01	3.90E-02	2.76E-11	0.00E+00	1.00E-03	2.02E-07	1.13E-01
BATCH-823	11/2/28	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.20E+01	1.15E-12	2.24E+00	3.44E+01	3.70E-02	3.25E-11	0.00E+00	1.00E-03	1.65E-07	1.10E-01
BATCH-824	11/5/28	143	14.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.52E+01	3.09E-12	3.74E+00	4.07E+01	5.20E-02	1.06E-10	0.00E+00	2.00E-03	1.87E-08	1.92E-01
BATCH-825	11/15/28	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.64E+01	2.60E-12	3.15E+00	3.42E+01	4.30E-02	8.87E-11	0.00E+00	2.00E-03	1.58E-08	1.62E-01
BATCH-826	11/20/28	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.64E+01	2.60E-12	3.15E+00	3.42E+01	4.30E-02	8.87E-11	0.00E+00	2.00E-03	1.58E-08	1.62E-01
BATCH-827	11/27/28	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.90E+01	2.18E-12	2.64E+00	2.87E+01	3.60E-02	7.45E-11	0.00E+00	2.00E-03	1.33E-08	1.36E-01
BATCH-828	12/3/28	42	4.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.10E-04	1.77E+01	2.52E-13	5.60E+00	4.15E+00	1.20E-04	3.21E-13	0.00E+00	8.25E-04	6.73E-07	4.40E-02
BATCH-829	12/8/28	93	9.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.59E+01	2.01E-12	2.44E+00	2.65E+01	3.40E-02	6.87E-11	0.00E+00	1.00E-03	1.23E-08	1.25E-01
BATCH-830	12/8/28	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.56E+01	2.56E-12	3.09E+00	3.36E+01	4.30E-02	8.72E-11	0.00E+00	2.00E-03	1.54E-08	1.59E-01
BATCH-831	12/18/28	86	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.22E+01	4.81E-11	2.28E+00	2.41E+01	3.00E-02	7.87E-11	0.00E+00	1.00E-03	4.86E-07	1.12E-01
BATCH-832	12/21/28	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	5.51E+00	5.12E-10	1.50E+00	7.91E+00	9.00E-03	2.00E-10	0.00E+00	2.00E-03	5.26E-06	1.40E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-833	12/26/28	15	1.6	0.24	0.00E+00	0.00E+00	2.00E-03	4.76E-04	1.71E-01	6.30E-03	4.95E+01	1.70E-02	2.00E-03	2.87E-01	4.72E-16	1.70E-02	3.18E-05	5.00E-03	1.21E-04
BATCH-834	12/27/28	128	13.3	0.24	0.00E+00	0.00E+00	2.30E-02	3.00E-03	1.74E+00	1.06E-01	7.86E+02	1.45E-01	1.50E-02	3.39E+00	3.32E-15	3.57E-01	2.21E-04	2.40E-02	3.50E-03
BATCH-835	12/28/28	145	15.1	0.24	0.00E+00	0.00E+00	2.70E-02	4.00E-03	2.06E+00	1.26E-01	9.33E+02	1.71E-01	1.70E-02	4.02E+00	3.91E-15	4.24E-01	2.61E-04	2.80E-02	4.25E-03
BATCH-836	1/9/29	48	5.0	0.24	0.00E+00	0.00E+00	2.20E-02	1.00E-03	1.68E+00	4.88E-01	9.67E+02	1.56E-01	7.00E-03	4.82E+00	1.98E-14	1.03E-01	7.64E-05	7.10E-02	2.00E-03
BATCH-837	1/12/29	157	16.4	0.24	0.00E+00	0.00E+00	2.40E-02	3.00E-03	1.79E+00	2.12E-01	9.30E+02	1.55E-01	1.30E-02	4.14E+00	6.62E-15	2.85E-01	1.56E-04	3.80E-02	3.25E-03
BATCH-838	1/15/29	150	15.7	0.24	0.00E+00	0.00E+00	2.90E-02	4.00E-03	2.17E+00	1.30E-01	9.43E+02	1.85E-01	1.80E-02	4.22E+00	2.19E-15	4.11E-01	2.25E-04	3.30E-02	4.25E-03
BATCH-839	1/29/29	70	7.3	0.24	0.00E+00	0.00E+00	3.30E-02	2.00E-03	2.43E+00	7.09E-01	1.40E+03	2.27E-01	1.00E-02	7.00E+00	2.88E-14	1.49E-01	1.11E-04	1.03E-01	2.75E-03
BATCH-840	1/30/29	49	5.1	0.24	0.00E+00	0.00E+00	8.00E-03	9.76E-04	6.00E-01	3.69E-02	2.66E+02	5.00E-02	5.00E-03	1.18E+00	5.79E-16	1.18E-01	5.98E-05	8.00E-03	1.25E-03
BATCH-841	2/5/29	47	4.9	0.24	0.00E+00	0.00E+00	8.00E-03	9.64E-04	5.96E-01	3.69E-02	2.65E+02	5.00E-02	5.00E-03	1.17E+00	5.72E-16	1.18E-01	5.91E-05	8.00E-03	1.25E-03
BATCH-842	2/5/29	160	16.7	0.24	0.00E+00	0.00E+00	2.50E-02	3.00E-03	1.87E+00	2.12E-01	9.47E+02	1.64E-01	1.40E-02	4.26E+00	6.74E-15	2.88E-01	1.72E-04	4.20E-02	3.25E-03
BATCH-843	2/10/29	52	5.5	0.24	0.00E+00	0.00E+00	7.00E-03	7.65E-04	5.32E-01	6.30E-02	2.77E+02	4.60E-02	4.00E-03	1.23E+00	1.98E-15	8.50E-02	4.65E-05	1.10E-02	1.00E-03
BATCH-844	2/15/29	48	5.0	0.24	0.00E+00	0.00E+00	8.00E-03	1.00E-03	6.22E-01	3.69E-02	2.70E+02	5.30E-02	5.00E-03	1.21E+00	6.27E-16	1.18E-01	6.42E-05	9.00E-03	1.25E-03
BATCH-845	2/21/29	17	1.8	0.24	0.00E+00	0.00E+00	2.00E-03	2.35E-04	1.44E-01	9.00E-03	6.40E+01	1.20E-02	1.00E-03	2.83E-01	1.39E-16	2.80E-02	1.44E-05	2.00E-03	2.50E-04
BATCH-846	2/22/29	50	5.2	0.24	0.00E+00	0.00E+00	2.30E-02	1.00E-03	1.71E+00	5.00E-01	9.90E+02	1.60E-01	7.00E-03	4.93E+00	2.03E-14	1.05E-01	7.80E-05	7.30E-02	2.00E-03
BATCH-847	2/23/29	16	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	2.32E-04	1.43E-01	9.00E-03	6.37E+01	1.20E-02	1.00E-03	2.81E-01	1.38E-16	2.80E-02	1.42E-05	2.00E-03	2.50E-04
BATCH-848	2/25/29	18	1.8	0.24	0.00E+00	0.00E+00	2.00E-03	1.80E-04	1.26E-01	1.53E-02	6.54E+01	1.10E-02	9.05E-04	2.91E-01	4.66E-16	2.00E-02	1.10E-05	3.00E-03	2.23E-04
BATCH-849	2/27/29	17	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	2.53E-04	1.49E-01	9.00E-03	6.48E+01	1.30E-02	1.00E-03	2.90E-01	1.51E-16	2.80E-02	1.54E-05	2.00E-03	2.50E-04
BATCH-850	2/28/29	52	5.4	0.24	0.00E+00	0.00E+00	7.00E-03	8.22E-04	5.42E-01	6.12E-02	2.74E+02	4.80E-02	4.00E-03	1.23E+00	1.95E-15	8.30E-02	4.98E-05	1.20E-02	1.00E-03
BATCH-851	3/1/29	70	7.3	0.24	0.00E+00	0.00E+00	3.30E-02	2.00E-03	2.43E+00	7.08E-01	1.40E+03	2.27E-01	1.00E-02	6.99E+00	2.87E-14	1.48E-01	1.11E-04	1.03E-01	2.75E-03
BATCH-852	3/5/29	70	7.3	0.24	0.00E+00	0.00E+00	3.20E-02	2.00E-03	2.43E+00	7.07E-01	1.40E+03	2.26E-01	1.00E-02	6.98E+00	2.87E-14	1.48E-01	1.10E-04	1.03E-01	2.75E-03
BATCH-853	3/8/29	155	16.1	0.24	0.00E+00	0.00E+00	1.50E-02	8.96E-04	1.16E+00	3.37E-01	8.85E+02	1.08E-01	5.00E-03	3.94E+00	1.37E-14	7.10E-02	5.26E-05	4.90E-02	1.25E-03
BATCH-854	3/13/29	119	12.4	0.24	0.00E+00	0.00E+00	4.50E-02	3.00E-03	3.41E+00	4.88E-01	2.08E+03	2.74E-01	1.80E-02	8.66E+00	1.23E-14	6.79E-01	2.13E-04	5.00E-02	8.00E-03
BATCH-855	3/24/29	168	17.5	0.24	0.00E+00	0.00E+00	6.10E-02	5.00E-03	4.59E+00	4.39E-01	2.58E+03	3.49E-01	2.60E-02	1.04E+01	4.42E-15	1.12E+00	3.11E-04	2.70E-02	1.25E-02
BATCH-856	3/25/29	17	1.8	0.24	0.00E+00	0.00E+00	2.00E-03	1.93E-04	1.27E-01	1.44E-02	6.43E+01	1.10E-02	9.58E-04	2.89E-01	4.58E-16	2.00E-02	1.17E-05	3.00E-03	2.13E-04
BATCH-857	3/27/29	119	12.4	0.24	0.00E+00	0.00E+00	4.30E-02	4.00E-03	3.24E+00	3.10E-01	1.82E+03	2.46E-01	1.90E-02	7.32E+00	3.13E-15	7.87E-01	2.19E-04	1.90E-02	8.75E-03
BATCH-858	4/9/29	119	12.4	0.24	0.00E+00	0.00E+00	4.30E-02	4.00E-03	3.24E+00	3.10E-01	1.82E+03	2.46E-01	1.90E-02	7.32E+00	3.13E-15	7.87E-01	2.19E-04	1.90E-02	8.75E-03
BATCH-859	4/11/29	42	4.4	0.24	0.00E+00	0.00E+00	4.00E-03	2.18E-04	2.82E-01	8.19E-02	2.16E+02	2.60E-02	1.00E-03	9.61E-01	3.33E-15	1.70E-02	1.26E-05	1.20E-02	2.50E-04
BATCH-860	4/16/29	120	12.5	0.24	0.00E+00	0.00E+00	4.30E-02	4.00E-03	3.27E+00	3.12E-01	1.83E+03	2.49E-01	1.90E-02	7.39E+00	3.15E-15	7.95E-01	2.21E-04	1.90E-02	9.00E-03
BATCH-861	4/21/29	168	17.5	0.24	0.00E+00	0.00E+00	6.10E-02	5.00E-03	4.58E+00	4.37E-01	2.57E+03	3.48E-01	2.60E-02	1.03E+01	4.41E-15	1.11E+00	3.10E-04	2.70E-02	1.25E-02
BATCH-862	4/28/29	125	13.1	0.24	0.00E+00	0.00E+00	1.40E-02	9.33E-04	1.05E+00	2.28E-01	7.20E+02	9.10E-02	5.00E-03	3.11E+00	8.06E-15	1.36E-01	5.64E-05	3.00E-02	1.75E-03
BATCH-863	5/9/29	140	14.6	0.24	0.00E+00	0.00E+00	5.10E-02	4.00E-03	3.83E+00	3.66E-01	2.15E+03	2.92E-01	2.20E-02	8.66E+00	3.69E-15	9.32E-01	2.60E-04	2.20E-02	1.05E-02
BATCH-864	5/12/29	15	1.6	0.24	0.00E+00	0.00E+00	8.99E-04	5.21E-05	6.70E-02	1.98E-02	5.14E+01	6.00E-03	2.89E-04	2.29E-01	7.94E-16	4.00E-03	3.06E-06	3.00E-03	7.65E-05
BATCH-865	5/13/29	125	13.0	0.24	0.00E+00	0.00E+00	1.40E-02	9.31E-04	1.04E+00	2.27E-01	7.18E+02	9.10E-02	5.00E-03	3.10E+00	8.04E-15	1.36E-01	5.63E-05	3.00E-02	1.75E-03
BATCH-866	5/24/29	95	9.9	0.24	0.00E+00	0.00E+00	4.20E-02	4.00E-03	3.17E+00	2.48E-01	1.54E+03	2.53E-01	2.20E-02	6.77E+00	2.54E-15	6.83E-01	3.30E-02	7.50E-03	1.05E-02
BATCH-867	5/27/29	134	14.0	0.24	0.00E+00	0.00E+00	6.00E-02	6.00E-03	4.49E+00	3.48E-01	2.18E+03	3.59E-01	3.10E-02	9.57E+00	3.58E-15	9.64E-01	3.82E-04	4.70E-02	1.05E-02
BATCH-868	6/3/29	40	4.2	0.24	0.00E+00	0.00E+00	4.00E-03	2.65E-04	2.97E-01	6.48E-02	2.04E+02	2.60E-02	1.00E-03	8.84E-01	2.29E-15	3.90E-02	1.60E-05	8.00E-03	5.00E-04
BATCH-869	6/7/29	159	16.6	0.24	0.00E+00	0.00E+00	7.10E-02	7.00E-03	5.35E+00	4.15E-01	2.59E+03	4.28E-01	3.70E-02	1.14E+01	4.26E-15	1.15E+00	4.55E-04	5.60E-02	1.25E-02
BATCH-870	6/10/29	112	11.7	0.24	0.00E+00	0.00E+00	5.00E-02	5.00E-03	3.76E+00	2.92E-01	1.82E+03	3.01E-01	2.60E-02	8.02E+00	3.00E-15	8.07E-01	3.20E-04	3.90E-02	8.75E-03
BATCH-871	6/22/29	40	4.1	0.24	0.00E+00	0.00E+00	4.00E-03	2.65E-04	2.97E-01	6.48E-02	2.04E+02	2.60E-02	1.00E-03	8.82E-01	2.28E-15	3.90E-02	1.60E-05	8.00E-03	5.00E-04
BATCH-872	6/24/29	148	15.4	0.24	0.00E+00	0.00E+00	2.00E-02	2.00E-03	1.49E+00	2.38E-01	9.17E+02	1.24E-01	8.00E-03	3.92E+00	7.00E-15	2.59E-01	9.54E-05	2.90E-02	3.00E-03
BATCH-873	6/26/29	14	1.5	0.24	0.00E+00	0.00E+00	9.49E-04	6.34E-05	7.10E-02	1.53E-02	4.89E+01	6.00E-03	3.44E-04	2.11E-01	5.47E-16	9.00E-03	3.83E-06	2.00E-03	1.24E-04
BATCH-874	6/28/29	113	11.8	0.24	0.00E+00	0.00E+00	5.00E-02	5.00E-03	3.79E+00	2.93E-01	1.84E+03	3.03E-01	2.60E-02	8.08E+00	3.02E-15	8.13E-01	3.22E-04	4.00E-02	9.00E-03
BATCH-875	7/9/29	122	12.7	0.24	0.00E+00	0.00E+00	1.80E-02	2.00E-03	1.32E+00	1.19E-01	7.11E+02	1.02E-01	8.00E-03	2.94E+00	1.21E-15	3.10E-01	9.63E-05	9.00E-03	3.50E-03
BATCH-876	7/10/29	135	14.0	0.24	0.00E+00	0.00E+00	6.00E-02	6.00E-03	4.51E+00	3.50E-01	2.19E+03	3.61E-01	3.10E-02	9.62E+00	3.60E-15	9.68E-01	3.83E-04	4.70E-02	1.05E-02
BATCH-877	7/22/29	14	1.5	0.24	0.00E+00	0.00E+00	9.47E-04	6.33E-05	7.10E-02	1.53E-02	4.88E+01	6.00E-03	3.44E-04	2.11E-01	5.46E-16	9.00E-03	3.82E-06	2.00E-03	1.24E-04
BATCH-878	7/24/29	149	15.5	0.24	0.00E+00	0.00E+00	6.40E-02	6.00E-03	4.85E+00	3.79E-01	2.34E+03	3.84E-01	3.40E-02	1.03E+01	3.80E-15	1.05E+00	4.10E-04	4.80E-02	1.15E-02
BATCH-879	7/24/29	48	5.0	0.24	0.00E+00	0.00E+00	6.00E-03	4.44E-04	4.30E-01	6.84E-02	2.64E+02	3.60E-02	2.00E-03	1.13E+00	2.02E-15	7.50E-02	2.75E-05	8.00E-03	1.00E-03
BATCH-880	7/29/29	121	12.7	0.24	0.00E+00	0.00E+00	1.80E-02	2.00E-03	1.39E+00	1.17E-01	7.11E+02	1.09E-01	9.00E-03	3.02E+00	1.19E-15	3.12E-01	1.09E-04	1.20E-02	3.50E-03
BATCH-881	8/9/29	53	5.6	0.24	0.00E+00	0.00E+00	7.00E-03	6.05E-04	5.23E-01	4.68E-02	2.81E+02	4.00E-02	3.00E-03	1.16E+00	4.77E-16	1.23E-01	3.81E-05	4.00E-03	1.25E-03

Appendix A Nominal ILAW Inventory

TWRS Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs		137-Cs		151-Sm		152-Eu		154-Eu		155-Eu		226-Ra		227-Ac		228-Ra		229-Th		231-Pa		232-Th		232-U		233-U		234-U	
					Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00	Ci	1.00
Fraction Remaining After Volatization Losses				0.24		1.14E-09		4.51E+01		8.73E+00		6.99E-04		3.80E-02		2.00E-03		2.22E-07		2.89E-07		3.85E-06		2.92E-06		3.99E-06		8.38E-06		4.62E-04		2.00E-03		7.54E-04
BATCH-833	12/26/28	15	1.6																													
BATCH-834	12/27/28	128	13.3	0.24		2.40E-08		3.83E+02		3.59E+01		3.00E-03		1.57E-01		8.00E-03		2.65E-06		1.19E-06		9.37E-05		2.40E-05		2.66E-05		6.63E-05		2.00E-03		1.10E-02		3.00E-03
BATCH-835	12/28/28	145	15.1	0.24		2.86E-08		4.34E+02		4.18E+01		3.00E-03		1.83E-01		1.00E-02		3.13E-06		1.38E-06		1.12E-04		2.83E-05		3.13E-05		7.82E-05		2.00E-03		1.20E-02		4.00E-03
BATCH-836	1/9/29	48	5.0	0.24		2.54E-08		1.45E+02		2.14E+01		2.00E-03		8.70E-02		4.00E-03		7.91E-04		6.93E-07		2.21E-05		9.59E-06		1.44E-05		2.69E-05		1.00E-03		7.00E-03		7.00E-03
BATCH-837	1/12/29	157	16.4	0.24		1.98E-08		4.72E+02		3.48E+01		3.00E-03		1.42E-01		7.00E-03		2.15E-04		1.12E-06		6.96E-05		2.12E-05		2.48E-05		5.90E-05		2.00E-03		1.10E-02		5.00E-03
BATCH-838	1/15/29	150	15.7	0.24		2.08E-08		4.51E+02		5.00E+01		4.00E-03		2.04E-01		1.00E-02		4.61E-06		1.61E-06		1.01E-04		3.07E-05		3.48E-05		8.52E-05		3.00E-03		1.50E-02		5.00E-03
BATCH-839	1/29/29	70	7.3	0.24		3.68E-08		2.11E+02		3.10E+01		2.00E-03		1.26E-01		6.00E-03		1.00E-03		1.00E-06		3.19E-05		1.39E-05		2.09E-05		3.90E-05		2.00E-03		1.10E-02		1.00E-02
BATCH-840	1/30/29	49	5.1	0.24		5.96E-09		1.48E+02		1.23E+01		9.29E-04		5.00E-02		2.00E-03		9.19E-07		3.98E-07		2.93E-05		8.31E-06		9.22E-06		2.30E-05		6.91E-04		4.00E-03		1.00E-03
BATCH-841	2/5/29	47	4.9	0.24		5.95E-09		1.41E+02		1.21E+01		9.08E-04		4.90E-02		2.00E-03		9.11E-07		3.89E-07		2.93E-05		8.23E-06		9.10E-06		2.28E-05		6.77E-04		4.00E-03		1.00E-03
BATCH-842	2/5/29	160	16.7	0.24		1.99E-08		4.80E+02		4.14E+01		3.00E-03		1.69E-01		8.00E-03		2.14E-04		1.34E-06		6.93E-05		2.30E-05		2.74E-05		6.41E-05		2.00E-03		1.30E-02		5.00E-03
BATCH-843	2/10/29	52	5.5	0.24		5.91E-09		1.57E+02		1.04E+01		7.79E-04		4.20E-02		2.00E-03		6.40E-05		3.35E-07		2.08E-05		6.33E-06		7.40E-06		1.76E-05		5.92E-04		3.00E-03		1.00E-03
BATCH-844	2/15/29	48	5.0	0.24		5.94E-09		1.44E+02		1.43E+01		1.00E-03		5.80E-02		3.00E-03		1.32E-06		4.61E-07		2.89E-05		8.78E-06		9.95E-06		2.44E-05		7.96E-04		4.00E-03		1.00E-03
BATCH-845	2/21/29	17	1.8	0.24		1.43E-09		5.12E+01		2.97E+00		2.23E-04		1.20E-02		5.94E-04		2.21E-07		9.58E-08		7.05E-06		2.00E-06		2.22E-06		5.53E-06		1.66E-04		8.94E-04		2.85E-04
BATCH-846	2/22/29	50	5.2	0.24		2.60E-08		1.48E+02		2.19E+01		2.00E-03		8.90E-02		4.00E-03		8.10E-04		7.07E-07		2.25E-05		9.79E-06		1.48E-05		2.75E-05		1.00E-03		7.00E-03		7.00E-03
BATCH-847	2/23/29	16	1.7	0.24		1.43E-09		4.91E+01		2.90E+00		2.18E-04		1.20E-02		5.80E-04		2.19E-07		9.36E-08		7.04E-06		1.98E-06		2.19E-06		5.48E-06		1.63E-04		8.74E-04		2.80E-04
BATCH-848	2/25/29	18	1.8	0.24		1.39E-09		5.26E+01		2.45E+00		1.84E-04		1.00E-02		4.89E-04		1.51E-05		7.90E-08		4.90E-06		1.49E-06		1.74E-06		4.15E-06		1.40E-04		7.51E-04		3.25E-04
BATCH-849	2/27/29	17	1.7	0.24		1.43E-09		5.02E+01		3.43E+00		2.59E-04		1.40E-02		6.88E-04		3.16E-07		1.11E-07		6.94E-06		2.11E-06		2.39E-06		5.86E-06		1.91E-04		1.00E-03		3.26E-04
BATCH-850	2/28/29	52	5.4	0.24		5.76E-09		1.55E+02		1.20E+01		9.01E-04		4.90E-02		2.00E-03		6.18E-05		3.87E-07		2.01E-05		6.66E-06		7.94E-06		1.86E-05		6.77E-04		4.00E-03		2.00E-03
BATCH-851	3/1/29	70	7.3	0.24		3.68E-08		2.10E+02		3.10E+01		2.00E-03		1.26E-01		6.00E-03		1.00E-03		1.00E-06		3.19E-05		1.39E-05		2.09E-05		3.90E-05		2.00E-03		1.10E-02		1.00E-02
BATCH-852	3/5/29	70	7.3	0.24		3.68E-08		2.10E+02		3.10E+01		2.00E-03		1.26E-01		6.00E-03		1.00E-03		1.00E-06		3.18E-05		1.39E-05		2.09E-05		3.89E-05		2.00E-03		1.10E-02		1.00E-02
BATCH-853	3/8/29	155	16.1	0.24		1.75E-08		4.64E+02		1.47E+01		1.00E-03		6.00E-02		3.00E-03		5.46E-04		4.77E-07		1.52E-05		6.60E-06		9.95E-06		1.85E-05		9.36E-04		5.00E-03		5.00E-03
BATCH-854	3/13/29	119	12.4	0.24		4.59E-08		3.55E+02		1.60E+01		1.00E-03		6.50E-02		3.00E-03		4.29E-04		5.17E-07		1.72E-04		3.35E-05		3.31E-05		9.00E-05		1.00E-03		6.00E-03		6.00E-03
BATCH-855	3/24/29	168	17.5	0.24		5.93E-08		5.04E+02		9.72E+00		7.23E-04		4.00E-02		2.00E-03		6.80E-05		3.12E-07		2.87E-04		5.11E-05		4.61E-05		1.36E-04		9.34E-04		5.00E-03		4.00E-03
BATCH-856	3/25/29	17	1.8	0.24		1.35E-09		5.20E+01		2.81E+00		2.11E-04		1.10E-02		5.62E-04		1.45E-05		9.07E-08		4.70E-06		1.56E-06		1.86E-06		4.35E-06		1.59E-04		8.54E-04		3.52E-04
BATCH-857	3/27/29	119	12.4	0.24		4.18E-08		3.55E+02		6.87E+00		5.11E-04		2.80E-02		1.00E-03		4.86E-05		2.21E-07		2.02E-04		3.60E-05		3.25E-05		9.61E-05		6.59E-04		4.00E-03		3.00E-03
BATCH-858	4/9/29	119	12.4	0.24		4.18E-08		3.55E+02		6.87E+00		5.11E-04		2.80E-02		1.00E-03		4.86E-05		2.21E-07		2.02E-04		3.60E-05		3.25E-05		9.61E-05		6.59E-04		4.00E-03		3.00E-03
BATCH-859	4/11/29	42	4.4	0.24		4.27E-09		1.27E+02		3.59E+00		2.66E-04		1.50E-02		7.07E-04		1.33E-04		1.16E-07		3.70E-06		1.61E-06		2.42E-06		4.52E-06		2.28E-04		1.00E-03		1.00E-03
BATCH-860	4/16/29	120	12.5	0.24		4.22E-08		3.59E+02		6.92E+00		5.15E-04		2.80E-02		1.00E-03		4.86E-05		2.22E-07		2.04E-04		3.64E-05		3.28E-05		9.71E-05		6.65E-04		4.00E-03		3.00E-03
BATCH-861	4/21/29	168	17.5	0.24		5.91E-08		5.03E+02		9.69E+00		7.21E-04		4.00E-02		2.00E-03		6.78E-05		3.11E-07		2.86E-04		5.09E-05		4.60E-05		1.36E-04		9.31E-04		5.00E-03		4.00E-03
BATCH-862	4/28/29	125	13.1	0.24		1.50E-08		3.75E+02		9.12E+00		6.76E-04		3.70E-02		2.00E-03		6.78E-05		3.13E-04		2.95E-07		3.33E-05		8.12E-06		9.57E-06		2.22E-05		6.07E-04		3.00E-03		3.00E-03
BATCH-863	5/9/29	140	14.6	0.24		4.95E-08		4.21E+02		8.11E+00		6.04E-04		3.30E-02		2.00E-03		5.67E-05		2.61E-07		2.39E-04		4.26E-05		3.85E-05		1.14E-04		7.79E-04		4.00E-03		3.00E-03
BATCH-864	5/12/29	15	1.6	0.24		1.02E-09		4.52E+01		8.56E-01		6.35E-05		3.00E-03		1.69E-04		3.17E-05		2.77E-08		8.81E-07		3.83E-07		5.78E-07		1.08E-06		5.44E-05		2.92E-04		2.76E-04
BATCH-865	5/13/29	125	13.0	0.24		1.49E-08		3.75E+02		9.10E+00		6.74E-04		3.70E-02		2.00E-03		3.12E-04		2.94E-07		3.32E-05		8.10E-06		9.55E-06		2.22E-05		6.05E-04		3.00E-03		3.00E-03
BATCH-866	5/24/29	95	9.9	0.24		3.44E-08		2.85E+02		3.82E+01		3.00E-03		1.55E-01		7.00E-03		6.05E-06		1.24E-06		1.75E-04		4.01E-05		4.05E-05		1.09E-04		2.00E-03		1.30E-02		5.00E-03
BATCH-867	5/27/29	134	14.0	0.24		4.84E-08		4.01E+02		5.56E+01		4.00E-03		2.26E-01		1.10E-02		6.69E-06		1.81E-06		2.48E-04		5.70E-05		5.78E-05		1.55E-04		3.00E-03		1.90E-02		7.00E-03
BATCH-868	6/3/29	40	4.2	0.24		4.25E-09		1.19E+02		2.59E+00		1.92E-04		1.10E-02		5.10E-04		8.88E-05		8.38E-08		9.45E-06		2.31E-06		2.72E-06		6.30E-06		1.72E-04		9.25E-04		8.51E-04
BATCH-869	6/7/29	159	16.6	0.24		5.77E-08		4.78E+02		6.62E+01		5.00E-03		2.69E-01		1.30E-02		7.93E-06		2.15E-06		2.95E-04		6.79E-05		6.89E-05		1.85E-04		4.00E-03		2.20E-02		8.00E-03
BATCH-870	6/10/29	112	11.7	0.24		4.06E-08		3.36E+02		4.65E+01		3.00E-03		1.89E-01		9.00E-03		5.61E-06		1.51E-06		2.07E-04		4.78E-05		4.84E-05		1.30E-04		3.00E-03		1.60E-02		6.00E-03
BATCH-871	6/22/29	40	4.1	0.24		4.24E-09		1.19E+02		2.58E+00		1.92E-04		1.10E-02		5.09E-04		8.86E-05		8.36E-08		9.44E-06		2.30E-06		2.71E-06		6.29E-06		1.72E-04		9.23E-04		8.49E-04
BATCH-872	6/24/29	148	15.4	0.24		1.97E-08		4.44E+02		1.22E+01		8.95E-04		5.00E-02		2.00E-03		2.54E-04		3.94E-07		6.51E-05		1.43E-05		1.52E-05		3.89E-05		8.13E-04		4.00E-03		3.00E-03
BATCH-873	6/26/29	14	1.5	0.24		1.02E-09		4.21E+01		6.19E-01		4.59E-05		3.00E-03		1.22E-04		2.12E-05		2.00E-08		2.26E-06		5.51E-07		6.50E-07		1.51E-06		4.12E-05		2.21E-04		2.04E-04
BATCH-874	6/28/29	113	11.8	0.24		4.09E-08		3.39E+02		4.69E+01		3.00E-03		1.90E-01		9.00E-03		5.61E-06		1.52E-06		2.09E-04		4.81E-05		4.88E-05		1.31E-04		3.00E-03		1.60E-02		6.00E-03
BATCH-875	7/9/29	122	12.7	0.24		1.62E-08		3.65E+02		6.85E+00		5.00E-04		2.80E-02		1.00E-03		1.43E-05		2.22E-07		7.96E-05		1.53E-05		1.44E-05		4.12E-05		4.95E-04		3.00E-03		1.00E-03
BATCH-876	7/10/29	135	14.0	0.24		4.87E-08		4.03E+02		5.59E+01		4.00E-03		2.27E-01		1.10E-02		6.69E-06		1.81E-06		2.49E-04		5.73E-05		5.81E-05		1.56E-04		4.00E-03		1.90E-02		7.00E-03
BATCH-877	7/22/29	14	1.5	0.24		1.01E-09		4.20E+01		6.18E-01		4.58E-05		3.00E-03		1.22E-04		2.12E-05		2.00E-08		2.26E-06		5.50E-07		6.49E-07		1.50E-06		4.11E-05		2.21E-04		2.03E-04
BATCH-878	7/24/29	149	15.5	0.24		5.28E-08		4.45E+02		5.67E+01		4.00E-03		2.33E-01		1.10E-02		7.43E-06		1.84E-06		2.79E-04		6.54E-05		6.20E-05		1.73E-04		4.00E-03		2.00E-02		7.00E-03
BATCH-879	7/24/29	48	5.0	0.24		5.67E-09		1.43E+02		3.50E+00		2.58E-04		1.40E-02		6.84E-04		7.32E-05		1.13E-07		1.88E-05		4.13E-06		4.38E-06		1.12E-05		2.34E-04		1.00E-03		9.17E-04
BATCH-880	7/29/29	121	12.7	0.24		1.60E-08		3.64E+02		1.19E+01		8.66E-04		4.90E-02		2.00E-03		8.84E-06		3.87E-07		8.01E-05		1.68E-05		1.64E-05		4.55E-05		7.86E-04		4.00E-03		2.00E-03
BATCH-881	8/9/29	53	5.6	0.24		6.42E-09		1.60E+02		2.71E+00		1.98E-04		1.10E-02		5.25E-04		5.66E-06		8.78E-08		3.15E-05		6.06E-06		5.69E-06		1.63E-05		1.96E-04		1.00E-03		5.47E-04

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-833	12/26/28	15	1.6	0.24	3.07E-05	2.33E-05	8.41E-04	1.00E-03	8.71E-04	4.80E-02	8.00E-03	5.20E-02	1.90E-02	2.60E-27	5.30E-07	1.93E-06	7.54E-06	4.64E-05	2.19E-13
BATCH-834	12/27/28	128	13.3	0.24	1.40E-04	1.02E-04	8.00E-03	6.00E-03	4.00E-03	2.55E-01	4.20E-02	2.31E-01	9.50E-02	2.65E-26	2.67E-06	8.60E-06	8.09E-05	4.89E-04	1.95E-11
BATCH-835	12/28/28	145	15.1	0.24	1.63E-04	1.18E-04	9.00E-03	6.00E-03	5.00E-03	2.98E-01	5.00E-02	2.69E-01	1.11E-01	3.13E-26	3.12E-06	1.00E-05	9.57E-05	5.79E-04	2.18E-11
BATCH-836	1/9/29	48	5.0	0.24	2.78E-04	2.62E-04	3.00E-03	3.00E-03	6.00E-03	1.39E-01	2.30E-02	7.02E-01	5.00E-02	4.24E-27	1.47E-06	2.87E-05	5.26E-05	5.21E-04	1.43E-07
BATCH-837	1/12/29	157	16.4	0.24	1.88E-04	1.53E-04	7.00E-03	5.00E-03	5.00E-03	2.41E-01	4.00E-02	3.75E-01	8.60E-02	5.46E-27	2.54E-06	1.47E-05	7.50E-05	5.03E-04	3.85E-08
BATCH-838	1/15/29	150	15.7	0.24	1.94E-04	1.42E-04	1.00E-02	7.00E-03	5.00E-03	3.45E-01	5.70E-02	3.20E-01	1.23E-01	7.06E-27	3.63E-06	1.20E-05	9.92E-05	5.90E-04	2.56E-10
BATCH-839	1/29/29	70	7.3	0.24	4.04E-04	3.81E-04	5.00E-03	4.00E-03	9.00E-03	2.02E-01	3.40E-02	1.02E+00	7.20E-02	6.15E-27	2.13E-06	4.17E-05	7.62E-05	7.57E-04	2.08E-07
BATCH-840	1/30/29	49	5.1	0.24	4.85E-05	3.52E-05	3.00E-03	2.00E-03	1.00E-03	8.80E-02	1.50E-02	8.00E-02	3.10E-02	1.94E-27	9.26E-07	2.98E-06	2.74E-05	1.63E-04	6.77E-12
BATCH-841	2/5/29	47	4.9	0.24	4.75E-05	3.45E-05	3.00E-03	2.00E-03	1.00E-03	8.70E-02	1.40E-02	7.80E-02	3.10E-02	1.93E-27	9.09E-07	2.92E-06	2.72E-05	1.62E-04	6.34E-12
BATCH-842	2/5/29	160	16.7	0.24	2.11E-04	1.71E-04	7.00E-03	6.00E-03	6.00E-03	2.77E-01	4.60E-02	4.13E-01	9.90E-02	5.78E-27	2.93E-06	1.61E-05	7.91E-05	5.25E-04	3.82E-08
BATCH-843	2/10/29	52	5.5	0.24	5.60E-05	4.56E-05	2.00E-03	2.00E-03	1.00E-03	7.20E-02	1.20E-02	1.12E-01	2.60E-02	1.63E-27	7.57E-07	4.38E-06	2.24E-05	1.50E-04	1.15E-08
BATCH-844	2/15/29	48	5.0	0.24	5.54E-05	4.05E-05	3.00E-03	2.00E-03	2.00E-03	9.90E-02	1.60E-02	9.20E-02	3.50E-02	2.02E-27	1.04E-06	3.42E-06	2.84E-05	1.69E-04	7.31E-11
BATCH-845	2/21/29	17	1.8	0.24	1.17E-05	8.47E-06	6.29E-04	4.59E-04	3.25E-04	2.10E-02	4.00E-03	1.90E-02	8.00E-03	4.67E-28	2.23E-07	7.17E-07	6.58E-06	3.93E-05	1.63E-12
BATCH-846	2/22/29	50	5.2	0.24	2.84E-04	2.69E-04	4.00E-03	3.00E-03	7.00E-03	1.42E-01	2.40E-02	7.18E-01	5.10E-02	4.33E-27	1.50E-06	2.94E-05	5.37E-05	5.33E-04	1.47E-07
BATCH-847	2/23/29	16	1.7	0.24	1.14E-05	8.28E-06	6.23E-04	4.51E-04	3.18E-04	2.10E-02	3.00E-03	1.90E-02	7.00E-03	4.63E-28	2.19E-07	7.02E-07	6.54E-06	3.90E-05	1.52E-12
BATCH-848	2/25/29	18	1.8	0.24	1.32E-05	1.08E-05	4.77E-04	3.69E-04	3.44E-04	1.70E-02	3.00E-03	2.60E-02	6.00E-03	3.85E-28	1.79E-07	1.03E-06	5.28E-06	3.54E-05	2.71E-09
BATCH-849	2/27/29	17	1.7	0.24	1.33E-05	9.74E-06	6.57E-04	5.14E-04	3.71E-04	2.40E-02	4.00E-03	2.20E-02	8.00E-03	4.85E-28	2.49E-07	8.21E-07	6.82E-06	4.06E-05	1.76E-11
BATCH-850	2/28/29	52	5.4	0.24	6.10E-05	4.93E-05	2.00E-03	2.00E-03	2.00E-03	8.00E-02	1.30E-02	1.20E-01	2.90E-02	1.67E-27	8.47E-07	4.66E-06	2.29E-05	1.52E-04	1.11E-08
BATCH-851	3/1/29	70	7.3	0.24	4.03E-04	3.81E-04	5.00E-03	4.00E-03	9.00E-03	2.01E-01	3.40E-02	1.02E+00	7.20E-02	6.14E-27	2.13E-06	4.16E-05	7.62E-05	7.56E-04	2.08E-07
BATCH-852	3/5/29	70	7.3	0.24	4.03E-04	3.80E-04	5.00E-03	4.00E-03	9.00E-03	2.01E-01	3.40E-02	1.02E+00	7.20E-02	6.14E-27	2.12E-06	4.16E-05	7.61E-05	7.55E-04	2.07E-07
BATCH-853	3/8/29	155	16.1	0.24	1.92E-04	1.81E-04	2.00E-03	2.00E-03	4.00E-03	9.60E-02	1.60E-02	4.84E-01	3.40E-02	2.92E-27	1.01E-06	1.98E-05	3.62E-05	3.60E-04	9.88E-08
BATCH-854	3/13/29	119	12.4	0.24	2.26E-04	1.84E-04	1.20E-02	5.00E-03	5.00E-03	2.34E-01	3.70E-02	4.93E-01	7.40E-02	1.04E-26	2.19E-06	1.99E-05	1.45E-04	9.87E-04	1.07E-07
BATCH-855	3/24/29	168	17.5	0.24	1.58E-04	9.74E-05	1.70E-02	6.00E-03	4.00E-03	2.93E-01	4.50E-02	2.61E-01	8.90E-02	1.47E-26	2.61E-06	1.02E-05	2.11E-04	1.00E-03	6.54E-08
BATCH-856	3/25/29	17	1.8	0.24	1.43E-05	1.16E-05	4.92E-04	4.10E-04	3.77E-04	1.90E-02	3.00E-03	2.80E-02	7.00E-03	3.92E-28	1.99E-07	1.09E-06	5.37E-06	3.57E-05	2.60E-09
BATCH-857	3/27/29	119	12.4	0.24	1.11E-04	6.88E-05	1.20E-02	4.00E-03	3.00E-03	2.07E-01	3.20E-02	1.84E-01	6.30E-02	1.04E-26	1.84E-06	7.18E-06	1.49E-04	9.14E-04	4.62E-08
BATCH-858	4/9/29	119	12.4	0.24	1.11E-04	6.88E-05	1.20E-02	4.00E-03	3.00E-03	2.07E-01	3.20E-02	1.84E-01	6.30E-02	1.04E-26	1.84E-06	7.18E-06	1.49E-04	9.14E-04	4.62E-08
BATCH-859	4/11/29	42	4.4	0.24	4.67E-05	4.41E-05	5.84E-04	5.16E-04	1.00E-03	2.30E-02	4.00E-03	1.18E-01	8.00E-03	7.12E-28	2.47E-07	4.83E-06	8.83E-06	8.77E-05	2.41E-08
BATCH-860	4/16/29	120	12.5	0.24	1.12E-04	6.94E-05	1.20E-02	4.00E-03	3.00E-03	2.09E-01	3.20E-02	1.86E-01	6.30E-02	1.05E-26	1.86E-06	7.23E-06	1.50E-04	9.23E-04	4.66E-08
BATCH-861	4/21/29	168	17.5	0.24	1.57E-04	9.71E-05	1.70E-02	6.00E-03	4.00E-03	2.92E-01	4.50E-02	2.60E-01	8.90E-02	1.47E-26	2.60E-06	1.01E-05	2.11E-04	1.00E-03	6.52E-08
BATCH-862	4/28/29	125	13.1	0.24	1.21E-04	1.10E-04	3.00E-03	2.00E-03	3.00E-03	7.90E-02	1.30E-02	2.95E-01	2.70E-02	2.91E-27	7.94E-07	1.20E-05	3.86E-05	3.14E-04	6.12E-08
BATCH-863	5/9/29	140	14.6	0.24	1.32E-04	8.12E-05	1.50E-02	5.00E-03	3.00E-03	2.45E-01	3.80E-02	2.17E-01	7.40E-02	1.23E-26	2.18E-06	8.47E-06	1.76E-04	1.00E-03	5.46E-08
BATCH-864	5/12/29	15	1.6	0.24	1.11E-05	1.05E-05	1.39E-04	1.23E-04	2.60E-04	6.00E-03	9.32E-04	2.80E-02	2.00E-03	1.70E-28	5.88E-08	1.15E-06	2.11E-06	2.09E-05	5.74E-09
BATCH-865	5/13/29	125	13.0	0.24	1.21E-04	1.10E-04	3.00E-03	2.00E-03	3.00E-03	7.90E-02	1.30E-02	2.94E-01	2.70E-02	2.91E-27	7.92E-07	1.20E-05	3.85E-05	3.13E-04	6.10E-08
BATCH-866	5/24/29	95	9.9	0.24	2.03E-04	1.39E-04	1.30E-02	7.00E-03	5.00E-03	3.28E-01	5.40E-02	3.12E-01	1.12E-01	9.75E-27	3.29E-06	1.16E-05	1.39E-04	8.49E-04	1.48E-09
BATCH-867	5/27/29	134	14.0	0.24	2.92E-04	2.00E-04	1.90E-02	1.00E-02	8.00E-03	4.70E-01	7.70E-02	4.48E-01	1.61E-01	1.38E-26	4.74E-06	1.67E-05	1.96E-04	1.00E-03	7.60E-11
BATCH-868	6/3/29	40	4.2	0.24	3.45E-05	3.13E-05	8.11E-04	4.75E-04	8.05E-04	2.20E-02	4.00E-03	8.40E-02	8.00E-03	8.27E-28	2.25E-07	3.41E-06	1.10E-05	8.92E-05	1.74E-08
BATCH-869	6/7/29	159	16.6	0.24	3.47E-04	2.38E-04	2.20E-02	1.20E-02	9.00E-03	5.60E-01	9.20E-02	5.34E-01	1.91E-01	1.64E-26	5.64E-06	1.98E-05	2.34E-04	1.00E-03	5.14E-11
BATCH-870	6/10/29	112	11.7	0.24	2.44E-04	1.68E-04	1.60E-02	8.00E-03	6.00E-03	3.94E-01	6.40E-02	3.76E-01	1.35E-01	1.16E-26	3.97E-06	1.39E-05	1.64E-04	1.00E-03	6.90E-11
BATCH-871	6/22/29	40	4.1	0.24	3.44E-05	3.12E-05	8.10E-04	4.74E-04	8.02E-04	2.20E-02	4.00E-03	8.30E-02	8.00E-03	8.26E-28	2.25E-07	3.40E-06	1.09E-05	8.90E-05	1.73E-08
BATCH-872	6/24/29	148	15.4	0.24	1.30E-04	1.10E-04	5.00E-03	2.00E-03	3.00E-03	1.19E-01	1.90E-02	2.87E-01	4.00E-02	4.38E-27	1.17E-06	1.15E-05	6.02E-05	4.31E-04	5.32E-08
BATCH-873	6/26/29	14	1.5	0.24	8.24E-06	7.48E-06	1.94E-04	1.14E-04	1.92E-04	5.00E-03	8.78E-04	2.00E-02	2.00E-03	1.98E-28	5.39E-08	8.15E-07	2.62E-06	2.13E-05	4.15E-09
BATCH-874	6/28/29	113	11.8	0.24	2.46E-04	1.69E-04	1.60E-02	8.00E-03	7.00E-03	3.97E-01	6.50E-02	3.78E-01	1.36E-01	1.16E-26	4.00E-06	1.41E-05	1.65E-04	1.00E-03	3.59E-11
BATCH-875	7/9/29	122	12.7	0.24	5.74E-05	3.72E-05	5.00E-03	2.00E-03	1.00E-03	1.01E-01	1.60E-02	9.20E-02	3.20E-02	4.18E-27	9.43E-07	3.51E-06	5.99E-05	3.67E-04	1.32E-08
BATCH-876	7/10/29	135	14.0	0.24	2.93E-04	2.01E-04	1.90E-02	1.00E-02	8.00E-03	4.73E-01	7.70E-02	4.51E-01	1.61E-01	1.39E-26	4.76E-06	1.67E-05	1.97E-04	1.00E-03	4.27E-11
BATCH-877	7/22/29	14	1.5	0.24	8.22E-06	7.46E-06	1.94E-04	1.13E-04	1.92E-04	5.00E-03	8.77E-04	2.00E-02	2.00E-03	1.97E-28	5.38E-08	8.13E-07	2.62E-06	2.13E-05	4.14E-09
BATCH-878	7/24/29	149	15.5	0.24	3.06E-04	2.08E-04	2.00E-02	1.00E-02	8.00E-03	4.96E-01	8.10E-02	4.66E-01	1.68E-01	1.48E-26	4.95E-06	1.73E-05	2.11E-04	1.00E-03	4.95E-10
BATCH-879	7/24/29	48	5.0	0.24	3.74E-05	3.16E-05	1.00E-03	7.10E-04	8.93E-04	3.40E-02	6.00E-03	8.30E-02	1.10E-02	1.26E-27	3.38E-07	3.32E-06	1.74E-05	1.24E-04	1.53E-08
BATCH-880	7/29/29	121	12.7	0.24	7.44E-05	4.99E-05	6.00E-03	3.00E-03	2.00E-03	1.24E-01	2.00E-02	1.17E-01	4.10E-02	4.33E-27	1.22E-06	4.38E-06	6.17E-05	3.78E-04	7.26E-09
BATCH-881	8/9/29	53	5.6	0.24	2.27E-05	1.47E-05	2.00E-03	7.88E-04	5.66E-04	4.00E-02	6.00E-03	3.60E-02	1.30E-02	1.65E-27	3.73E-07	1.39E-06	2.37E-05	1.45E-04	5.22E-09

Appendix A Nominal tLAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-833	12/26/28	15	1.6	0.24	3.94E+01	0.00E+00	5.47E-13	1.11E-05	5.05E-13	1.20E-26	2.00E-03	1.60E-02	5.23E-12	2.58E-04	5.19E-01	0.00E+00	1.47E+00	0.00E+00	1.60E-06
BATCH-834	12/27/28	128	13.3	0.24	4.62E+02	0.00E+00	8.45E-12	3.45E-06	3.40E-11	9.22E-25	1.10E-02	3.31E-01	2.85E-10	1.50E-02	1.21E+01	0.00E+00	1.60E+01	0.00E+00	6.54E-06
BATCH-835	12/28/28	145	15.1	0.24	4.85E+02	0.00E+00	9.52E-12	4.36E-06	3.77E-11	3.92E-25	1.20E-02	3.67E-01	3.22E-10	1.80E-02	1.44E+01	0.00E+00	1.67E+01	0.00E+00	7.61E-06
BATCH-836	1/9/29	48	5.0	0.24	1.52E-09	4.22E+01	1.12E-07	2.46E-06	4.20E-08	1.36E-40	3.00E-03	3.31E-01	9.97E-08	4.00E-03	1.16E+01	0.00E+00	5.27E-11	1.18E+01	5.06E-06
BATCH-837	1/12/29	157	16.4	0.24	6.20E+02	0.00E+00	3.01E-08	2.65E-06	1.13E-08	3.73E-31	1.00E-02	5.98E-01	2.70E-08	1.30E-02	1.22E+01	0.00E+00	3.05E+01	0.00E+00	6.70E-06
BATCH-838	1/15/29	150	15.7	0.24	5.26E+02	0.00E+00	1.87E-10	2.08E-06	1.28E-10	1.06E-25	1.20E-02	3.92E-01	6.30E-10	1.90E-02	1.45E+01	0.00E+00	1.86E+01	0.00E+00	9.20E-06
BATCH-839	1/29/29	70	7.3	0.24	4.00E-03	6.12E+01	1.63E-07	3.58E-06	6.11E-08	1.35E-30	4.00E-03	4.81E-01	1.45E-07	5.00E-03	1.69E+01	0.00E+00	1.66E-04	1.72E+01	7.34E-06
BATCH-840	1/30/29	49	5.1	0.24	1.60E+02	0.00E+00	2.93E-12	1.20E-06	1.18E-11	3.20E-25	4.00E-03	1.15E-01	9.89E-11	5.00E-03	4.20E+00	0.00E+00	5.56E+00	0.00E+00	2.27E-06
BATCH-841	2/5/29	47	4.9	0.24	1.41E+02	0.00E+00	2.77E-12	1.27E-06	1.10E-11	1.14E-25	3.00E-03	1.07E-01	9.39E-11	5.00E-03	4.20E+00	0.00E+00	4.87E+00	0.00E+00	2.22E-06
BATCH-842	2/5/29	160	16.7	0.24	6.47E+02	0.00E+00	3.00E-08	7.63E-07	1.13E-08	6.52E-35	1.10E-02	6.02E-01	2.70E-08	1.40E-02	1.21E+01	0.00E+00	3.13E+01	0.00E+00	7.92E-06
BATCH-843	2/10/29	52	5.5	0.24	1.85E+02	0.00E+00	8.98E-09	7.89E-07	3.38E-09	1.11E-31	3.00E-03	1.78E-01	8.06E-09	4.00E-03	3.65E+00	0.00E+00	9.11E+00	0.00E+00	2.00E-06
BATCH-844	2/15/29	48	5.0	0.24	1.50E+02	0.00E+00	5.36E-11	5.94E-07	3.66E-11	3.03E-26	3.00E-03	1.12E-01	1.80E-10	5.00E-03	4.14E+00	0.00E+00	5.32E+00	0.00E+00	2.63E-06
BATCH-845	2/21/29	17	1.8	0.24	3.85E+01	0.00E+00	7.04E-13	2.88E-07	2.84E-12	7.68E-26	9.29E-04	2.80E-02	2.38E-11	1.00E-03	1.01E+00	0.00E+00	1.34E+00	0.00E+00	5.45E-07
BATCH-846	2/22/29	50	5.2	0.24	2.31E-06	4.31E+01	1.15E-07	2.52E-06	4.30E-08	6.99E-34	3.00E-03	3.39E-01	1.02E-07	4.00E-03	1.19E+01	0.00E+00	8.60E-08	1.21E+01	5.17E-06
BATCH-847	2/23/29	16	1.7	0.24	3.39E+01	0.00E+00	6.66E-13	3.06E-07	2.64E-12	2.75E-26	8.14E-04	2.60E-02	2.26E-11	1.00E-03	1.01E+00	0.00E+00	1.17E+00	0.00E+00	5.33E-07
BATCH-848	2/25/29	18	1.8	0.24	4.36E+01	0.00E+00	2.12E-09	1.86E-07	7.97E-10	2.63E-32	7.20E-04	4.20E-02	1.90E-09	8.86E-04	8.61E-01	0.00E+00	2.15E+00	0.00E+00	4.71E-07
BATCH-849	2/27/29	17	1.7	0.24	3.61E+01	0.00E+00	1.29E-11	1.43E-07	8.79E-12	7.27E-27	8.36E-04	2.70E-02	4.33E-11	1.00E-03	9.93E-01	0.00E+00	1.28E+00	0.00E+00	6.32E-07
BATCH-850	2/28/29	52	5.4	0.24	1.87E+02	0.00E+00	8.67E-09	2.21E-07	3.27E-09	1.89E-35	3.00E-03	1.74E-01	7.82E-09	4.00E-03	3.51E+00	0.00E+00	9.07E+00	0.00E+00	2.29E-06
BATCH-851	3/1/29	70	7.3	0.24	4.00E-03	6.11E+01	1.63E-07	3.57E-06	6.10E-08	8.50E-30	4.00E-03	4.81E-01	1.45E-07	5.00E-03	1.68E+01	0.00E+00	1.48E-04	1.72E+01	7.33E-06
BATCH-852	3/5/29	70	7.3	0.24	4.00E-03	6.11E+01	1.63E-07	3.57E-06	6.09E-08	3.15E-30	4.00E-03	4.80E-01	1.45E-07	5.00E-03	1.68E+01	0.00E+00	1.34E-04	1.72E+01	7.32E-06
BATCH-853	3/8/29	155	16.1	0.24	6.74E+02	0.00E+00	7.74E-08	1.70E-06	2.90E-08	3.76E-31	4.00E-03	8.92E-01	6.88E-08	3.00E-03	8.01E+00	0.00E+00	4.67E+01	0.00E+00	3.49E-06
BATCH-854	3/13/29	119	12.4	0.24	4.00E-03	1.16E+02	1.33E-07	1.20E-05	5.74E-08	2.31E-36	7.00E-03	5.39E-01	7.14E-08	3.60E-02	3.13E+01	0.00E+00	1.89E-04	8.31E+00	3.88E-06
BATCH-855	3/24/29	168	17.5	0.24	5.00E-03	1.70E+02	1.38E-07	1.92E-05	6.51E-08	9.47E-31	1.10E-02	6.68E-01	3.94E-08	6.10E-02	4.54E+01	0.00E+00	1.67E-04	4.37E+00	2.47E-06
BATCH-856	3/25/29	17	1.8	0.24	4.39E+01	0.00E+00	2.03E-09	5.18E-08	7.66E-10	4.43E-36	7.29E-04	4.10E-02	1.83E-09	9.33E-04	8.24E-01	0.00E+00	2.13E+00	0.00E+00	5.38E-07
BATCH-857	3/27/29	119	12.4	0.24	2.59E-06	1.20E+02	9.72E-08	1.35E-05	4.59E-08	5.17E-33	8.00E-03	4.71E-01	2.79E-08	4.30E-02	3.20E+01	0.00E+00	8.98E-08	3.09E+00	1.75E-06
BATCH-858	4/9/29	119	12.4	0.24	2.36E-06	1.20E+02	9.72E-08	1.35E-05	4.59E-08	1.91E-33	8.00E-03	4.71E-01	2.79E-08	4.30E-02	3.20E+01	0.00E+00	8.15E-08	3.09E+00	1.75E-06
BATCH-859	4/11/29	42	4.4	0.24	1.64E+02	0.00E+00	1.89E-08	4.15E-07	7.08E-09	9.16E-32	1.00E-03	2.18E-01	1.68E-08	6.23E-04	1.95E+00	0.00E+00	1.14E+01	0.00E+00	8.50E-07
BATCH-860	4/16/29	120	12.5	0.24	2.31E-06	1.21E+02	9.81E-08	1.36E-05	4.63E-08	1.39E-39	8.00E-03	4.75E-01	2.81E-08	4.30E-02	3.23E+01	0.00E+00	1.14E-07	3.11E+00	1.76E-06
BATCH-861	4/21/29	168	17.5	0.24	6.00E-03	1.69E+02	1.37E-07	1.91E-05	6.49E-08	6.15E-40	1.10E-02	6.66E-01	3.93E-08	6.10E-02	4.52E+01	0.00E+00	2.95E-04	4.36E+00	2.46E-06
BATCH-862	4/28/29	125	13.1	0.24	4.96E+02	0.00E+00	5.54E-08	2.61E-06	2.19E-08	2.27E-30	8.00E-03	6.38E-01	4.21E-08	7.00E-03	8.42E+00	0.00E+00	3.14E+01	0.00E+00	2.17E-06
BATCH-863	5/9/29	140	14.6	0.24	2.41E-06	1.42E+02	1.15E-07	1.60E-05	5.43E-08	4.84E-34	9.00E-03	5.57E-01	3.29E-08	5.10E-02	3.79E+01	0.00E+00	8.52E-08	3.65E+00	2.06E-06
BATCH-864	5/12/29	15	1.6	0.24	3.92E+01	0.00E+00	4.50E-09	9.88E-08	1.69E-09	2.18E-32	2.48E-04	5.20E-02	4.00E-09	1.49E-04	4.65E-01	0.00E+00	2.72E+00	0.00E+00	2.03E-07
BATCH-865	5/13/29	125	13.0	0.24	4.95E+02	0.00E+00	5.52E-08	2.60E-06	2.19E-08	8.39E-31	8.00E-03	6.37E-01	4.20E-08	7.00E-03	8.40E+00	0.00E+00	3.14E+01	0.00E+00	2.17E-06
BATCH-866	5/24/29	95	9.9	0.24	1.32E-09	1.07E+02	3.19E-09	7.04E-07	1.50E-09	7.97E-43	6.00E-03	3.47E-01	1.07E-09	2.70E-02	2.59E+01	0.00E+00	6.52E-11	2.98E+00	6.92E-06
BATCH-867	5/27/29	134	14.0	0.24	3.14E-06	1.51E+02	2.77E-10	4.20E-07	1.16E-10	3.16E-43	8.00E-03	4.86E-01	3.10E-10	3.70E-02	3.65E+01	0.00E+00	1.52E-07	4.21E+00	1.00E-05
BATCH-868	6/3/29	40	4.2	0.24	1.41E+02	0.00E+00	1.57E-08	7.41E-07	6.23E-09	6.46E-31	2.00E-03	1.81E-01	1.20E-08	2.00E-03	2.39E+00	0.00E+00	8.92E+00	0.00E+00	6.17E-07
BATCH-869	6/7/29	159	16.6	0.24	5.00E-03	1.80E+02	2.46E-10	4.89E-07	9.91E-11	3.01E-36	9.00E-03	5.79E-01	3.46E-10	4.40E-02	4.35E+01	0.00E+00	3.74E-04	5.02E+00	1.20E-05
BATCH-870	6/10/29	112	11.7	0.24	1.48E-09	1.26E+02	2.43E-10	3.54E-07	1.03E-10	2.97E-37	7.00E-03	4.07E-01	2.63E-10	3.10E-02	3.06E+01	0.00E+00	5.23E-11	3.53E+00	8.41E-06
BATCH-871	6/22/29	40	4.1	0.24	1.41E+02	0.00E+00	1.57E-08	7.40E-07	6.22E-09	2.39E-31	2.00E-03	1.81E-01	1.19E-08	2.00E-03	2.39E+00	0.00E+00	8.91E+00	0.00E+00	6.15E-07
BATCH-872	6/24/29	148	15.4	0.24	4.86E+02	0.00E+00	5.36E-08	3.43E-06	2.20E-08	1.45E-36	1.50E-02	5.92E-01	3.63E-08	1.20E-02	1.26E+01	0.00E+00	2.68E+01	0.00E+00	2.67E-06
BATCH-873	6/26/29	14	1.5	0.24	3.37E+01	0.00E+00	3.76E-09	1.77E-07	1.49E-09	1.54E-31	5.59E-04	4.30E-02	2.86E-09	4.55E-04	5.72E-01	0.00E+00	2.13E+00	0.00E+00	1.48E-07
BATCH-874	6/28/29	113	11.8	0.24	1.91E-09	1.27E+02	1.74E-10	3.47E-07	7.01E-11	1.93E-46	7.00E-03	4.10E-01	2.45E-10	3.10E-02	3.08E+01	0.00E+00	9.25E-11	3.56E+00	8.48E-06
BATCH-875	7/9/29	122	12.7	0.24	3.84E+02	0.00E+00	2.78E-08	3.90E-06	1.31E-08	1.05E-31	1.80E-02	4.14E-01	7.98E-09	1.60E-02	1.24E+01	0.00E+00	1.64E+01	0.00E+00	1.38E-06
BATCH-876	7/10/29	135	14.0	0.24	2.75E-06	1.52E+02	2.07E-10	4.13E-07	8.34E-11	1.54E-39	8.00E-03	4.88E-01	2.92E-10	3.70E-02	3.67E+01	0.00E+00	1.91E-07	4.23E+00	1.01E-05
BATCH-877	7/22/29	14	1.5	0.24	3.36E+01	0.00E+00	3.75E-09	1.77E-07	1.49E-09	5.70E-32	5.59E-04	4.30E-02	2.85E-09	4.54E-04	5.71E-01	0.00E+00	2.13E+00	0.00E+00	1.47E-07
BATCH-878	7/24/29	149	15.5	0.24	5.00E-03	1.64E+02	2.54E-10	4.91E-07	1.32E-10	2.14E-35	9.00E-03	5.38E-01	8.42E-10	4.20E-02	4.00E+01	0.00E+00	2.95E-04	4.42E+00	1.03E-05
BATCH-879	7/24/29	48	5.0	0.24	1.40E+02	0.00E+00	1.55E-08	9.88E-07	6.33E-09	4.17E-37	4.00E-03	1.70E-01	1.04E-08	4.00E-03	3.63E+00	0.00E+00	7.71E+00	0.00E+00	7.68E-07
BATCH-880	7/29/29	121	12.7	0.24	3.96E+02	0.00E+00	1.53E-08	2.20E-06	7.24E-09	6.84E-41	1.60E-02	3.88E-01	4.43E-09	1.40E-02	1.22E+01	0.00E+00	1.65E+01	0.00E+00	2.24E-06
BATCH-881	8/9/29	53	5.6	0.24	1.52E-02	0.00E+00	1.10E-08	1.54E-06	5.20E-09	4.13E-32	7.00E-03	1.64E-01	3.16E-09	6.00E-03	4.89E+00	0.00E+00	6.51E+00	0.00E+00	5.47E-07

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	NH+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-833	12/26/28	15	1.6	0.24	9.72E-14	2.56E+00	2.30E-02	0.00E+00	0.00E+00	9.49E-05	1.09E-01	1.03E-07	5.25E-12	2.01E-11	1.60E-02	5.71E-13	2.57E+02	0.00E+00	1.00E-03
BATCH-834	12/27/28	128	13.3	0.24	1.88E-11	2.01E+01	3.47E-01	0.00E+00	0.00E+00	4.00E-04	3.44E+00	1.18E-06	3.68E-10	3.20E-10	6.10E-02	1.56E-10	2.18E+03	0.00E+00	3.00E-02
BATCH-835	12/28/28	145	15.1	0.24	2.09E-11	2.37E+01	3.91E-01	0.00E+00	0.00E+00	4.00E-04	4.10E+00	1.46E-06	4.11E-10	3.77E-10	7.10E-02	1.73E-10	2.48E+03	0.00E+00	3.50E-02
BATCH-836	1/9/29	48	5.0	0.24	2.61E-10	6.85E+00	5.70E-02	0.00E+00	0.00E+00	1.31E-04	2.08E+00	1.19E-04	4.01E-08	1.44E-06	3.60E-02	1.85E-08	8.27E+02	0.00E+00	3.20E-02
BATCH-837	1/12/29	157	16.4	0.24	8.79E-11	1.76E+01	3.88E-01	0.00E+00	0.00E+00	4.00E-04	3.14E+00	3.28E-05	1.11E-08	3.88E-07	6.00E-02	5.11E-09	2.69E+03	0.00E+00	3.10E-02
BATCH-838	1/15/29	150	15.7	0.24	3.49E-11	2.61E+01	4.13E-01	0.00E+00	0.00E+00	6.00E-04	4.09E+00	1.18E-06	7.20E-10	2.65E-09	8.70E-02	3.18E-10	2.57E+03	0.00E+00	3.60E-02
BATCH-839	1/29/29	70	7.3	0.24	3.79E-10	9.90E+00	8.30E-02	0.00E+00	0.00E+00	1.90E-04	3.01E+00	1.73E-04	5.83E-08	2.10E-06	5.20E-02	2.69E-08	1.20E+03	0.00E+00	4.60E-02
BATCH-840	1/30/29	49	5.1	0.24	6.53E-12	6.98E+00	1.21E-01	0.00E+00	0.00E+00	1.35E-04	1.19E+00	4.10E-07	1.29E-10	1.11E-10	2.10E-02	5.42E-11	8.41E+02	0.00E+00	1.00E-02
BATCH-841	2/5/29	47	4.9	0.24	6.08E-12	6.90E+00	1.14E-01	0.00E+00	0.00E+00	1.32E-04	1.20E+00	4.25E-07	1.20E-10	1.10E-10	2.10E-02	5.04E-11	8.03E+02	0.00E+00	1.00E-02
BATCH-842	2/5/29	160	16.7	0.24	9.83E-11	1.93E+01	3.99E-01	0.00E+00	0.00E+00	4.00E-04	3.11E+00	3.22E-05	1.13E-08	3.86E-07	7.20E-02	5.18E-09	2.73E+03	0.00E+00	3.10E-02
BATCH-843	2/10/29	52	5.5	0.24	2.62E-11	5.25E+00	1.16E-01	0.00E+00	0.00E+00	1.05E-04	9.38E-01	9.77E-06	3.32E-09	1.16E-07	1.80E-02	1.53E-09	8.96E+02	0.00E+00	9.00E-03
BATCH-844	2/15/29	48	5.0	0.24	9.97E-12	7.45E+00	1.18E-01	0.00E+00	0.00E+00	1.55E-04	1.17E+00	3.36E-07	2.06E-10	7.57E-10	2.50E-02	9.09E-11	8.19E+02	0.00E+00	1.00E-02
BATCH-845	2/21/29	17	1.8	0.24	1.57E-12	1.68E+00	2.90E-02	0.00E+00	0.00E+00	3.24E-05	2.87E-01	9.84E-08	3.07E-11	2.67E-11	5.00E-03	1.30E-11	2.92E+02	0.00E+00	2.00E-03
BATCH-846	2/22/29	50	5.2	0.24	2.67E-10	6.98E+00	5.80E-02	0.00E+00	0.00E+00	1.34E-04	2.12E+00	1.22E-04	4.11E-08	1.48E-06	3.70E-02	1.89E-08	8.46E+02	0.00E+00	3.20E-02
BATCH-847	2/23/29	16	1.7	0.24	1.46E-12	1.66E+00	2.70E-02	0.00E+00	0.00E+00	3.17E-05	2.87E-01	1.02E-07	2.88E-11	2.64E-11	5.00E-03	1.21E-11	2.80E+02	0.00E+00	2.00E-03
BATCH-848	2/25/29	18	1.8	0.24	6.18E-12	1.24E+00	2.70E-02	0.00E+00	0.00E+00	2.47E-05	2.21E-01	2.31E-06	7.83E-10	2.73E-08	4.00E-03	3.60E-10	3.00E+02	0.00E+00	2.00E-03
BATCH-849	2/27/29	17	1.7	0.24	2.40E-12	1.79E+00	2.80E-02	0.00E+00	0.00E+00	3.72E-05	2.81E-01	8.07E-08	4.94E-11	1.82E-10	6.00E-03	2.18E-11	2.86E+02	0.00E+00	2.00E-03
BATCH-850	2/28/29	52	5.4	0.24	2.85E-11	5.60E+00	1.16E-01	0.00E+00	0.00E+00	1.21E-04	8.99E-01	9.32E-06	3.26E-09	1.12E-07	2.10E-02	1.50E-09	8.85E+02	0.00E+00	9.00E-03
BATCH-851	3/1/29	70	7.3	0.24	3.79E-10	9.89E+00	8.30E-02	0.00E+00	0.00E+00	1.89E-04	3.01E+00	1.73E-04	5.83E-08	2.09E-06	5.20E-02	2.68E-08	1.20E+03	0.00E+00	4.60E-02
BATCH-852	3/5/29	70	7.3	0.24	3.78E-10	9.88E+00	8.30E-02	0.00E+00	0.00E+00	1.89E-04	3.01E+00	1.73E-04	5.82E-08	2.09E-06	5.20E-02	2.68E-08	1.20E+03	0.00E+00	4.60E-02
BATCH-853	3/8/29	155	16.1	0.24	1.80E-10	4.71E+00	3.13E-01	0.00E+00	0.00E+00	9.01E-05	1.43E+00	8.22E-05	2.77E-08	9.96E-07	2.50E-02	1.28E-08	2.64E+03	0.00E+00	2.20E-02
BATCH-854	3/13/29	119	12.4	0.24	4.43E-10	3.09E+01	5.26E-01	0.00E+00	0.00E+00	4.00E-04	8.25E+00	2.40E-04	4.50E-08	2.79E-06	3.50E-02	1.58E-08	2.02E+03	0.00E+00	7.80E-02
BATCH-855	3/24/29	168	17.5	0.24	5.59E-10	4.90E+01	8.85E-01	0.00E+00	0.00E+00	6.00E-04	1.28E+01	3.22E-04	4.48E-08	3.70E-06	3.10E-02	1.19E-08	2.87E+03	0.00E+00	1.11E-01
BATCH-856	3/25/29	17	1.8	0.24	6.67E-12	1.31E+00	2.70E-02	0.00E+00	0.00E+00	2.84E-05	2.11E-01	2.19E-06	7.65E-10	2.62E-08	5.00E-03	3.52E-10	2.96E+02	0.00E+00	2.00E-03
BATCH-857	3/27/29	119	12.4	0.24	3.94E-10	3.45E+01	6.24E-01	0.00E+00	0.00E+00	4.00E-04	9.05E+00	2.27E-04	3.16E-08	2.61E-06	2.20E-02	8.43E-09	2.03E+03	0.00E+00	7.80E-02
BATCH-858	4/9/29	119	12.4	0.24	3.94E-10	3.45E+01	6.24E-01	0.00E+00	0.00E+00	4.00E-04	9.05E+00	2.27E-04	3.16E-08	2.61E-06	2.20E-02	8.43E-09	2.03E+03	0.00E+00	7.80E-02
BATCH-859	4/11/29	42	4.4	0.24	4.39E-11	1.15E+00	7.60E-02	0.00E+00	0.00E+00	2.20E-05	3.49E-01	2.00E-05	6.76E-09	2.43E-07	6.00E-03	3.11E-09	7.25E+02	0.00E+00	5.00E-03
BATCH-860	4/16/29	120	12.5	0.24	3.98E-10	3.48E+01	6.30E-01	0.00E+00	0.00E+00	4.00E-04	9.13E+00	2.29E-04	3.19E-08	2.63E-06	2.20E-02	8.50E-09	2.04E+03	0.00E+00	7.90E-02
BATCH-861	4/21/29	168	17.5	0.24	5.57E-10	4.88E+01	8.83E-01	0.00E+00	0.00E+00	4.00E-04	1.28E+01	3.21E-04	4.47E-08	3.68E-06	3.10E-02	1.19E-08	2.86E+03	0.00E+00	1.11E-01
BATCH-862	4/28/29	125	13.1	0.24	1.50E-10	6.87E+00	3.05E-01	0.00E+00	0.00E+00	9.39E-05	1.91E+00	7.40E-05	1.94E-08	8.79E-07	1.70E-02	8.20E-09	2.14E+03	0.00E+00	2.20E-02
BATCH-863	5/9/29	140	14.6	0.24	4.66E-10	4.09E+01	7.39E-01	0.00E+00	0.00E+00	4.00E-04	1.07E+01	2.68E-04	3.74E-08	3.08E-06	2.60E-02	9.96E-09	2.40E+03	0.00E+00	9.30E-02
BATCH-864	5/12/29	15	1.6	0.24	1.05E-11	2.73E-01	1.80E-02	0.00E+00	0.00E+00	5.24E-06	8.30E-02	4.78E-06	1.61E-09	5.79E-08	1.00E-03	7.42E-10	2.58E+02	0.00E+00	1.00E-03
BATCH-865	5/13/29	125	13.0	0.24	1.49E-10	6.86E+00	3.04E-01	0.00E+00	0.00E+00	9.37E-05	1.91E+00	7.38E-05	1.94E-08	8.77E-07	1.70E-02	8.18E-09	2.14E+03	0.00E+00	2.20E-02
BATCH-866	5/24/29	95	9.9	0.24	1.26E-11	2.58E+01	4.17E-01	0.00E+00	0.00E+00	6.00E-04	7.34E+00	1.22E-04	1.75E-09	8.97E-08	1.12E-01	2.64E-10	1.63E+03	0.00E+00	6.00E-02
BATCH-867	5/27/29	134	14.0	0.24	6.27E-13	3.62E+01	5.82E-01	0.00E+00	0.00E+00	8.00E-04	1.03E+01	1.69E-04	1.13E-09	1.35E-08	1.63E-01	6.12E-12	2.29E+03	0.00E+00	8.40E-02
BATCH-868	6/3/29	40	4.2	0.24	4.25E-11	1.95E+00	8.60E-02	0.00E+00	0.00E+00	2.67E-05	5.43E-01	2.10E-05	5.52E-09	2.50E-07	5.00E-03	2.33E-09	6.81E+02	0.00E+00	6.00E-03
BATCH-869	6/7/29	159	16.6	0.24	4.07E-13	4.31E+01	6.93E-01	0.00E+00	0.00E+00	1.00E-03	1.23E+01	2.01E-04	1.32E-09	1.39E-08	1.95E-01	1.02E-13	2.72E+03	0.00E+00	1.00E-01
BATCH-870	6/10/29	112	11.7	0.24	5.71E-13	3.03E+01	4.87E-01	0.00E+00	0.00E+00	6.66E-04	1.41E-04	9.48E-10	1.16E-08	1.37E-01	6.11E-12	1.92E+03	0.00E+00	7.00E-02
BATCH-871	6/22/29	40	4.1	0.24	4.24E-11	1.95E+00	8.60E-02	0.00E+00	0.00E+00	2.66E-05	5.42E-01	2.10E-05	5.51E-09	2.49E-07	5.00E-03	2.32E-09	6.80E+02	0.00E+00	6.00E-03
BATCH-872	6/24/29	148	15.4	0.24	1.58E-10	1.16E+01	3.82E-01	0.00E+00	0.00E+00	1.69E-04	3.20E+00	9.39E-05	1.87E-08	9.56E-07	2.80E-02	7.36E-09	2.53E+03	0.00E+00	3.10E-02
BATCH-873	6/26/29	14	1.5	0.24	1.02E-11	4.67E-01	2.10E-02	0.00E+00	0.00E+00	6.37E-06	1.30E-01	5.02E-06	1.32E-09	5.97E-08	1.00E-03	5.57E-10	2.40E+02	0.00E+00	1.00E-03
BATCH-874	6/28/29	113	11.8	0.24	2.88E-13	3.05E+01	4.91E-01	0.00E+00	0.00E+00	6.00E-04	8.72E+00	1.42E-04	9.32E-10	9.82E-09	1.38E-01	3.73E-15	1.93E+03	0.00E+00	7.10E-02
BATCH-875	7/9/29	122	12.7	0.24	1.13E-10	1.31E+01	3.90E-01	0.00E+00	0.00E+00	1.70E-04	3.50E+00	7.97E-05	9.13E-09	7.46E-07	2.10E-02	2.41E-09	2.08E+03	0.00E+00	3.00E-02
BATCH-876	7/10/29	135	14.0	0.24	3.42E-13	5.84E+01	0.00E+00	0.00E+00	0.00E+00	8.00E-04	1.04E+01	1.69E-04	1.11E-09	1.17E-08	1.64E-01	5.22E-17	2.30E+03	0.00E+00	8.40E-02
BATCH-877	7/22/29	14	1.5	0.24	1.01E-11	3.64E+01	2.10E-02	0.00E+00	0.00E+00	6.36E-06	1.30E-01	5.01E-06	1.32E-09	5.95E-08	1.00E-03	5.56E-10	2.39E+02	0.00E+00	1.00E-03
BATCH-878	7/24/29	149	15.5	0.24	1.11E-11	4.07E+01	6.41E-01	0.00E+00	0.00E+00	8.00E-04	1.14E+01	1.74E-04	2.86E-09	3.90E-08	1.67E-01	9.80E-09	2.54E+03	0.00E+00	9.20E-02
BATCH-879	7/24/29	48	5.0	0.24	4.54E-11	3.34E+00	1.10E-01	0.00E+00	0.00E+00	4.86E-05	9.20E-01	2.71E-05	5.38E-09	2.75E-07	8.00E-03	2.12E-09	8.15E+02	0.00E+00	9.00E-03
BATCH-880	7/29/29	121	12.7	0.24	6.20E-11	1.25E+01	3.63E-01	0.00E+00	0.00E+00	2.00E-04	3.44E+00	6.86E-05	5.18E-09	4.12E-07	3.50E-02	1.32E-09	2.07E+03	0.00E+00	2.90E-02
BATCH-881	8/9/29	53	5.6	0.24	4.46E-11	5.17E+00	1.54E-01	0.00E+00	0.00E+00	6.71E-05	1.38E+00	3.15E-05	3.61E-09	2.95E-07	8.00E-03	9.52E-10	9.14E+02	0.00E+00	1.20E-02

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-833	12/26/28	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-04	4.21E+00	5.97E-14	1.33E+00	9.86E-01	2.86E-05	7.63E-14	0.00E+00	1.96E-04	1.60E-07	1.00E-02
BATCH-834	12/27/28	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.83E+01	5.30E-13	7.11E+00	1.39E+01	1.40E-02	1.61E-11	0.00E+00	1.00E-03	5.17E-08	4.50E-02
BATCH-835	12/28/28	145	15.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.16E+01	5.96E-13	7.46E+00	1.63E+01	1.70E-02	1.78E-11	0.00E+00	2.00E-03	6.51E-08	5.20E-02
BATCH-836	1/9/29	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.43E+00	5.05E-10	1.48E+00	7.80E+00	9.00E-03	1.97E-10	0.00E+00	2.00E-03	5.18E-06	1.40E-02
BATCH-837	1/12/29	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.38E+01	1.36E-10	8.15E+00	1.26E+01	1.30E-02	6.84E-11	0.00E+00	2.00E-03	1.42E-06	4.10E-02
BATCH-838	1/15/29	150	15.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.27E+01	1.69E-12	8.13E+00	1.64E+01	1.80E-02	3.02E-11	0.00E+00	2.00E-03	4.14E-08	6.30E-02
BATCH-839	1/29/29	70	7.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.86E+00	7.34E-10	2.15E+00	1.13E+01	1.30E-02	2.87E-10	0.00E+00	3.00E-03	7.53E-06	2.10E-02
BATCH-840	1/30/29	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-04	9.82E+00	1.84E-13	2.47E+00	4.81E+00	5.00E-03	5.57E-12	0.00E+00	4.99E-04	1.79E-08	1.60E-02
BATCH-841	2/5/29	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.93E-04	9.21E+00	1.74E-13	2.17E+00	4.76E+00	5.00E-03	5.17E-12	0.00E+00	4.56E-04	1.90E-08	1.50E-02
BATCH-842	2/5/29	160	16.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.45E+01	1.36E-10	8.69E+00	1.25E+01	1.50E-02	7.78E-11	0.00E+00	2.00E-03	1.39E-06	4.90E-02
BATCH-843	2/10/29	52	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.99E-04	7.11E+00	4.06E-11	2.43E+00	3.76E+00	4.00E-03	2.04E-11	0.00E+00	5.42E-04	4.25E-07	1.20E-02
BATCH-844	2/15/29	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.42E-04	9.35E+00	4.84E-13	2.33E+00	4.69E+00	5.00E-03	8.65E-12	0.00E+00	5.14E-04	1.18E-08	1.80E-02
BATCH-845	2/21/29	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-04	2.36E+00	4.42E-14	5.93E-01	1.16E+00	1.00E-03	1.34E-12	0.00E+00	1.20E-04	4.31E-09	4.00E-03
BATCH-846	2/22/29	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	5.54E+00	5.17E-10	1.52E+00	7.97E+00	9.00E-03	2.02E-10	0.00E+00	2.00E-03	5.31E-06	1.40E-02
BATCH-847	2/23/29	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E-04	2.21E+00	4.17E-14	5.22E-01	1.14E+00	1.00E-03	1.24E-12	0.00E+00	4.56E-09	4.00E-03	
BATCH-848	2/25/29	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-04	1.68E+00	9.59E-12	5.73E-01	8.87E-01	9.47E-04	4.81E-12	0.00E+00	1.28E-04	1.00E-07	3.00E-03
BATCH-849	2/27/29	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E-04	2.25E+00	1.16E-13	5.59E-01	1.13E+00	1.00E-03	2.08E-12	0.00E+00	1.23E-04	2.84E-09	4.00E-03
BATCH-850	2/28/29	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	7.09E+00	3.93E-11	2.52E+00	3.63E+00	4.00E-03	2.25E-11	0.00E+00	5.92E-04	4.02E-07	1.40E-02
BATCH-851	3/1/29	70	7.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.85E+00	7.33E-10	2.15E+00	1.13E+01	1.30E-02	2.87E-10	0.00E+00	3.00E-03	7.53E-06	2.10E-02
BATCH-852	3/5/29	70	7.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	7.84E+00	7.33E-10	2.15E+00	1.13E+01	1.30E-02	2.86E-10	0.00E+00	3.00E-03	7.52E-06	2.10E-02
BATCH-853	3/8/29	155	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	5.83E+00	3.49E-10	6.69E+00	5.61E+00	6.00E-03	1.36E-10	0.00E+00	2.00E-03	3.58E-06	1.00E-02
BATCH-854	3/13/29	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	3.25E+01	5.45E-10	1.52E+00	3.03E+01	4.00E-02	1.63E-10	0.00E+00	4.00E-03	3.48E-06	2.40E-02
BATCH-855	3/24/29	168	17.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.29E+01	5.24E-10	1.41E+00	4.69E+01	6.30E-02	1.16E-10	0.00E+00	5.00E-03	1.63E-06	3.10E-02
BATCH-856	3/25/29	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.37E-04	1.66E+00	9.21E-12	5.90E-01	8.51E-01	9.87E-04	5.28E-12	0.00E+00	1.39E-04	9.43E-08	3.00E-03
BATCH-857	3/27/29	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.73E+01	3.70E-10	9.94E-01	3.31E+01	4.40E-02	8.21E-11	0.00E+00	3.00E-03	1.15E-06	2.20E-02
BATCH-858	4/9/29	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.73E+01	3.70E-10	9.94E-01	3.31E+01	4.40E-02	8.21E-11	0.00E+00	3.00E-03	1.15E-06	2.20E-02
BATCH-859	4/11/29	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.42E+00	8.50E-11	1.63E+00	1.37E+00	1.00E-03	3.32E-11	0.00E+00	4.10E-04	8.73E-07	2.00E-03
BATCH-860	4/16/29	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.77E+01	3.73E-10	1.00E+00	3.34E+01	4.50E-02	8.28E-11	0.00E+00	3.00E-03	1.16E-06	2.20E-02
BATCH-861	4/21/29	168	17.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.28E+01	5.23E-10	1.41E+00	4.68E+01	6.30E-02	1.16E-10	0.00E+00	5.00E-03	2.15E-06	3.10E-02
BATCH-862	4/28/29	125	13.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.24E+01	2.41E-10	5.87E+00	7.49E+00	9.00E-03	8.67E-11	0.00E+00	1.00E-03	2.15E-06	8.00E-03
BATCH-863	5/9/29	140	14.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.42E+01	4.37E-10	1.18E+00	3.92E+01	5.30E-02	9.70E-11	0.00E+00	4.00E-03	1.36E-06	2.60E-02
BATCH-864	5/12/29	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.98E-04	3.39E-01	2.03E-11	3.89E-01	3.26E-01	3.47E-04	7.92E-12	0.00E+00	9.78E-05	2.08E-07	5.68E-04
BATCH-865	5/13/29	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.24E+01	2.41E-10	5.86E+00	7.47E+00	9.00E-03	8.64E-11	0.00E+00	1.00E-03	2.15E-06	8.00E-03
BATCH-866	5/24/29	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.16E-11	8.80E-01	2.71E+01	2.40E-02	2.57E-12	0.00E+00	3.00E-03	4.11E-08	1.90E-02	
BATCH-867	5/27/29	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.60E+01	2.69E-13	1.24E+00	3.82E+01	3.30E-02	5.96E-14	0.00E+00	4.00E-03	8.33E-09	2.70E-02
BATCH-868	6/3/29	40	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.57E-04	3.52E+00	6.85E-11	1.67E+00	2.13E+00	2.00E-03	2.46E-11	0.00E+00	3.85E-04	6.11E-07	2.00E-03
BATCH-869	6/7/29	159	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.29E+01	2.79E-15	1.48E+00	4.55E+01	4.00E-02	1.09E-15	0.00E+00	4.00E-03	8.96E-09	3.30E-02
BATCH-870	6/10/29	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.02E+01	2.68E-13	1.04E+00	3.20E+01	2.80E-02	5.95E-14	0.00E+00	3.00E-03	7.11E-09	2.30E-02
BATCH-871	6/22/29	40	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.54E-04	3.52E+00	6.84E-11	1.67E+00	2.12E+00	2.00E-03	2.46E-11	0.00E+00	3.84E-04	6.10E-07	2.00E-03
BATCH-872	6/24/29	148	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.37E+01	2.28E-10	7.15E+00	1.26E+01	1.40E-02	7.71E-11	0.00E+00	2.00E-03	1.83E-06	1.10E-02
BATCH-873	6/26/29	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-04	8.42E-01	1.64E-11	3.98E-01	5.09E-01	5.97E-04	5.89E-12	0.00E+00	9.19E-05	1.46E-07	5.54E-04
BATCH-874	6/28/29	113	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.04E+01	1.64E-16	1.05E+00	3.22E+01	2.80E-02	3.63E-17	0.00E+00	3.00E-03	6.33E-09	2.30E-02
BATCH-875	7/9/29	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.82E+01	1.06E-10	6.58E+00	1.37E+01	1.60E-02	2.35E-11	0.00E+00	1.00E-03	3.29E-07	9.00E-03
BATCH-876	7/10/29	135	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.62E+01	1.43E-18	1.25E+00	3.84E+01	3.30E-02	5.57E-19	0.00E+00	4.00E-03	7.54E-09	2.80E-02
BATCH-877	7/22/29	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-04	8.42E-01	1.63E-11	3.98E-01	5.08E-01	5.96E-04	5.87E-12	0.00E+00	9.18E-05	1.46E-07	5.53E-04
BATCH-878	7/24/29	149	15.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.03E+01	9.50E-12	1.37E+00	4.26E+01	3.70E-02	1.20E-09	0.00E+00	4.00E-03	7.29E-08	2.90E-02
BATCH-879	7/24/29	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.81E-04	6.82E+00	6.58E-11	2.06E+00	3.62E+00	4.00E-03	2.22E-11	0.00E+00	5.05E-04	5.26E-07	3.00E-03
BATCH-880	7/29/29	121	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	2.68E+01	5.81E-11	6.37E+00	1.36E+01	1.30E-02	1.29E-11	0.00E+00	1.00E-03	1.82E-07	9.00E-03
BATCH-881	8/9/29	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.03E-04	1.11E+01	4.18E-11	2.60E+00	5.44E+00	6.00E-03	9.28E-12	0.00E+00	5.51E-04	1.30E-07	3.00E-03

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-882	8/11/29	133	13.9	0.24	0.00E+00	0.00E+00	4.20E-02	3.00E-03	3.12E+00	2.76E-01	1.47E+03	2.19E-01	2.00E-02	6.86E+00	1.89E-15	7.31E-01	2.45E-04	1.10E-02	9.50E-03
BATCH-883	8/15/29	186	19.4	0.24	0.00E+00	0.00E+00	5.80E-02	5.00E-03	4.37E+00	3.86E-01	2.05E+03	3.06E-01	2.80E-02	9.58E+00	2.63E-15	1.02E+00	3.42E-04	1.50E-02	1.35E-02
BATCH-884	8/25/29	17	1.7	0.24	0.00E+00	0.00E+00	1.00E-03	1.06E-04	1.03E-01	1.62E-02	6.32E+01	9.00E-03	5.68E-04	2.70E-01	4.83E-16	1.80E-02	6.58E-06	2.00E-03	2.15E-04
BATCH-885	8/27/29	146	15.2	0.24	0.00E+00	0.00E+00	4.60E-02	4.00E-03	3.42E+00	3.02E-01	1.61E+03	2.40E-01	2.20E-02	7.50E+00	2.06E-15	7.99E-01	2.68E-04	1.20E-02	1.05E-02
BATCH-886	9/3/29	51	5.4	0.24	0.00E+00	0.00E+00	7.00E-03	6.58E-04	5.30E-01	4.50E-02	2.72E+02	4.20E-02	3.00E-03	1.16E+00	4.55E-16	1.19E-01	4.17E-05	5.00E-03	1.25E-03
BATCH-887	9/9/29	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.45E-04	1.25E-01	1.17E-02	6.72E+01	1.00E-02	7.63E-04	2.78E-01	1.14E-16	2.90E-02	9.11E-06	8.98E-04	2.50E-04
BATCH-888	9/11/29	117	12.2	0.24	0.00E+00	0.00E+00	1.80E-02	2.00E-03	1.33E+00	1.06E-01	6.40E+02	1.04E-01	9.00E-03	2.85E+00	1.01E-15	2.91E-01	1.11E-04	1.20E-02	3.25E-03
BATCH-889	9/12/29	186	19.4	0.24	0.00E+00	0.00E+00	5.80E-02	5.00E-03	4.36E+00	3.85E-01	2.05E+03	3.06E-01	2.80E-02	9.57E+00	2.63E-15	1.02E+00	3.42E-04	1.50E-02	1.35E-02
BATCH-890	9/23/29	161	16.8	0.24	0.00E+00	0.00E+00	5.00E-02	4.00E-03	3.78E+00	3.34E-01	1.78E+03	2.65E-01	2.40E-02	8.30E+00	2.28E-15	8.84E-01	2.96E-04	1.30E-02	1.15E-02
BATCH-891	10/1/29	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.58E-04	1.28E-01	1.08E-02	6.54E+01	1.00E-02	8.31E-04	2.78E-01	1.09E-16	2.90E-02	1.00E-05	1.00E-03	2.50E-04
BATCH-892	10/3/29	126	13.1	0.24	0.00E+00	0.00E+00	3.90E-02	3.00E-03	2.95E+00	2.61E-01	1.39E+03	2.07E-01	1.90E-02	6.48E+00	1.78E-15	6.91E-01	2.31E-04	1.00E-02	9.00E-03
BATCH-893	10/10/29	183	19.1	0.24	0.00E+00	0.00E+00	5.20E-02	4.00E-03	3.91E+00	3.78E-01	1.72E+03	2.64E-01	2.70E-02	8.72E+00	2.13E-15	8.66E-01	3.25E-04	1.30E-02	1.28E-02
BATCH-894	10/16/29	49	5.1	0.24	0.00E+00	0.00E+00	7.00E-03	6.31E-04	4.97E-01	3.96E-02	2.39E+02	3.90E-02	3.00E-03	1.07E+00	3.76E-16	1.09E-01	4.15E-05	4.00E-03	1.25E-03
BATCH-895	10/22/29	168	17.5	0.24	0.00E+00	0.00E+00	4.40E-02	3.00E-03	3.31E+00	3.45E-01	1.37E+03	2.15E-01	2.40E-02	7.48E+00	1.62E-15	6.95E-01	2.89E-04	1.10E-02	1.15E-02
BATCH-896	10/30/29	193	20.1	0.24	0.00E+00	0.00E+00	5.10E-02	3.00E-03	3.81E+00	3.98E-01	1.58E+03	2.48E-01	2.80E-02	8.62E+00	1.87E-15	8.00E-01	3.33E-04	1.20E-02	1.30E-02
BATCH-897	11/8/29	145	15.1	0.24	0.00E+00	0.00E+00	3.80E-02	3.00E-03	2.87E+00	2.99E-01	1.18E+03	1.87E-01	2.10E-02	6.48E+00	1.41E-15	6.02E-01	2.51E-04	9.00E-03	9.75E-03
BATCH-898	11/19/29	114	11.8	0.24	0.00E+00	0.00E+00	3.00E-02	2.00E-03	2.24E+00	2.34E-01	9.27E+02	1.46E-01	1.60E-02	5.07E+00	1.10E-15	4.71E-01	1.96E-04	7.00E-03	7.75E-03
BATCH-899	11/24/29	17	1.7	0.24	0.00E+00	0.00E+00	2.00E-03	1.52E-04	1.20E-01	9.90E-03	5.76E+01	9.00E-03	8.20E-04	2.57E-01	9.05E-17	2.60E-02	1.00E-05	1.00E-03	2.50E-04
BATCH-900	11/26/29	163	17.0	0.24	0.00E+00	0.00E+00	4.30E-02	3.00E-03	3.21E+00	3.35E-01	1.33E+03	2.09E-01	2.30E-02	7.27E+00	1.58E-15	6.74E-01	2.81E-04	1.10E-02	1.10E-02
BATCH-901	12/1/29	147	15.3	0.24	0.00E+00	0.00E+00	3.90E-02	3.00E-03	2.90E+00	3.02E-01	1.20E+03	1.89E-01	2.10E-02	6.56E+00	1.42E-15	6.08E-01	2.53E-04	9.00E-03	1.00E-02
BATCH-902	12/13/29	160	16.6	0.24	0.00E+00	0.00E+00	3.60E-02	2.00E-03	2.71E+00	4.61E-01	8.72E+02	1.41E-01	3.60E-02	6.75E+00	9.24E-16	4.44E-01	3.13E-04	1.70E-02	1.15E-02
BATCH-903	12/17/29	121	12.6	0.24	0.00E+00	0.00E+00	2.50E-02	1.00E-03	1.91E+00	3.90E-01	5.25E+02	8.70E-02	3.10E-02	4.99E+00	5.04E-16	2.68E-01	2.48E-04	1.40E-02	9.00E-03
BATCH-904	12/29/29	182	19.0	0.24	0.00E+00	0.00E+00	3.80E-02	2.00E-03	2.88E+00	5.88E-01	7.91E+02	1.31E-01	4.70E-02	7.52E+00	7.60E-16	4.04E-01	3.74E-04	2.20E-02	1.35E-02
BATCH-905	12/30/29	155	16.1	0.24	0.00E+00	0.00E+00	2.20E-02	2.00E-03	1.66E+00	1.40E-01	7.84E+02	1.24E-01	1.10E-02	3.61E+00	1.15E-15	3.68E-01	1.38E-04	1.20E-02	4.50E-03
BATCH-906	1/15/30	135	14.1	0.24	0.00E+00	0.00E+00	2.90E-02	1.00E-03	2.13E+00	4.37E-01	5.75E+02	9.70E-02	3.30E-02	5.60E+00	2.85E-16	2.87E-01	2.17E-04	1.60E-02	1.00E-02
BATCH-907	1/18/30	122	12.7	0.24	0.00E+00	0.00E+00	2.60E-02	9.27E-04	1.92E+00	3.95E-01	5.20E+02	8.80E-02	3.00E-02	5.06E+00	2.57E-16	2.59E-01	1.96E-04	1.50E-02	9.00E-03
BATCH-908	1/29/30	131	13.6	0.24	0.00E+00	0.00E+00	1.40E-02	8.80E-04	1.06E+00	1.15E-01	4.49E+02	7.00E-02	8.00E-03	2.42E+00	2.86E-16	2.20E-01	7.28E-05	4.00E-03	3.50E-03
BATCH-909	1/31/30	138	14.4	0.24	0.00E+00	0.00E+00	2.90E-02	1.00E-03	2.16E+00	4.45E-01	5.85E+02	9.90E-02	3.40E-02	5.69E+00	2.90E-16	2.92E-01	2.21E-04	1.70E-02	1.03E-02
BATCH-910	2/12/30	54	5.6	0.24	0.00E+00	0.00E+00	7.00E-03	5.40E-04	5.19E-01	4.41E-02	2.41E+02	3.90E-02	3.00E-03	1.13E+00	1.82E-16	1.10E-01	3.38E-05	4.00E-03	1.50E-03
BATCH-911	2/14/30	159	16.6	0.24	0.00E+00	0.00E+00	3.40E-02	1.00E-03	2.50E+00	5.14E-01	6.75E+02	1.14E-01	3.90E-02	6.57E+00	3.34E-16	3.37E-01	2.55E-04	1.90E-02	1.18E-02
BATCH-912	2/18/30	116	12.1	0.24	0.00E+00	0.00E+00	3.10E-02	2.00E-03	2.30E+00	2.68E-01	7.90E+02	1.29E-01	2.00E-02	4.87E+00	4.59E-16	4.01E-01	1.53E-04	1.00E-02	7.50E-03
BATCH-913	3/2/30	128	13.4	0.24	0.00E+00	0.00E+00	1.30E-02	7.84E-04	9.89E-01	1.13E-01	4.02E+02	6.40E-02	8.00E-03	2.28E+00	2.50E-16	1.98E-01	7.03E-05	4.00E-03	3.50E-03
BATCH-914	3/3/30	59	6.2	0.24	0.00E+00	0.00E+00	6.00E-03	3.62E-04	4.36E-01	4.77E-02	1.85E+02	2.90E-02	3.00E-03	9.96E-01	1.18E-16	9.00E-02	2.99E-05	2.00E-03	1.50E-03
BATCH-915	3/9/30	123	12.9	0.24	0.00E+00	0.00E+00	3.70E-02	2.00E-03	2.76E+00	2.09E-01	1.04E+03	1.68E-01	1.40E-02	5.20E+00	6.35E-16	5.33E-01	1.40E-04	8.00E-03	7.25E-03
BATCH-916	3/16/30	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.29E-04	1.24E-01	1.08E-02	5.74E+01	9.00E-03	8.09E-04	2.71E-01	4.35E-17	2.60E-02	8.05E-06	8.91E-04	2.50E-04
BATCH-917	3/18/30	140	14.6	0.24	0.00E+00	0.00E+00	1.50E-02	8.09E-04	1.08E+00	1.37E-01	4.17E+02	6.60E-02	1.00E-02	2.53E+00	2.54E-16	2.06E-01	8.07E-05	5.00E-03	4.00E-03
BATCH-918	3/22/30	143	14.9	0.24	0.00E+00	0.00E+00	4.30E-02	3.00E-03	3.19E+00	2.42E-01	1.21E+03	1.94E-01	1.70E-02	6.02E+00	7.35E-16	6.17E-01	1.61E-04	1.00E-02	8.25E-03
BATCH-919	4/2/30	19	2.0	0.24	0.00E+00	0.00E+00	1.00E-03	8.65E-05	1.04E-01	1.17E-02	4.42E+01	7.00E-03	8.01E-04	2.38E-01	2.81E-17	2.20E-02	7.16E-06	4.23E-04	2.50E-04
BATCH-920	4/4/30	59	6.1	0.24	0.00E+00	0.00E+00	6.00E-03	3.25E-04	4.10E-01	4.68E-02	1.67E+02	2.60E-02	3.00E-03	9.47E-01	1.04E-16	8.20E-02	2.92E-05	2.00E-03	1.50E-03
BATCH-921	4/6/30	185	19.3	0.24	0.00E+00	0.00E+00	5.60E-02	3.00E-03	4.14E+00	3.14E-01	1.57E+03	2.52E-01	2.20E-02	7.81E+00	9.54E-16	8.01E-01	2.09E-04	1.30E-02	1.08E-02
BATCH-922	4/10/30	128	13.3	0.24	0.00E+00	0.00E+00	1.30E-02	6.57E-04	9.33E-01	1.19E-01	3.37E+02	5.50E-02	8.00E-03	2.14E+00	1.97E-16	1.69E-01	6.92E-05	4.00E-03	3.50E-03
BATCH-923	4/23/30	56	5.8	0.24	0.00E+00	0.00E+00	5.00E-03	2.91E-04	3.90E-01	4.95E-02	1.50E+02	2.40E-02	4.00E-03	9.09E-01	9.13E-17	7.40E-02	2.91E-05	2.00E-03	1.50E-03
BATCH-924	4/26/30	185	19.3	0.24	0.00E+00	0.00E+00	5.60E-02	3.00E-03	4.14E+00	3.13E-01	1.57E+03	2.52E-01	2.20E-02	7.80E+00	9.53E-16	8.00E-01	2.09E-04	1.30E-02	1.08E-02
BATCH-925	4/29/30	126	13.1	0.24	0.00E+00	0.00E+00	3.80E-02	2.00E-03	2.82E+00	2.13E-01	1.07E+03	1.72E-01	1.50E-02	5.31E+00	6.48E-16	5.44E-01	1.42E-04	9.00E-03	7.25E-03
BATCH-926	5/13/30	19	2.0	0.24	0.00E+00	0.00E+00	1.00E-03	7.67E-05	9.70E-02	1.08E-02	3.94E+01	6.00E-03	7.76E-04	2.24E-01	2.45E-17	1.90E-02	6.88E-06	3.92E-04	2.50E-04
BATCH-927	5/15/30	57	6.0	0.24	0.00E+00	0.00E+00	5.00E-03	2.68E-04	3.80E-01	4.86E-02	1.37E+02	2.20E-02	3.00E-03	8.71E-01	8.04E-17	6.90E-02	2.82E-05	2.00E-03	1.50E-03
BATCH-928	5/15/30	163	17.0	0.24	0.00E+00	0.00E+00	5.00E-02	3.00E-03	3.65E+00	2.76E-01	1.38E+03	2.23E-01	1.90E-02	6.89E+00	8.41E-16	7.06E-01	1.85E-04	1.10E-02	9.50E-03
BATCH-929	5/21/30	19	1.9	0.24	0.00E+00	0.00E+00	1.00E-03	6.95E-05	9.30E-02	1.17E-02	3.59E+01	6.00E-03	8.44E-04	2.17E-01	2.18E-17	1.80E-02	6.94E-06	4.28E-04	2.50E-04
BATCH-930	5/23/30	119	12.4	0.24	0.00E+00	0.00E+00	1.10E-02	5.39E-04	8.41E-01	1.17E-01	2.74E+02	4.50E-02	9.00E-03	1.89E+00	1.54E-16	1.39E-01	6.36E-05	4.00E-03	3.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-882	8/11/29	133	13.9	0.24	3.91E-08	3.99E+02	6.30E+00	1.00E-03	5.00E-02	3.00E-03	7.00E-06	2.10E-07	2.85E-04	7.78E-05	3.68E-05	1.60E-04	2.00E-03	1.00E-02	3.00E-03
BATCH-883	8/15/29	186	19.4	0.24	5.46E-08	5.58E+02	8.77E+00	1.00E-03	7.00E-02	4.00E-03	9.79E-06	2.92E-07	3.98E-04	1.09E-04	5.15E-05	2.24E-04	3.00E-03	1.40E-02	4.00E-03
BATCH-884	8/25/29	17	1.7	0.24	1.36E-09	5.03E+01	8.39E-01	6.17E-05	3.00E-03	1.64E-04	1.75E-05	2.72E-08	4.49E-06	9.88E-07	1.05E-06	2.68E-06	5.61E-05	3.01E-04	2.20E-04
BATCH-885	8/27/29	146	15.2	0.24	4.27E-08	4.37E+02	6.89E+00	1.00E-03	5.50E-02	3.00E-03	7.65E-06	2.29E-07	3.12E-04	8.51E-05	4.03E-05	1.75E-04	2.00E-03	1.10E-02	3.00E-03
BATCH-886	9/3/29	51	5.4	0.24	6.13E-09	1.54E+02	4.57E+00	3.31E-04	1.90E-02	8.78E-04	3.38E-06	1.48E-07	3.06E-05	6.43E-06	6.27E-06	1.74E-05	3.00E-04	2.00E-03	6.89E-04
BATCH-887	9/9/29	18	1.9	0.24	1.53E-09	5.43E+01	6.48E-01	4.73E-05	3.00E-03	1.25E-04	1.35E-06	2.10E-08	7.53E-06	1.45E-06	1.36E-06	3.89E-06	4.69E-05	2.52E-04	1.31E-04
BATCH-888	9/11/29	117	12.2	0.24	1.48E-08	3.51E+02	1.36E+01	1.00E-03	5.70E-02	3.00E-03	2.18E-06	4.41E-07	8.34E-05	2.03E-05	1.68E-05	5.06E-05	9.80E-04	5.00E-03	2.00E-03
BATCH-889	9/12/29	186	19.4	0.24	5.45E-08	5.58E+02	8.75E+00	1.00E-03	7.00E-02	4.00E-03	9.77E-06	2.91E-07	3.98E-04	1.09E-04	5.14E-05	2.24E-04	3.00E-03	1.40E-02	4.00E-03
BATCH-890	9/23/29	161	16.8	0.24	4.72E-08	4.83E+02	7.59E+00	1.00E-03	6.10E-02	3.00E-03	8.47E-06	2.53E-07	3.45E-04	9.42E-05	4.46E-05	1.94E-04	2.00E-03	1.20E-02	3.00E-03
BATCH-891	10/1/29	18	1.9	0.24	1.48E-09	5.33E+01	1.10E+00	7.97E-05	4.00E-03	2.11E-04	8.13E-07	3.57E-08	7.38E-06	1.55E-06	1.51E-06	4.18E-06	7.23E-05	3.88E-04	1.66E-04
BATCH-892	10/3/29	126	13.1	0.24	3.69E-08	3.78E+02	5.93E+00	9.52E-04	4.70E-02	3.00E-03	6.61E-06	1.97E-07	2.69E-04	7.36E-05	3.48E-05	1.51E-04	2.00E-03	9.00E-03	3.00E-03
BATCH-893	10/10/29	183	19.1	0.24	5.95E-08	5.49E+02	5.71E+00	2.00E-03	7.30E-02	4.00E-03	7.37E-06	1.97E-07	4.33E-04	1.34E-04	5.06E-05	2.56E-04	3.00E-03	1.60E-02	3.00E-03
BATCH-894	10/16/29	49	5.1	0.24	5.54E-09	1.46E+02	5.07E+00	3.85E-04	2.10E-02	1.00E-03	8.16E-07	1.65E-07	3.12E-05	7.59E-06	6.28E-06	1.89E-05	3.66E-04	2.00E-03	7.11E-04
BATCH-895	10/22/29	168	17.5	0.24	5.87E-08	5.02E+02	3.15E+00	2.00E-03	7.00E-02	4.00E-03	5.15E-06	1.17E-07	4.26E-04	1.42E-04	4.64E-05	2.60E-04	3.00E-03	1.70E-02	3.00E-03
BATCH-896	10/30/29	193	20.1	0.24	6.76E-08	5.79E+02	3.62E+00	2.00E-03	8.10E-02	5.00E-03	5.93E-06	1.35E-07	4.91E-04	1.63E-04	5.34E-05	3.00E-04	4.00E-03	1.90E-02	3.00E-03
BATCH-897	11/8/29	145	15.1	0.24	5.09E-08	4.35E+02	2.73E+00	1.00E-03	6.10E-02	4.00E-03	4.46E-06	1.01E-07	3.69E-04	1.23E-04	4.02E-05	2.26E-04	3.00E-03	1.40E-02	3.00E-03
BATCH-898	11/19/29	114	11.8	0.24	3.98E-08	3.40E+02	2.13E+00	1.00E-03	4.70E-02	3.00E-03	3.49E-06	7.92E-08	2.88E-04	9.59E-05	3.14E-05	1.76E-04	2.00E-03	1.10E-02	2.00E-03
BATCH-899	11/24/29	17	1.7	0.24	1.33E-09	5.02E+01	1.22E+00	9.28E-05	5.00E-03	2.46E-04	1.97E-07	3.97E-08	7.51E-06	1.83E-06	1.51E-06	4.56E-06	8.82E-05	4.74E-04	1.71E-04
BATCH-900	11/26/29	163	17.0	0.24	5.70E-08	4.88E+02	3.06E+00	1.00E-03	6.80E-02	4.00E-03	5.00E-06	1.14E-07	4.13E-04	1.38E-04	4.50E-05	2.53E-04	3.00E-03	1.60E-02	3.00E-03
BATCH-901	12/1/29	147	15.3	0.24	5.14E-08	4.40E+02	2.76E+00	1.00E-03	6.10E-02	4.00E-03	4.51E-06	1.02E-07	3.73E-04	1.24E-04	4.06E-05	2.28E-04	3.00E-03	1.40E-02	3.00E-03
BATCH-902	12/13/29	160	16.6	0.24	4.77E-08	4.78E+02	1.98E+00	4.00E-03	1.68E-01	1.40E-02	4.03E-06	8.58E-08	5.63E-04	2.29E-04	4.46E-05	3.85E-04	1.10E-02	6.10E-02	1.30E-02
BATCH-903	12/17/29	121	12.6	0.24	3.34E-08	3.62E+02	1.18E+00	4.00E-03	1.58E-01	1.40E-02	2.78E-05	5.69E-08	4.76E-04	2.03E-04	3.38E-05	3.34E-04	1.10E-02	6.00E-02	1.30E-02
BATCH-904	12/29/29	182	19.0	0.24	5.04E-08	5.45E+02	1.78E+00	5.00E-03	2.39E-01	2.10E-02	4.19E-06	8.58E-08	7.17E-04	3.06E-04	5.10E-05	5.03E-04	1.70E-02	9.10E-02	2.00E-02
BATCH-905	12/30/29	155	16.1	0.24	2.03E-08	4.64E+02	1.22E+01	1.00E-03	5.80E-02	3.00E-03	2.93E-06	3.99E-07	1.27E-04	3.41E-05	2.10E-05	7.57E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-906	1/15/30	135	14.1	0.24	2.68E-08	4.06E+02	1.32E+00	4.00E-03	1.64E-01	1.30E-02	3.12E-06	6.19E-08	4.81E-04	2.28E-04	3.80E-05	3.74E-04	1.20E-02	6.70E-02	1.50E-02
BATCH-907	1/18/30	122	12.7	0.24	2.42E-08	3.67E+02	1.19E+00	3.00E-03	1.48E-01	1.20E-02	2.82E-06	5.59E-08	4.35E-04	2.06E-04	3.43E-05	3.38E-04	1.10E-02	6.10E-02	1.30E-02
BATCH-908	1/29/30	131	13.6	0.24	1.09E-08	3.91E+02	1.69E+00	5.74E-04	2.60E-02	2.00E-03	2.13E-06	5.71E-08	1.17E-04	4.28E-05	1.40E-05	7.93E-05	1.00E-03	8.00E-03	2.00E-03
BATCH-909	1/31/30	138	14.4	0.24	2.73E-08	4.13E+02	1.34E+00	4.00E-03	1.67E-01	1.40E-02	3.17E-06	6.29E-08	4.90E-04	2.32E-04	3.86E-05	3.81E-04	1.30E-02	6.90E-02	1.50E-02
BATCH-910	2/12/30	54	5.6	0.24	4.56E-09	1.62E+02	3.82E+00	3.19E-04	1.70E-02	7.76E-04	9.22E-07	1.22E-07	3.60E-05	1.07E-05	6.59E-06	2.38E-05	3.76E-04	2.00E-03	6.53E-04
BATCH-911	2/14/30	159	16.6	0.24	3.15E-08	4.77E+02	1.54E+00	4.00E-03	1.92E-01	1.60E-02	3.66E-06	7.26E-08	5.65E-04	2.67E-04	4.46E-05	4.40E-04	1.50E-02	7.90E-02	1.70E-02
BATCH-912	2/18/30	116	12.1	0.24	2.97E-08	3.49E+02	3.26E+00	2.00E-03	1.05E-01	9.00E-03	3.54E-06	1.12E-07	2.79E-04	1.09E-04	2.82E-05	1.96E-04	6.00E-03	3.40E-02	8.00E-03
BATCH-913	3/2/30	128	13.4	0.24	1.12E-08	3.84E+02	1.28E+00	5.89E-04	2.60E-02	2.00E-03	1.79E-06	4.47E-08	1.20E-04	4.56E-05	1.37E-05	8.28E-05	2.00E-03	8.00E-03	2.00E-03
BATCH-914	3/3/30	59	6.2	0.24	4.48E-09	1.77E+02	6.95E-01	2.36E-04	1.10E-02	7.06E-04	8.74E-07	2.35E-08	4.80E-05	1.76E-05	5.74E-06	3.26E-05	6.10E-04	3.00E-03	7.56E-04
BATCH-915	3/9/30	123	12.9	0.24	3.62E-08	3.70E+02	4.94E+00	2.00E-03	8.70E-02	8.00E-03	4.34E-06	1.60E-07	2.01E-04	5.49E-05	2.67E-05	1.20E-04	4.00E-03	1.90E-02	6.00E-03
BATCH-916	3/16/30	18	1.9	0.24	1.09E-09	5.45E+01	9.11E-01	7.60E-05	4.00E-03	1.85E-04	2.20E-07	2.90E-08	8.59E-06	2.56E-06	1.57E-06	5.68E-06	8.96E-05	4.86E-04	1.56E-04
BATCH-917	3/18/30	140	14.6	0.24	1.24E-08	4.19E+02	1.37E+00	8.51E-04	3.80E-02	3.00E-03	1.92E-06	4.86E-08	1.45E-04	5.82E-05	1.53E-05	1.03E-04	2.00E-03	1.30E-02	3.00E-03
BATCH-918	3/22/30	143	14.9	0.24	4.19E-08	4.27E+02	5.72E+00	2.00E-03	1.00E-01	1.00E-02	5.02E-06	1.85E-07	2.32E-04	6.35E-05	3.09E-05	1.38E-04	4.00E-03	2.20E-02	7.00E-03
BATCH-919	4/2/30	19	2.0	0.24	1.07E-09	5.77E+01	1.66E-01	5.64E-05	3.00E-03	1.69E-04	2.09E-07	5.61E-09	1.15E-05	4.21E-06	1.37E-06	1.46E-04	7.90E-04	1.81E-04	7.39E-04
BATCH-920	4/4/30	59	6.1	0.24	4.65E-09	1.76E+02	5.32E-01	2.44E-04	1.10E-02	7.30E-04	7.43E-07	1.85E-08	4.96E-05	1.89E-05	5.68E-06	3.43E-05	6.37E-04	3.00E-03	1.56E-04
BATCH-921	4/6/30	185	19.3	0.24	5.43E-08	5.55E+02	7.42E+00	3.00E-03	1.30E-01	1.30E-02	6.52E-06	2.40E-07	3.02E-04	8.23E-05	4.01E-05	1.79E-04	5.00E-03	2.90E-02	9.00E-03
BATCH-922	4/10/30	128	13.3	0.24	1.19E-08	3.82E+02	9.70E-01	8.07E-04	3.60E-02	3.00E-03	1.44E-06	3.55E-08	1.29E-04	5.26E-05	1.33E-05	9.25E-05	2.00E-03	1.20E-02	3.00E-03
BATCH-923	4/23/30	56	5.8	0.24	4.48E-09	1.67E+02	4.95E-01	3.06E-04	1.40E-02	1.00E-03	6.91E-07	1.75E-08	5.22E-05	2.10E-05	5.51E-06	3.71E-05	8.73E-04	5.00E-03	1.00E-03
BATCH-924	4/26/30	185	19.3	0.24	5.43E-08	5.54E+02	7.42E+00	3.00E-03	1.30E-01	1.30E-02	6.51E-06	2.40E-07	3.01E-04	8.22E-05	4.00E-05	1.79E-04	5.00E-03	2.90E-02	9.00E-03
BATCH-925	4/29/30	126	13.1	0.24	3.69E-08	3.77E+02	5.05E+00	2.00E-03	8.90E-02	9.00E-03	4.43E-06	1.63E-07	2.05E-04	5.59E-05	2.72E-05	1.22E-04	4.00E-03	2.00E-02	6.00E-03
BATCH-926	5/13/30	19	2.0	0.24	1.10E-09	5.70E+01	1.26E-01	5.77E-05	3.00E-03	1.72E-04	1.75E-07	4.38E-09	1.17E-05	4.47E-06	1.34E-06	8.11E-06	1.51E-04	8.15E-04	1.74E-04
BATCH-927	5/15/30	57	6.0	0.24	4.87E-09	1.72E+02	3.95E-01	3.29E-04	1.50E-02	1.00E-03	5.85E-07	1.45E-08	5.26E-05	2.14E-05	5.40E-06	3.76E-05	9.20E-04	5.00E-03	1.00E-03
BATCH-928	5/15/30	163	17.0	0.24	4.79E-08	4.89E+02	6.55E+00	2.00E-03	1.15E-01	1.10E-02	5.75E-06	2.12E-07	2.66E-04	7.26E-05	3.53E-05	1.58E-04	5.00E-03	2.60E-02	8.00E-03
BATCH-929	5/21/30	19	1.9	0.24	1.07E-09	5.57E+01	1.18E-01	7.32E-05	3.00E-03	2.43E-04	1.65E-07	4.18E-09	1.25E-05	5.00E-06	1.32E-06	8.86E-06	2.09E-04	1.00E-03	2.49E-04
BATCH-930	5/23/30	119	12.4	0.24	1.08E-08	3.56E+02	1.03E+00	9.97E-04	4.50E-02	4.00E-03	1.28E-06	3.69E-08	1.24E-04	5.25E-05	1.15E-05	9.09E-05	3.00E-03	1.60E-02	4.00E-03

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses					0.24	1.15E-04	6.13E-05	1.20E-02	4.00E-03	3.00E-03	2.12E-01	3.10E-02	1.37E-01	5.80E-02	8.94E-27	1.70E-06	4.95E-06	1.30E-04	7.66E-04	4.41E-09
BATCH-882	8/11/29	133	13.9		0.24	1.60E-04	8.56E-05	1.70E-02	5.00E-03	4.00E-03	2.96E-01	4.30E-02	1.91E-01	8.10E-02	1.25E-26	2.37E-06	6.91E-06	1.81E-04	1.00E-03	6.17E-09
BATCH-883	8/15/29	186	19.4		0.24	8.94E-06	7.56E-06	3.37E-04	1.70E-04	2.14E-04	8.00E-03	1.00E-03	2.00E-02	3.00E-03	3.02E-28	8.08E-08	7.95E-07	4.15E-06	2.97E-05	3.67E-09
BATCH-884	8/25/29	17	1.7		0.24	1.26E-04	6.70E-05	1.30E-02	4.00E-03	3.00E-03	2.32E-01	3.40E-02	1.50E-01	6.40E-02	9.78E-27	1.86E-06	5.41E-06	1.42E-04	8.38E-04	4.82E-09
BATCH-885	8/27/29	146	15.2		0.24	2.85E-05	1.91E-05	2.00E-03	9.72E-04	7.36E-04	4.80E-02	8.00E-03	4.50E-02	1.60E-02	1.65E-27	4.64E-07	1.67E-06	2.36E-05	1.45E-04	2.78E-09
BATCH-886	9/3/29	51	5.4		0.24	5.43E-06	3.52E-06	4.88E-04	1.88E-04	1.35E-04	1.00E-02	2.00E-03	9.00E-03	3.00E-03	3.95E-28	8.91E-08	3.32E-07	5.66E-06	3.47E-05	1.25E-09
BATCH-887	9/9/29	18	1.9		0.24	7.85E-05	5.23E-05	5.00E-03	3.00E-03	2.00E-03	1.29E-01	2.10E-02	1.17E-01	4.30E-02	4.03E-27	1.26E-06	4.34E-06	5.74E-05	3.49E-04	4.05E-10
BATCH-888	9/11/29	117	12.2		0.24	1.60E-04	8.55E-05	1.70E-02	5.00E-03	4.00E-03	2.96E-01	4.30E-02	1.91E-01	8.10E-02	1.25E-26	2.37E-06	6.90E-06	1.81E-04	1.00E-03	6.16E-09
BATCH-889	9/12/29	186	19.4		0.24	1.39E-04	7.41E-05	1.50E-02	4.00E-03	3.00E-03	2.56E-01	3.80E-02	1.65E-01	7.00E-02	1.08E-26	2.05E-06	5.98E-06	1.57E-04	9.27E-04	5.34E-09
BATCH-890	9/23/29	161	16.8		0.24	6.85E-06	4.59E-06	5.12E-04	2.34E-04	1.77E-04	1.10E-02	2.00E-03	1.10E-02	4.00E-03	3.98E-28	1.12E-07	4.03E-07	5.68E-06	3.48E-05	6.68E-10
BATCH-891	10/1/29	18	1.9		0.24	6.85E-06	4.59E-06	5.12E-04	2.34E-04	1.77E-04	1.10E-02	2.00E-03	1.10E-02	4.00E-03	3.98E-28	1.12E-07	4.03E-07	5.68E-06	3.48E-05	6.68E-10
BATCH-892	10/3/29	126	13.1		0.24	1.09E-04	5.79E-05	1.10E-02	3.00E-03	3.00E-03	2.00E-01	2.90E-02	1.29E-01	5.50E-02	8.45E-27	1.60E-06	4.67E-06	1.22E-04	7.24E-04	4.17E-09
BATCH-893	10/10/29	183	19.1		0.24	1.41E-04	8.15E-05	1.50E-02	4.00E-03	3.00E-03	2.50E-01	3.60E-02	2.00E-01	6.60E-02	1.10E-26	1.91E-06	7.22E-06	1.53E-04	9.00E-04	2.66E-09
BATCH-894	10/16/29	49	5.1		0.24	2.93E-05	1.95E-05	2.00E-03	9.84E-04	7.67E-04	4.80E-02	8.00E-03	4.40E-02	1.60E-02	1.51E-27	4.71E-07	1.62E-06	2.15E-05	1.31E-04	1.51E-10
BATCH-895	10/22/29	168	17.5		0.24	1.17E-04	7.28E-05	1.20E-02	3.00E-03	3.00E-03	2.00E-01	2.80E-02	1.92E-01	5.00E-02	9.09E-27	1.45E-06	6.92E-06	1.23E-04	7.16E-04	3.20E-12
BATCH-896	10/30/29	193	20.1		0.24	1.35E-04	8.38E-05	1.40E-02	4.00E-03	3.00E-03	2.30E-01	3.20E-02	2.21E-01	5.80E-02	1.05E-26	1.67E-06	7.97E-06	1.42E-04	8.24E-04	1.12E-13
BATCH-897	11/8/29	145	15.1		0.24	1.02E-04	6.31E-05	1.10E-02	3.00E-03	2.00E-03	1.73E-01	2.40E-02	1.66E-01	4.30E-02	7.88E-27	1.26E-06	5.99E-06	1.07E-04	6.20E-04	3.20E-12
BATCH-898	11/19/29	114	11.8		0.24	7.95E-05	4.93E-05	8.00E-03	2.00E-03	2.00E-03	1.35E-01	1.90E-02	1.30E-01	3.40E-02	6.16E-27	9.84E-07	4.69E-06	8.34E-05	4.85E-04	3.18E-12
BATCH-899	11/24/29	17	1.7		0.24	7.06E-06	4.71E-06	4.88E-04	2.37E-04	1.85E-04	1.20E-02	2.00E-03	1.10E-02	4.00E-03	3.62E-28	1.13E-07	3.90E-07	5.17E-06	3.15E-05	3.64E-11
BATCH-900	11/26/29	163	17.0		0.24	1.14E-04	7.07E-05	1.20E-02	3.00E-03	3.00E-03	1.94E-01	2.70E-02	1.86E-01	4.90E-02	8.83E-27	1.41E-06	6.72E-06	1.20E-04	6.95E-04	1.43E-12
BATCH-901	12/1/29	147	15.3		0.24	1.03E-04	6.38E-05	1.10E-02	3.00E-03	2.00E-03	1.75E-01	2.50E-02	1.68E-01	4.40E-02	7.96E-27	1.27E-06	6.06E-06	1.08E-04	6.27E-04	1.91E-14
BATCH-902	12/13/29	160	16.6		0.24	5.44E-04	2.15E-04	9.00E-03	4.00E-03	1.20E-02	1.96E-01	3.10E-02	1.60E+00	6.80E-02	9.04E-27	2.04E-06	3.04E-05	1.24E-04	2.00E-03	1.81E-10
BATCH-903	12/17/29	121	12.6		0.24	5.47E-04	2.08E-04	6.00E-03	3.00E-03	1.20E-02	1.50E-01	2.50E-02	1.65E+00	5.80E-02	6.96E-27	1.75E-06	3.05E-05	9.59E-05	2.00E-03	1.94E-10
BATCH-904	12/29/29	182	19.0		0.24	8.26E-04	3.15E-04	1.00E-02	5.00E-03	1.90E-02	2.27E-01	3.70E-02	2.49E+00	8.70E-02	1.05E-26	2.64E-06	4.60E-05	1.45E-04	2.00E-03	2.92E-10
BATCH-905	12/30/29	155	16.1		0.24	8.56E-05	5.49E-05	7.00E-03	3.00E-03	2.00E-03	1.44E-01	2.30E-02	1.25E-01	4.50E-02	4.92E-27	1.33E-06	4.59E-06	7.00E-05	4.22E-04	8.54E-10
BATCH-906	1/15/30	135	14.1		0.24	6.14E-04	2.34E-04	7.00E-03	4.00E-03	1.40E-02	1.69E-01	2.80E-02	1.85E+00	6.20E-02	1.66E-27	1.96E-06	3.42E-05	1.05E-04	2.00E-03	2.17E-10
BATCH-907	1/18/30	122	12.7		0.24	5.55E-04	2.11E-04	6.00E-03	3.00E-03	1.30E-02	1.52E-01	2.50E-02	1.67E+00	5.60E-02	1.50E-27	1.77E-06	3.09E-05	9.49E-05	2.00E-03	1.96E-10
BATCH-908	1/29/30	131	13.6		0.24	7.67E-05	3.50E-05	4.00E-03	1.00E-03	2.00E-03	7.20E-02	1.10E-02	1.73E-01	2.00E-02	6.69E-28	6.14E-07	3.97E-06	4.36E-05	3.30E-04	1.00E-09
BATCH-909	1/31/30	138	14.4		0.24	6.25E-04	2.38E-04	7.00E-03	4.00E-03	1.40E-02	1.72E-01	2.80E-02	1.88E+00	6.30E-02	1.69E-27	2.00E-06	3.48E-05	1.07E-04	2.00E-03	2.21E-10
BATCH-910	2/12/30	54	5.6		0.24	2.69E-05	1.73E-05	2.00E-03	8.77E-04	6.88E-04	4.50E-02	7.00E-03	3.90E-02	1.40E-02	3.29E-28	4.19E-07	1.44E-06	2.15E-05	1.28E-04	2.68E-10
BATCH-911	2/14/30	159	16.6		0.24	2.75E-04	8.00E-03	4.00E-03	1.60E-02	1.98E-01	3.30E-02	2.17E+00	7.30E-02	1.95E-27	2.31E-06	4.02E-05	1.23E-04	2.00E-03	2.55E-10
BATCH-912	2/18/30	116	12.1		0.24	3.47E-04	8.00E-03	3.00E-03	8.00E-03	1.74E-01	2.50E-02	7.70E-01	4.70E-02	1.31E-27	1.42E-06	1.78E-05	8.50E-05	8.76E-04	1.28E-10
BATCH-913	3/2/30	128	13.4		0.24	7.41E-05	3.43E-05	4.00E-03	1.00E-03	2.00E-03	6.60E-02	1.00E-02	1.75E-01	1.80E-02	6.20E-28	5.49E-07	4.01E-06	3.97E-05	3.07E-04	5.44E-10
BATCH-914	3/3/30	59	6.2		0.24	3.15E-05	1.44E-05	2.00E-03	5.33E-04	7.27E-04	3.00E-02	4.00E-03	7.10E-02	8.00E-03	2.75E-28	2.52E-07	1.63E-06	1.79E-05	1.36E-04	4.13E-10
BATCH-915	3/9/30	123	12.9		0.24	2.42E-04	9.23E-05	9.00E-03	3.00E-03	6.00E-03	2.05E-01	2.70E-02	2.44E-01	4.50E-02	1.31E-27	1.32E-06	1.08E-05	8.64E-05	5.23E-04	9.46E-11
BATCH-916	3/16/30	18	1.9		0.24	6.42E-06	4.12E-06	4.98E-04	2.09E-04	1.64E-04	1.10E-02	2.00E-03	9.00E-03	3.00E-03	7.84E-29	1.00E-07	3.44E-07	5.13E-06	3.05E-05	6.40E-11
BATCH-917	3/18/30	140	14.6		0.24	1.21E-04	5.10E-05	4.00E-03	1.00E-03	3.00E-03	7.50E-02	1.10E-02	3.10E-01	2.20E-02	6.97E-28	6.68E-07	6.53E-06	4.47E-05	4.17E-04	5.57E-10
BATCH-918	3/22/30	143	14.9		0.24	2.79E-04	1.07E-04	1.10E-02	4.00E-03	6.00E-03	2.37E-01	3.20E-02	2.82E-01	5.20E-02	1.52E-27	1.52E-06	1.25E-05	9.99E-05	6.05E-04	1.09E-10
BATCH-919	4/2/30	19	2.0		0.24	7.54E-06	3.44E-06	3.96E-04	1.28E-04	1.74E-04	7.00E-03	1.00E-03	1.70E-02	2.00E-03	6.58E-29	6.04E-08	3.91E-07	4.29E-06	3.24E-05	9.87E-11
BATCH-920	4/4/30	59	6.1		0.24	3.07E-05	1.42E-05	2.00E-03	4.82E-04	7.05E-04	2.70E-02	4.00E-03	7.30E-02	7.00E-03	2.57E-28	2.28E-07	1.66E-06	1.65E-05	1.27E-04	2.26E-10
BATCH-921	4/6/30	185	19.3		0.24	3.62E-04	1.39E-04	1.40E-02	5.00E-03	8.00E-03	3.08E-01	4.10E-02	3.64E-01	6.70E-02	1.97E-27	1.98E-06	1.62E-05	1.30E-04	7.84E-04	1.42E-10
BATCH-922	4/10/30	128	13.3		0.24	1.12E-04	4.65E-05	3.00E-03	1.00E-03	3.00E-03	6.40E-02	9.00E-03	2.77E-01	1.80E-02	5.77E-28	5.48E-07	6.07E-06	3.65E-05	3.48E-04	3.43E-11
BATCH-923	4/23/30	56	5.8		0.24	4.35E-05	1.84E-05	1.00E-03	5.01E-04	9.94E-04	2.70E-02	4.00E-03	1.12E-01	8.00E-03	2.51E-28	2.41E-07	2.35E-06	1.61E-05	1.50E-04	2.01E-10
BATCH-924	4/26/30	185	19.3		0.24	3.62E-04	1.38E-04	1.40E-02	5.00E-03	8.00E-03	3.08E-01	4.10E-02	3.64E-01	6.70E-02	1.97E-27	1.98E-06	1.62E-05	1.30E-04	7.84E-04	1.42E-10
BATCH-925	4/29/30	126	13.1		0.24	2.46E-04	9.41E-05	1.00E-02	3.00E-03	6.00E-03	2.09E-01	2.80E-02	2.47E-01	4.60E-02	1.34E-27	1.34E-06	1.10E-05	8.81E-05	5.33E-04	9.64E-11
BATCH-926	5/13/30	19	2.0		0.24	7.26E-06	3.36E-06	3.64E-04	1.14E-04	1.67E-04	6.00E-03	9.48E-04	1.70E-02	2.00E-03	6.07E-29	5.38E-08	3.93E-07	3.89E-06	3.00E-05	5.33E-11
BATCH-927	5/15/30	57	6.0		0.24	4.54E-05	1.89E-05	1.00E-03	4.70E-04	1.00E-03	2.60E-02	4.00E-03	1.13E-01	7.00E-03	2.35E-28	2.23E-07	2.47E-06	1.49E-05	1.14E-04	1.25E-10
BATCH-928	5/15/30	163	17.0		0.24	3.20E-04	1.22E-04	1.20E-02	4.00E-03	7.00E-03	2.71E-01	3.60E-02	3.21E-01	5.90E-02	1.74E-27	1.74E-06	1.43E-05	1.14E-04	6.92E-04	4.79E-11
BATCH-929	5/21/30	19	1.9		0.24	1.04E-05	4.39E-06	3.43E-04	1.20E-04	2.37E-04	6.00E-03	9.71E-04	2.70E-02	2.00E-03	6.00E-29	5.75E-08	5.62E-07	3.85E-06	3.59E-05	4.79E-11
BATCH-930	5/23/30	119	12.4		0.24	1.56E-04	5.95E-05	3.00E-03	1.00E-03	4.00E-03	6.50E-02	1.00E-02	3.95E-01	1.90E-02	5.25E-28	5.85E-07	8.28E-06	3.37E-05	4.08E-04	5.67E-11

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-882	8/11/29	133	13.9	0.24	1.70E-09	1.18E+02	4.43E-10	7.49E-07	4.73E-10	9.48E-43	6.00E-03	4.75E-01	5.36E-09	4.30E-02	3.12E+01	0.00E+00	1.18E-10	1.71E+00	1.20E-06
BATCH-883	8/15/29	186	19.4	0.24	5.00E-03	1.65E+02	6.20E-10	1.05E-06	6.62E-10	8.89E-36	8.00E-03	6.64E-01	7.49E-09	6.00E-02	4.37E+01	0.00E+00	3.32E-04	2.38E+00	1.67E-06
BATCH-884	8/25/29	17	1.7	0.24	3.35E+01	0.00E+00	3.70E-09	2.37E-07	1.52E-09	9.98E-38	1.00E-03	4.10E-02	2.50E-09	8.52E-04	6.70E-01	0.00E+00	1.85E+00	0.00E+00	1.84E-07
BATCH-885	8/27/29	146	15.2	0.24	2.63E-06	1.29E+02	4.85E-10	8.19E-07	5.17E-10	1.21E-38	7.00E-03	5.19E-01	5.86E-09	4.70E-02	3.42E+01	0.00E+00	1.67E-07	1.86E+00	1.31E-06
BATCH-886	9/3/29	51	5.4	0.24	1.51E+02	0.00E+00	5.86E-09	8.43E-07	2.77E-09	2.61E-41	6.00E-03	1.48E-01	1.69E-09	5.00E-03	4.65E+00	0.00E+00	6.32E+00	0.00E+00	8.56E-07
BATCH-887	9/9/29	18	1.9	0.24	3.63E+01	0.00E+00	2.63E-09	3.69E-07	1.24E-09	9.88E-33	2.00E-03	3.90E-02	7.54E-10	1.00E-03	1.17E+00	0.00E+00	1.56E+00	0.00E+00	1.31E-07
BATCH-888	9/11/29	117	12.2	0.24	3.85E+02	0.00E+00	8.80E-11	1.63E-07	6.18E-11	3.21E-37	1.40E-02	3.49E-01	5.47E-10	1.20E-02	1.13E+01	0.00E+00	1.50E+01	0.00E+00	2.46E-06
BATCH-889	9/12/29	186	19.4	0.24	4.00E-03	1.64E+02	6.19E-10	1.05E-06	6.61E-10	1.31E-41	8.00E-03	6.63E-01	7.48E-09	6.00E-02	4.36E+01	0.00E+00	2.42E-04	2.38E+00	1.66E-06
BATCH-890	9/23/29	161	16.8	0.24	2.67E-06	1.43E+02	5.36E-10	9.07E-07	5.73E-10	4.53E-39	7.00E-03	5.74E-01	6.49E-09	5.20E-02	3.78E+01	0.00E+00	1.69E-07	2.06E+00	1.44E-06
BATCH-891	10/1/29	18	1.9	0.24	3.64E+01	0.00E+00	1.41E-09	2.03E-07	6.66E-10	6.29E-42	1.00E-03	3.60E-02	4.08E-10	1.00E-03	1.12E+00	0.00E+00	1.52E+00	0.00E+00	2.06E-07
BATCH-892	10/3/29	126	13.1	0.24	1.71E-09	1.11E+02	4.19E-10	7.08E-07	4.47E-10	7.85E-42	6.00E-03	4.49E-01	5.07E-09	4.00E-02	2.95E+01	0.00E+00	1.09E-10	1.61E+00	1.13E-06
BATCH-893	10/10/29	183	19.1	0.24	4.00E-03	1.58E+02	2.67E-10	6.26E-07	2.85E-10	1.18E-36	7.00E-03	6.27E-01	3.29E-09	4.70E-02	3.98E+01	0.00E+00	1.85E-04	2.53E+00	1.08E-06
BATCH-894	10/16/29	49	5.1	0.24	1.44E+02	0.00E+00	3.29E-11	6.10E-08	2.31E-11	1.20E-37	5.00E-03	1.30E-01	2.05E-10	5.00E-03	4.23E+00	0.00E+00	5.59E+00	0.00E+00	9.19E-07
BATCH-895	10/22/29	168	17.5	0.24	2.27E-06	1.42E+02	3.26E-13	2.84E-07	3.62E-13	6.76E-45	5.00E-03	5.57E-01	9.78E-11	3.40E-02	3.43E+01	0.00E+00	1.25E-07	2.45E+00	5.87E-07
BATCH-896	10/30/29	193	20.1	0.24	5.00E-03	1.64E+02	1.95E-13	3.27E-07	1.13E-13	8.38E-46	6.00E-03	6.41E-01	1.08E-10	4.00E-02	3.95E+01	0.00E+00	2.03E-04	2.82E+00	6.76E-07
BATCH-897	11/8/29	145	15.1	0.24	1.59E-09	1.23E+02	3.25E-13	2.46E-07	3.59E-13	2.69E-42	4.00E-03	4.82E-01	8.52E-11	3.00E-02	2.97E+01	0.00E+00	1.01E-10	2.12E+00	5.09E-07
BATCH-898	11/19/29	114	11.8	0.24	1.30E-12	9.65E+01	3.23E-13	1.93E-07	3.54E-13	5.97E-45	3.00E-03	3.77E-01	6.75E-11	2.30E-02	2.32E+01	0.00E+00	8.25E-14	1.66E+00	3.98E-07
BATCH-899	11/24/29	17	1.7	0.24	3.46E+01	0.00E+00	7.92E-12	1.47E-08	5.56E-12	2.89E-38	1.00E-03	3.10E-02	4.93E-11	1.00E-03	1.02E+00	0.00E+00	1.35E+00	0.00E+00	2.21E-07
BATCH-900	11/26/29	163	17.0	0.24	2.29E-06	1.38E+02	1.48E-13	2.76E-07	1.72E-13	6.24E-40	5.00E-03	5.40E-01	9.30E-11	3.30E-02	3.33E+01	0.00E+00	9.81E-08	2.38E+00	5.70E-07
BATCH-901	12/1/29	147	15.3	0.24	1.33E-09	1.25E+02	5.79E-15	2.48E-07	1.86E-14	3.96E-48	4.00E-03	4.88E-01	8.23E-11	3.00E-02	3.00E+01	0.00E+00	7.33E-11	2.15E+00	5.14E-07
BATCH-902	12/13/29	160	16.6	0.24	2.14E-06	1.43E+02	4.02E-13	8.72E-08	1.09E-12	3.70E-49	7.00E-03	3.84E+00	4.77E-11	2.10E-02	2.56E+01	0.00E+00	8.94E-08	2.94E+00	8.14E-07
BATCH-903	12/17/29	121	12.6	0.24	1.07E-12	1.11E+02	4.28E-13	8.69E-09	1.15E-12	1.81E-45	6.00E-03	3.94E+00	2.30E-11	1.20E-02	1.71E+01	0.00E+00	6.78E-14	2.41E+00	6.96E-07
BATCH-904	12/29/29	182	19.0	0.24	5.00E-03	1.67E+02	6.47E-13	1.29E-08	1.74E-12	4.05E-42	1.00E-02	5.95E+00	3.46E-11	1.80E-02	2.58E+01	0.00E+00	1.89E-04	3.64E+00	1.05E-06
BATCH-905	12/30/29	155	16.1	0.24	4.37E+02	0.00E+00	1.25E-10	2.40E-07	1.07E-10	4.15E-36	1.70E-02	4.51E-01	1.09E-09	1.70E-02	1.51E+01	0.00E+00	1.59E+01	0.00E+00	2.23E-06
BATCH-906	1/15/30	135	14.1	0.24	1.37E-09	1.24E+02	4.81E-13	9.73E-08	1.30E-12	3.74E-43	7.00E-03	4.42E+00	2.58E-11	1.40E-02	1.92E+01	0.00E+00	5.88E-11	2.71E+00	7.81E-07
BATCH-907	1/18/30	122	12.7	0.24	8.82E-13	1.12E+02	4.34E-13	8.80E-09	1.17E-12	2.63E-51	7.00E-03	4.00E+00	2.33E-11	1.20E-02	1.73E+01	0.00E+00	4.86E-14	2.45E+00	7.05E-07
BATCH-908	1/29/30	131	13.6	0.24	3.66E+02	0.00E+00	9.93E-11	1.87E-07	1.06E-10	7.65E-37	1.40E-02	1.17E+00	1.21E-09	1.30E-02	1.06E+01	0.00E+00	1.26E+01	0.00E+00	3.60E-07
BATCH-909	1/31/30	138	14.4	0.24	1.26E-09	1.26E+02	4.89E-13	9.78E-09	1.32E-12	2.18E-52	7.00E-03	4.50E+00	2.62E-11	1.40E-02	1.95E+01	0.00E+00	5.26E-11	2.76E+00	7.94E-07
BATCH-910	2/12/30	54	5.6	0.24	1.37E+02	0.00E+00	3.94E-11	7.54E-08	3.36E-11	1.30E-36	5.00E-03	1.42E-01	3.42E-10	5.00E-03	4.73E+00	0.00E+00	5.01E+00	0.00E+00	7.00E-07
BATCH-911	2/14/30	159	16.6	0.24	2.47E-06	1.46E+02	5.65E-13	1.12E-08	1.52E-12	2.06E-45	9.00E-03	5.20E+00	3.02E-11	1.60E-02	2.25E+01	0.00E+00	9.59E-08	3.18E+00	9.17E-07
BATCH-912	2/18/30	116	12.1	0.24	8.28E-13	9.45E+01	8.28E-11	1.63E-08	4.83E-11	2.25E-46	5.00E-03	2.48E+00	7.99E-11	1.80E-02	2.12E+01	0.00E+00	3.55E-14	1.77E+00	9.15E-07
BATCH-913	3/2/30	128	13.4	0.24	3.53E+02	0.00E+00	5.32E-11	1.31E-07	5.68E-11	1.12E-42	1.30E-02	1.17E+00	6.57E-10	1.10E-02	9.98E+00	0.00E+00	1.25E+01	0.00E+00	2.82E-07
BATCH-914	3/3/30	59	6.2	0.24	1.51E+02	0.00E+00	4.08E-11	7.70E-08	4.36E-11	3.14E-37	6.00E-03	4.81E-01	4.97E-10	5.00E-03	4.36E+00	0.00E+00	5.19E+00	0.00E+00	1.48E-07
BATCH-915	3/9/30	123	12.9	0.24	8.51E-13	9.15E+01	1.45E-10	2.29E-08	8.41E-11	1.47E-55	4.00E-03	1.70E+00	1.25E-10	2.40E-02	2.58E+01	0.00E+00	3.55E-14	1.48E+00	1.14E-06
BATCH-916	3/16/30	18	1.9	0.24	3.28E+01	0.00E+00	9.40E-12	1.80E-08	8.02E-12	3.11E-37	1.00E-03	3.40E-02	8.17E-11	1.00E-03	1.13E+00	0.00E+00	1.20E+00	0.00E+00	1.67E-07
BATCH-917	3/18/30	140	14.6	0.24	3.55E+02	0.00E+00	5.63E-11	1.20E-07	5.84E-11	2.31E-37	1.20E-02	1.93E+00	6.52E-10	1.10E-02	1.07E+01	0.00E+00	1.21E+01	0.00E+00	3.43E-07
BATCH-918	3/22/30	143	14.9	0.24	1.44E-09	1.06E+02	1.68E-10	2.65E-08	9.73E-11	1.20E-48	5.00E-03	1.96E+00	1.44E-10	2.80E-02	2.98E+01	0.00E+00	5.60E-11	1.72E+00	1.32E-06
BATCH-919	4/2/30	19	2.0	0.24	3.60E+01	0.00E+00	9.77E-12	1.84E-08	1.04E-11	7.52E-38	1.00E-03	1.15E-01	1.19E-10	1.00E-03	1.04E+00	0.00E+00	1.24E+00	0.00E+00	3.54E-08
BATCH-920	4/4/30	59	6.1	0.24	1.46E+02	0.00E+00	2.21E-11	5.42E-08	2.36E-11	4.66E-43	5.00E-03	4.86E-01	2.73E-10	5.00E-03	4.14E+00	0.00E+00	5.17E+00	0.00E+00	1.17E-07
BATCH-921	4/6/30	185	19.3	0.24	5.00E-03	1.37E+02	2.18E-10	3.44E-08	1.26E-10	4.35E-41	6.00E-03	2.55E+00	1.88E-10	3.60E-02	3.87E+01	0.00E+00	1.67E-04	2.23E+00	1.71E-06
BATCH-922	4/10/30	128	13.3	0.24	3.31E+02	0.00E+00	1.09E-11	4.27E-08	6.42E-12	6.42E-47	1.00E-02	2.17E+00	2.57E-11	8.00E-03	9.13E+00	0.00E+00	1.10E-01	0.00E+00	2.65E-07
BATCH-923	4/23/30	56	5.8	0.24	1.28E+02	0.00E+00	2.03E-11	4.32E-08	2.11E-11	8.34E-38	4.00E-03	6.93E-01	2.35E-10	4.00E-03	3.84E+00	0.00E+00	4.34E+00	0.00E+00	1.24E-07
BATCH-924	4/26/30	185	19.3	0.24	5.00E-03	1.37E+02	2.18E-10	3.43E-08	1.26E-10	1.14E-41	6.00E-03	2.54E+00	1.88E-10	3.60E-02	3.87E+01	0.00E+00	1.88E-04	2.23E+00	1.71E-06
BATCH-925	4/29/30	126	13.1	0.24	9.51E-13	9.33E+01	1.48E-10	2.34E-08	8.59E-11	7.93E-52	4.00E-03	1.73E+00	1.28E-10	2.40E-02	2.63E+01	0.00E+00	3.70E-14	1.51E+00	1.16E-06
BATCH-926	5/13/30	19	2.0	0.24	3.46E+01	0.00E+00	5.21E-12	1.28E-08	5.56E-12	1.10E-43	1.00E-03	1.15E-01	6.43E-11	1.00E-03	9.77E-01	0.00E+00	1.22E+00	0.00E+00	2.76E-08
BATCH-927	5/15/30	57	6.0	0.24	1.35E+02	0.00E+00	4.42E-12	1.74E-08	2.61E-12	2.61E-47	4.00E-03	8.82E-01	1.05E-11	3.00E-03	3.72E+00	0.00E+00	4.49E+00	0.00E+00	1.08E-07
BATCH-928	5/15/30	163	17.0	0.24	2.33E-06	1.21E+02	1.92E-10	3.03E-08	1.11E-10	2.21E-44	5.00E-03	2.24E+00	1.65E-10	3.20E-02	3.41E+01	0.00E+00	8.49E-08	1.96E+00	1.51E-06
BATCH-929	5/21/30	19	1.9	0.24	3.05E+01	0.00E+00	4.84E-12	1.03E-08	5.03E-12	1.99E-38	1.00E-03	1.66E-01	5.61E-11	9.63E-04	9.17E-01	0.00E+00	1.04E+00	0.00E+00	2.95E-08
BATCH-930	5/23/30	119	12.4	0.24	3.16E+02	0.00E+00	2.28E-11	5.42E-09	1.34E-11	3.11E-43	1.00E-02	3.06E+00	2.45E-11	6.00E-03	7.73E+00	0.00E+00	9.50E+00	0.00E+00	3.28E-07

Appendix A Nominal ILAW Inventory

TWRSC&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-882	8/11/29	133	13.9	0.24	1.05E-10	4.17E+01	5.38E-01	0.00E+00	0.00E+00	4.00E-04	1.00E+01	3.65E-05	1.70E-08	2.66E-07	2.40E-02	9.57E-08	2.28E+03	0.00E+00	7.20E-02
BATCH-883	8/15/29	186	19.4	0.24	1.47E-10	5.83E+01	7.52E-01	0.00E+00	0.00E+00	4.00E-04	1.40E+01	5.09E-05	2.38E-08	3.73E-07	3.40E-02	1.34E-07	3.18E+03	0.00E+00	1.01E-01
BATCH-884	8/25/29	17	1.7	0.24	1.09E-11	8.00E-01	2.60E-02	0.00E+00	0.00E+00	1.16E-05	2.20E-01	6.48E-06	1.29E-09	6.59E-08	2.00E-03	5.07E-10	2.87E+02	0.00E+00	2.00E-03
BATCH-885	8/27/29	146	15.2	0.24	1.15E-10	4.56E+01	5.89E-01	0.00E+00	0.00E+00	4.00E-04	1.10E+01	3.99E-05	1.85E-08	2.91E-07	2.60E-02	1.05E-07	2.49E+03	0.00E+00	7.90E-02
BATCH-886	9/3/29	51	5.4	0.24	2.37E-11	4.78E+00	1.39E-01	0.00E+00	0.00E+00	7.95E-05	1.32E+00	2.62E-05	1.98E-09	1.58E-07	1.40E-02	5.06E-10	8.80E+02	0.00E+00	1.10E-02
BATCH-887	9/9/29	18	1.9	0.24	1.07E-11	1.24E+00	3.70E-02	0.00E+00	0.00E+00	1.60E-05	3.31E-01	7.54E-06	8.64E-10	7.06E-08	2.00E-03	2.28E-10	3.10E+02	0.00E+00	3.00E-03
BATCH-888	9/11/29	117	12.2	0.24	9.49E-12	1.22E+01	3.27E-01	0.00E+00	0.00E+00	2.00E-04	3.31E+00	4.27E-05	1.78E-09	2.66E-08	4.00E-02	8.56E-09	2.00E+03	0.00E+00	2.60E-02
BATCH-889	9/12/29	186	19.4	0.24	1.47E-10	5.83E+01	7.51E-01	0.00E+00	0.00E+00	4.00E-04	1.40E+01	5.08E-05	2.38E-08	3.72E-07	3.40E-02	1.34E-07	3.18E+03	0.00E+00	1.01E-01
BATCH-890	9/23/29	161	16.8	0.24	1.27E-10	5.05E+01	6.51E-01	0.00E+00	0.00E+00	4.00E-04	1.21E+01	4.41E-05	2.06E-08	3.23E-07	2.90E-02	1.16E-07	2.75E+03	0.00E+00	8.70E-02
BATCH-891	10/1/29	18	1.9	0.24	5.71E-12	1.15E+00	3.30E-02	0.00E+00	0.00E+00	1.91E-05	3.17E-01	6.31E-06	4.77E-10	3.79E-08	3.00E-03	1.22E-10	3.04E+02	0.00E+00	3.00E-03
BATCH-892	10/3/29	126	13.1	0.24	9.95E-11	3.94E+01	5.09E-01	0.00E+00	0.00E+00	2.00E-04	9.47E+00	3.44E-05	1.61E-08	2.52E-07	2.30E-02	9.05E-08	2.15E+03	0.00E+00	6.80E-02
BATCH-893	10/10/29	183	19.1	0.24	6.34E-11	6.06E+01	7.11E-01	0.00E+00	0.00E+00	4.00E-04	1.36E+01	7.78E-05	1.03E-08	1.61E-07	2.60E-02	5.77E-08	3.13E+03	0.00E+00	8.80E-02
BATCH-894	10/16/29	49	5.1	0.24	3.55E-12	4.56E+00	1.22E-01	0.00E+00	0.00E+00	7.83E-05	1.24E+00	1.60E-05	6.66E-10	9.93E-09	1.50E-02	3.20E-09	8.30E+02	0.00E+00	1.00E-02
BATCH-895	10/22/29	168	17.5	0.24	9.25E-14	5.78E+01	6.31E-01	0.00E+00	0.00E+00	2.00E-04	1.23E+01	9.11E-05	1.29E-11	4.59E-10	1.90E-02	6.91E-11	2.86E+03	0.00E+00	7.30E-02
BATCH-896	10/30/29	193	20.1	0.24	1.99E-14	6.66E+01	7.27E-01	0.00E+00	0.00E+00	4.00E-04	1.42E+01	1.05E-04	7.62E-13	3.13E-10	2.20E-02	1.01E-13	3.30E+03	0.00E+00	8.50E-02
BATCH-897	11/8/29	145	15.1	0.24	9.02E-14	5.01E+01	5.47E-01	0.00E+00	0.00E+00	2.00E-04	1.07E+01	7.89E-05	1.28E-11	4.23E-10	1.70E-02	6.90E-11	2.48E+03	0.00E+00	6.40E-02
BATCH-898	11/19/29	114	11.8	0.24	8.69E-14	3.92E+01	4.27E-01	0.00E+00	0.00E+00	1.81E-04	8.35E+00	6.17E-05	1.27E-11	3.73E-10	1.30E-02	6.88E-11	1.94E+03	0.00E+00	5.00E-02
BATCH-899	11/24/29	17	1.7	0.24	8.54E-13	1.10E+00	2.90E-02	0.00E+00	0.00E+00	1.89E-05	2.98E-01	3.84E-06	1.61E-10	2.39E-09	4.00E-03	7.71E-10	2.86E+02	0.00E+00	2.00E-03
BATCH-900	11/26/29	163	17.0	0.24	4.98E-14	5.61E+01	6.13E-01	0.00E+00	0.00E+00	2.00E-04	1.20E+01	8.85E-05	6.03E-12	3.45E-10	1.90E-02	3.07E-11	2.78E+03	0.00E+00	7.10E-02
BATCH-901	12/1/29	147	15.3	0.24	1.46E-14	5.06E+01	5.53E-01	0.00E+00	0.00E+00	2.00E-04	1.08E+01	7.98E-05	5.38E-13	2.34E-10	1.70E-02	2.51E+03	0.00E+00	6.40E-02	
BATCH-902	12/13/29	160	16.6	0.24	1.93E-14	6.18E+01	4.76E-01	0.00E+00	0.00E+00	4.00E-04	1.37E+01	3.94E-05	9.02E-12	7.70E-11	7.50E-02	1.11E-09	2.73E+03	0.00E+00	1.19E-01
BATCH-903	12/17/29	121	12.6	0.24	1.57E-14	4.89E+01	3.21E-01	0.00E+00	0.00E+00	4.00E-04	1.10E+01	1.49E-05	9.47E-12	2.77E-12	7.50E-02	1.18E-09	2.06E+03	0.00E+00	1.06E-01
BATCH-904	12/29/29	182	19.0	0.24	2.37E-14	7.37E+01	4.84E-01	0.00E+00	0.00E+00	6.00E-04	1.65E+01	2.25E-05	1.43E-11	4.09E-12	1.13E-01	1.78E-09	3.11E+03	0.00E+00	1.59E-01
BATCH-905	12/30/29	155	16.1	0.24	2.02E-11	1.83E+01	4.34E-01	0.00E+00	0.00E+00	2.00E-04	4.64E+00	4.51E-05	3.48E-09	5.33E-08	3.80E-02	1.83E-08	2.64E+03	0.00E+00	3.40E-02
BATCH-906	1/15/30	135	14.1	0.24	1.76E-14	5.48E+01	3.60E-01	0.00E+00	0.00E+00	4.00E-04	1.23E+01	1.68E-05	1.06E-11	3.00E-12	8.40E-02	1.33E-09	2.31E+03	0.00E+00	1.19E-01
BATCH-907	1/18/30	122	12.7	0.24	1.58E-14	4.95E+01	3.25E-01	0.00E+00	0.00E+00	4.00E-04	1.11E+01	1.51E-05	9.59E-12	2.68E-12	7.60E-02	1.20E-09	2.09E+03	0.00E+00	1.07E-01
BATCH-908	1/29/30	131	13.6	0.24	2.36E-11	1.70E+01	4.29E-01	0.00E+00	0.00E+00	1.21E-04	3.92E+00	1.53E-05	3.82E-09	5.97E-08	1.30E-02	2.15E-08	2.23E+03	0.00E+00	2.90E-02
BATCH-909	1/31/30	138	14.4	0.24	1.78E-14	5.58E+01	3.66E-01	0.00E+00	0.00E+00	6.00E-04	1.25E+01	1.70E-05	1.08E-11	2.89E-12	8.50E-02	1.35E-09	2.35E+03	0.00E+00	1.21E-01
BATCH-910	2/12/30	54	5.6	0.24	6.36E-12	5.76E+00	1.36E-01	0.00E+00	0.00E+00	7.10E-05	1.46E+00	1.42E-05	1.09E-09	1.68E-08	1.20E-02	5.77E-09	9.21E+02	0.00E+00	1.10E-02
BATCH-911	2/14/30	159	16.6	0.24	2.06E-14	6.44E+01	4.23E-01	0.00E+00	0.00E+00	6.00E-04	1.44E+01	1.96E-05	1.25E-11	3.28E-12	9.90E-02	1.56E-09	2.72E+03	0.00E+00	1.39E-01
BATCH-912	2/18/30	116	12.1	0.24	5.72E-13	4.44E+01	4.45E-01	0.00E+00	0.00E+00	2.00E-04	9.13E+00	4.70E-05	3.01E-11	2.03E-09	5.30E-02	5.68E-10	1.99E+03	0.00E+00	9.30E-02
BATCH-913	3/2/30	128	13.4	0.24	1.26E-11	1.71E+01	4.21E-01	0.00E+00	0.00E+00	1.10E-04	3.83E+00	1.85E-05	2.04E-09	3.20E-08	1.20E-02	1.16E-08	2.19E+03	0.00E+00	2.80E-02
BATCH-914	3/3/30	59	6.2	0.24	9.69E-12	6.99E+00	1.76E-01	0.00E+00	0.00E+00	4.97E-05	1.61E+00	6.30E-06	1.57E-09	2.46E-08	5.00E-03	8.85E-09	1.01E+03	0.00E+00	1.20E-02
BATCH-915	3/9/30	123	12.9	0.24	9.95E-13	4.52E+01	5.65E-01	0.00E+00	0.00E+00	2.00E-04	8.67E+00	7.25E-05	4.65E-11	3.57E-09	4.20E-02	1.98E-10	2.11E+03	0.00E+00	9.30E-02
BATCH-916	3/16/30	18	1.9	0.24	1.52E-12	1.38E+00	3.30E-02	0.00E+00	0.00E+00	1.69E-05	3.48E-01	3.38E-06	2.61E-10	4.00E-09	3.00E-03	1.38E-09	3.11E+02	0.00E+00	3.00E-03
BATCH-917	3/18/30	140	14.6	0.24	1.25E-11	2.00E+01	4.95E-01	0.00E+00	0.00E+00	1.42E-04	4.46E+00	1.79E-05	2.02E-09	3.17E-08	1.80E-02	1.16E-08	2.39E+03	0.00E+00	3.60E-02
BATCH-918	3/22/30	143	14.9	0.24	1.15E-12	5.22E+01	6.54E-01	0.00E+00	0.00E+00	2.00E-04	1.00E+01	8.39E-05	5.38E-11	4.12E-09	4.90E-02	2.29E-10	2.44E+03	0.00E+00	1.08E-01
BATCH-919	4/2/30	19	2.0	0.24	2.32E-12	1.67E+00	4.20E-02	0.00E+00	0.00E+00	1.19E-05	3.85E-01	1.51E-06	3.75E-10	5.87E-09	1.00E-03	2.12E-09	3.29E+02	0.00E+00	3.00E-03
BATCH-920	4/4/30	59	6.1	0.24	5.23E-12	7.10E+00	1.74E-01	0.00E+00	0.00E+00	4.56E-05	1.59E+00	7.67E-06	8.47E-10	1.33E-08	5.00E-03	4.80E-09	1.00E+03	0.00E+00	1.10E-02
BATCH-921	4/6/30	185	19.3	0.24	1.49E-12	6.78E+01	8.49E-01	0.00E+00	0.00E+00	4.00E-04	1.30E+01	1.09E-04	6.99E-11	5.36E-09	6.30E-02	2.97E-10	3.16E+03	0.00E+00	1.40E-01
BATCH-922	4/10/30	128	13.3	0.24	7.84E-14	1.84E+01	5.11E-01	0.00E+00	0.00E+00	1.17E-04	3.92E+00	2.03E-05	4.88E-12	3.03E-10	1.60E-02	1.81E-10	2.18E+03	0.00E+00	3.20E-02
BATCH-923	4/23/30	56	5.8	0.24	4.50E-12	1.78E+01	1.78E-01	0.00E+00	0.00E+00	5.10E-05	1.61E+00	6.46E-06	7.29E-10	1.14E-08	7.00E-03	4.16E-09	9.51E+02	0.00E+00	1.30E-02
BATCH-924	4/26/30	185	19.3	0.24	1.49E-12	6.78E+01	8.48E-01	0.00E+00	0.00E+00	4.00E-04	1.30E+01	1.09E-04	6.98E-11	5.35E-09	6.30E-02	2.97E-10	3.16E+03	0.00E+00	1.40E-01
BATCH-925	4/29/30	126	13.1	0.24	1.02E-12	4.61E+01	5.77E-01	0.00E+00	0.00E+00	2.00E-04	8.84E+00	7.40E-05	4.75E-11	4.30E-02	2.00E-02	2.15E-10	4.30E+02	0.00E+00	9.50E-02
BATCH-926	5/13/30	19	2.0	0.24	1.23E-12	1.68E+00	4.10E-02	0.00E+00	0.00E+00	1.08E-05	3.75E-01	1.81E-06	2.00E-10	3.13E-09	1.00E-03	1.13E-09	3.25E+02	0.00E+00	3.00E-03
BATCH-927	5/15/30	57	6.0	0.24	3.19E-14	7.47E+00	2.08E-01	0.00E+00	0.00E+00	4.77E-05	1.60E+00	8.25E-06	1.99E-12	1.23E-10	7.00E-03	7.39E-11	9.79E+02	0.00E+00	1.30E-02
BATCH-928	5/15/30	163	17.0	0.24	1.32E-12	5.98E+01	7.49E-01	0.00E+00	0.00E+00	4.00E-04	1.15E+01	9.60E-05	6.16E-11	4.72E-09	5.60E-02	2.62E-10	2.79E+03	0.00E+00	1.23E-01
BATCH-929	5/21/30	19	1.9	0.24	1.08E-12	1.72E+00	4.30E-02	0.00E+00	0.00E+00	1.22E-05	3.83E-01	1.54E-06	1.74E-10	2.73E-09	2.00E-03	9.93E-10	3.18E+02	0.00E+00	3.00E-03
BATCH-930	5/23/30	119	12.4	0.24	1.59E-13	1.76E+01	5.67E-01	0.00E+00	0.00E+00	1.32E-04	3.73E+00	1.46E-05	9.31E-12	5.58E-10	2.30E-02	2.87E-10	2.03E+03	0.00E+00	3.70E-02

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Tl+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-882	8/11/29	133	13.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.87E+01	9.27E-11	1.11E+00	4.03E+01	3.20E-02	1.17E-08	0.00E+00	3.00E-03	6.37E-07	1.60E-02
BATCH-883	8/15/29	186	19.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	5.40E+01	1.30E-10	1.54E+00	5.64E+01	4.50E-02	1.64E-08	0.00E+00	4.00E-03	8.91E-07	2.30E-02
BATCH-884	8/25/29	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.35E-04	1.63E+00	1.58E-11	4.93E-01	8.68E-01	9.57E-04	5.31E-12	0.00E+00	1.21E-04	1.26E-07	7.38E-04
BATCH-885	8/27/29	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.23E+01	1.01E-10	1.21E+00	4.41E+01	3.50E-02	1.28E-08	0.00E+00	3.00E-03	6.97E-07	1.80E-02
BATCH-886	9/3/29	51	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.67E-04	1.03E+01	2.22E-11	2.44E+00	5.21E+00	5.00E-03	4.93E-12	0.00E+00	5.73E-04	6.96E-08	3.00E-03
BATCH-887	9/9/29	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-04	2.66E+00	1.00E-11	6.22E-01	1.30E+00	1.00E-03	2.22E-12	0.00E+00	1.32E-04	3.11E-08	8.16E-04
BATCH-888	9/11/29	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.57E+01	8.30E-12	9.19E+00	1.36E+01	1.10E-02	1.05E-09	0.00E+00	1.00E-03	5.88E-08	8.00E-03
BATCH-889	9/12/29	186	19.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	5.40E+01	1.30E-10	1.54E+00	5.63E+01	4.50E-02	1.64E-08	0.00E+00	4.00E-03	8.90E-07	2.30E-02
BATCH-890	9/23/29	161	16.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	4.68E+01	1.12E-10	1.34E+00	4.88E+01	3.90E-02	1.42E-08	0.00E+00	3.00E-03	7.71E-07	2.00E-02
BATCH-891	10/1/29	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E-04	2.47E+00	5.35E-12	5.86E-01	1.25E+00	1.00E-03	1.19E-12	0.00E+00	1.38E-04	1.67E-08	8.07E-04
BATCH-892	10/3/29	126	13.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	3.65E+01	8.77E-11	1.04E+00	3.81E+01	3.00E-02	1.11E-08	0.00E+00	2.00E-03	6.03E-07	1.50E-02
BATCH-893	10/10/29	183	19.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	5.56E+01	5.59E-11	2.09E+00	5.43E+01	3.80E-02	7.08E-09	0.00E+00	2.00E-03	3.87E-07	1.90E-02
BATCH-894	10/16/29	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.72E-04	9.62E+00	3.10E-12	3.43E+00	5.07E+00	4.00E-03	3.92E-10	0.00E+00	5.32E-04	2.20E-08	3.00E-03
BATCH-895	10/22/29	168	17.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	5.27E+01	6.70E-14	2.33E+00	4.90E+01	3.00E-02	8.47E-12	0.00E+00	4.86E-04	4.88E-09	1.40E-02
BATCH-896	10/30/29	193	20.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	6.07E+01	9.14E-16	2.68E+00	5.64E+01	3.40E-02	9.06E-15	0.00E+00	5.58E-04	5.10E-09	1.70E-02
BATCH-897	11/8/29	145	15.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.56E+01	6.70E-14	2.01E+00	4.24E+01	2.60E-02	8.46E-12	0.00E+00	4.21E-04	4.29E-09	1.20E-02
BATCH-898	11/19/29	114	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	3.57E+01	6.68E-14	1.58E+00	3.32E+01	2.00E-02	8.44E-12	0.00E+00	3.30E-04	3.45E-09	1.00E-02
BATCH-899	11/24/29	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-04	2.32E+00	7.47E-13	8.27E-01	1.22E+00	9.61E-04	9.45E-11	0.00E+00	1.28E-04	5.29E-09	7.07E-04
BATCH-900	11/26/29	163	17.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	5.12E+01	2.98E-14	2.26E+00	4.76E+01	2.90E-02	3.76E-12	0.00E+00	4.71E-04	4.50E-09	1.40E-02
BATCH-901	12/1/29	147	15.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.61E+01	1.93E-16	2.04E+00	4.29E+01	2.60E-02	1.17E-14	0.00E+00	4.24E-04	3.87E-09	1.30E-02
BATCH-902	12/13/29	160	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-02	4.90E+01	4.50E-16	4.50E+00	4.85E+01	3.90E-02	1.25E-14	0.00E+00	9.44E-04	7.15E-09	1.30E-02
BATCH-903	12/17/29	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-02	3.66E+01	4.74E-16	4.12E+00	3.73E+01	3.30E-02	1.67E-14	0.00E+00	8.65E-04	6.33E-09	9.00E-03
BATCH-904	12/29/29	182	19.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.20E-02	5.53E+01	7.52E-16	6.22E+00	5.62E+01	5.00E-02	2.99E-14	0.00E+00	1.00E-03	9.55E-09	1.40E-02
BATCH-905	12/30/29	155	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.55E+01	1.78E-11	1.81E+01	1.94E+01	1.40E-02	2.25E-09	0.00E+00	1.00E-03	1.24E-07	9.00E-03
BATCH-906	1/15/30	135	14.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.30E-02	4.11E+01	4.99E-16	4.63E+00	4.18E+01	3.70E-02	1.46E-14	0.00E+00	9.70E-04	7.10E-09	1.00E-02
BATCH-907	1/18/30	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-02	3.71E+01	4.35E-16	4.18E+00	3.78E+01	3.40E-02	1.12E-14	0.00E+00	8.77E-04	6.41E-09	9.00E-03
BATCH-908	1/29/30	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.30E+01	2.08E-11	2.30E+01	1.67E+01	1.20E-02	2.63E-09	0.00E+00	7.60E-04	1.44E-07	5.00E-03
BATCH-909	1/31/30	138	14.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.40E-02	4.18E+01	4.89E-16	4.71E+00	4.25E+01	3.80E-02	1.26E-14	0.00E+00	9.87E-04	7.22E-09	1.10E-02
BATCH-910	2/12/30	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.79E-04	1.12E+01	5.59E-12	5.70E+00	6.09E+00	5.00E-03	7.07E-10	0.00E+00	4.59E-04	3.89E-08	3.00E-03
BATCH-911	2/14/30	159	16.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.30E-02	4.83E+01	5.65E-16	5.44E+00	4.91E+01	4.40E-02	1.45E-14	0.00E+00	1.00E-03	8.34E-09	1.20E-02
BATCH-912	2/18/30	116	12.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	4.20E+01	4.64E-12	3.06E+00	3.77E+01	3.10E-02	4.38E-15	0.00E+00	2.00E-03	6.93E-09	1.20E-02
BATCH-913	3/2/30	128	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.28E+01	1.11E-11	2.42E+01	1.63E+01	1.10E-02	1.41E-09	0.00E+00	5.09E-04	7.75E-08	5.00E-03
BATCH-914	3/3/30	59	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.36E+01	8.54E-12	9.47E+00	6.87E+00	5.00E-03	1.08E-09	0.00E+00	3.12E-04	5.90E-08	2.00E-03
BATCH-915	3/9/30	123	12.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	4.92E+01	8.15E-12	2.60E+00	4.12E+01	3.20E-02	2.84E-16	0.00E+00	3.00E-03	7.92E-09	1.40E-02
BATCH-916	3/16/30	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-04	2.67E+00	1.33E-12	1.36E+00	1.45E+00	1.00E-03	1.69E-10	0.00E+00	1.09E-04	9.29E-09	6.95E-04
BATCH-917	3/18/30	140	14.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.53E+01	1.12E-11	2.83E+01	1.85E+01	1.30E-02	1.39E-09	0.00E+00	6.28E-04	7.73E-08	5.00E-03
BATCH-918	3/22/30	143	14.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	5.69E+01	9.43E-12	3.01E+00	4.76E+01	3.70E-02	3.27E-16	0.00E+00	3.00E-03	9.16E-09	1.60E-02
BATCH-919	4/2/30	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.56E-04	3.24E+00	2.04E-12	2.26E+00	1.64E+00	1.00E-03	2.59E-10	0.00E+00	7.47E-05	1.41E-08	5.22E-04
BATCH-920	4/4/30	59	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.36E+01	4.61E-12	1.00E+01	6.75E+00	4.00E-03	5.83E-10	0.00E+00	2.11E-04	3.21E-08	2.00E-03
BATCH-921	4/6/30	185	19.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-02	7.39E+01	1.22E-11	3.90E+00	6.18E+01	4.80E-02	2.40E-14	0.00E+00	4.00E-03	1.19E-08	2.10E-02
BATCH-922	4/10/30	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.38E+01	6.06E-13	3.03E+01	1.68E+01	1.10E-02	2.67E-15	0.00E+00	4.59E-04	2.10E-09	4.00E-03
BATCH-923	4/23/30	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.27E+01	4.04E-12	1.02E+01	6.67E+00	5.00E-03	5.01E-10	0.00E+00	2.26E-04	2.78E-08	2.00E-03
BATCH-924	4/26/30	185	19.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-02	7.38E+01	1.22E-11	3.90E+00	6.17E+01	4.80E-02	3.96E-14	0.00E+00	4.00E-03	1.19E-08	2.10E-02
BATCH-925	4/29/30	126	13.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	5.02E+01	8.33E-12	2.65E+00	4.20E+01	3.30E-02	2.81E-16	0.00E+00	3.00E-03	8.08E-09	1.40E-02
BATCH-926	5/13/30	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E-04	3.21E+00	1.09E-12	2.37E+00	1.59E+00	1.00E-03	1.38E-10	0.00E+00	4.98E-05	7.59E-09	4.63E-04
BATCH-927	5/15/30	57	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.38E+01	2.47E-13	1.23E+01	6.83E+00	5.00E-03	1.09E-15	0.00E+00	1.87E-04	8.56E-10	2.00E-03
BATCH-928	5/15/30	163	17.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	6.51E+01	1.08E-11	3.44E+00	5.45E+01	4.30E-02	3.77E-16	0.00E+00	4.00E-03	1.05E-08	1.80E-02
BATCH-929	5/21/30	19	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.47E-04	3.04E+00	9.64E-13	2.43E+00	1.59E+00	1.00E-03	1.20E-10	0.00E+00	5.40E-05	6.65E-09	4.53E-04
BATCH-930	5/23/30	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.30E+01	1.27E-12	3.50E+01	1.61E+01	1.20E-02	3.45E-15	0.00E+00	7.10E-04	2.61E-09	4.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-931	6/2/30	141	14.7	0.24	0.00E+00	0.00E+00	1.55E-01	1.50E-02	1.16E+01	4.35E-01	2.82E+03	5.49E-01	7.50E-02	1.31E+01	5.16E-15	8.78E-01	7.50E-04	1.48E-01	1.30E-02
BATCH-932	6/5/30	155	16.1	0.24	0.00E+00	0.00E+00	2.18E-01	2.20E-02	1.63E+01	5.60E-01	3.09E+03	7.53E-01	1.07E-01	1.54E+01	7.54E-15	1.08E+00	1.00E-03	2.21E-01	1.63E-02
BATCH-933	6/17/30	19	2.0	0.24	0.00E+00	0.00E+00	1.00E-03	6.35E-05	9.00E-02	1.17E-02	3.26E+01	5.00E-03	8.19E-04	2.07E-01	1.91E-17	1.60E-02	6.69E-06	4.04E-04	2.50E-04
BATCH-934	6/19/30	154	16.1	0.24	0.00E+00	0.00E+00	2.18E-01	2.20E-02	1.63E+01	5.60E-01	3.09E+03	7.53E-01	1.07E-01	1.54E+01	7.54E-15	1.08E+00	1.00E-03	2.21E-01	1.63E-02
BATCH-935	6/21/30	121	12.6	0.24	0.00E+00	0.00E+00	1.70E-01	1.70E-02	1.27E+01	4.38E-01	2.42E+03	5.89E-01	8.30E-02	1.20E+01	5.90E-15	8.43E-01	8.39E-04	1.73E-01	1.28E-02
BATCH-936	7/4/30	58	6.0	0.24	0.00E+00	0.00E+00	5.00E-03	2.38E-04	3.71E-01	5.13E-02	1.21E+02	2.00E-02	4.00E-03	8.34E-01	6.79E-17	6.10E-02	2.80E-05	2.00E-03	1.25E-03
BATCH-937	7/5/30	121	12.6	0.24	0.00E+00	0.00E+00	1.71E-01	1.70E-02	1.28E+01	4.38E-01	2.42E+03	5.90E-01	8.40E-02	1.21E+01	5.91E-15	8.44E-01	8.40E-04	1.73E-01	1.28E-02
BATCH-938	7/10/30	154	16.1	0.24	0.00E+00	0.00E+00	2.17E-01	2.10E-02	1.62E+01	5.58E-01	3.08E+03	7.51E-01	1.06E-01	1.53E+01	7.51E-15	1.07E+00	1.00E-03	2.20E-01	1.63E-02
BATCH-939	7/18/30	130	13.5	0.24	0.00E+00	0.00E+00	2.32E-01	2.80E-02	1.73E+01	5.16E-01	2.59E+03	1.28E+00	1.57E-01	1.29E+01	1.02E-14	1.44E+00	2.00E-03	3.63E-01	1.50E-02
BATCH-940	7/26/30	100	10.4	0.24	0.00E+00	0.00E+00	2.05E-01	2.70E-02	1.53E+01	4.23E-01	2.00E+03	1.33E+00	1.58E-01	9.96E+00	9.99E-15	1.40E+00	2.00E-03	3.76E-01	1.25E-02
BATCH-941	8/1/30	128	13.3	0.24	0.00E+00	0.00E+00	2.62E-01	3.50E-02	1.96E+01	5.40E-01	2.55E+03	1.70E+00	2.01E-01	1.27E+01	1.28E-14	1.78E+00	2.00E-03	4.80E-01	1.60E-02
BATCH-942	8/6/30	19	2.0	0.24	0.00E+00	0.00E+00	1.00E-03	5.61E-05	8.80E-02	1.26E-02	2.85E+01	5.00E-03	9.01E-04	1.97E-01	1.60E-17	1.40E-02	6.62E-06	4.62E-04	2.50E-04
BATCH-943	8/8/30	100	10.4	0.24	0.00E+00	0.00E+00	2.05E-01	2.70E-02	1.53E+01	4.23E-01	2.00E+03	1.33E+00	1.58E-01	9.97E+00	1.00E-14	1.40E+00	2.00E-03	3.76E-01	1.25E-02
BATCH-944	8/14/30	128	13.3	0.24	0.00E+00	0.00E+00	2.62E-01	3.50E-02	1.96E+01	5.39E-01	2.55E+03	1.70E+00	2.01E-01	1.27E+01	1.27E-14	1.78E+00	2.00E-03	4.79E-01	1.60E-02
BATCH-945	8/19/30	112	11.7	0.24	0.00E+00	0.00E+00	2.29E-01	3.10E-02	1.72E+01	4.73E-01	2.24E+03	1.49E+00	1.76E-01	1.11E+01	1.12E-14	1.56E+00	2.00E-03	4.21E-01	1.40E-02
BATCH-946	8/28/30	88	9.2	0.24	0.00E+00	0.00E+00	1.81E-01	2.40E-02	1.35E+01	3.74E-01	1.77E+03	1.18E+00	1.39E-01	8.79E+00	8.82E-15	1.23E+00	1.00E-03	3.32E-01	1.10E-02
BATCH-947	8/31/30	162	16.9	0.24	0.00E+00	0.00E+00	1.45E-01	1.70E-02	1.08E+01	4.19E-01	3.25E+03	8.86E-01	1.00E-01	1.62E+01	6.07E-15	1.25E+00	9.85E-04	2.15E-01	1.35E-02
BATCH-948	9/6/30	148	15.4	0.24	0.00E+00	0.00E+00	5.00E-02	3.00E-03	3.67E+00	2.63E-01	1.45E+03	2.45E-01	2.30E-02	7.01E+00	1.07E-15	6.85E-01	2.21E-04	2.20E-02	9.25E-03
BATCH-949	9/17/30	116	12.1	0.24	0.00E+00	0.00E+00	3.90E-02	3.00E-03	2.88E+00	2.06E-01	1.13E+03	1.92E-01	1.80E-02	5.50E+00	8.38E-16	5.37E-01	1.74E-04	1.70E-02	7.25E-03
BATCH-950	9/22/30	148	15.4	0.24	0.00E+00	0.00E+00	5.00E-02	3.00E-03	3.67E+00	2.63E-01	1.44E+03	2.45E-01	2.20E-02	7.00E+00	1.07E-15	6.85E-01	2.21E-04	2.20E-02	9.25E-03
BATCH-951	9/29/30	130	13.5	0.24	0.00E+00	0.00E+00	4.40E-02	3.00E-03	3.22E+00	2.30E-01	1.27E+03	2.15E-01	2.00E-02	6.15E+00	9.36E-16	6.01E-01	1.94E-04	1.90E-02	8.00E-03
BATCH-952	10/7/30	108	11.2	0.24	0.00E+00	0.00E+00	4.20E-02	5.00E-03	3.11E+00	1.15E-01	1.18E+03	2.29E-01	2.70E-02	4.42E+00	1.68E-15	3.20E-01	2.64E-04	5.80E-02	3.50E-03
BATCH-953	10/13/30	158	16.5	0.24	0.00E+00	0.00E+00	5.30E-02	4.00E-03	3.92E+00	2.81E-01	1.54E+03	2.61E-01	2.40E-02	7.48E+00	1.14E-15	7.31E-01	2.35E-04	2.30E-02	1.00E-02
BATCH-954	10/19/30	130	13.5	0.24	0.00E+00	0.00E+00	4.40E-02	3.00E-03	3.22E+00	2.30E-01	1.27E+03	2.14E-01	2.00E-02	6.14E+00	9.31E-16	6.01E-01	1.93E-04	1.90E-02	8.00E-03
BATCH-955	10/29/30	114	11.8	0.24	0.00E+00	0.00E+00	3.80E-02	4.00E-03	2.80E+00	1.14E-01	1.04E+03	1.82E-01	2.20E-02	3.87E+00	1.36E-15	2.90E-01	2.14E-04	4.30E-02	3.50E-03
BATCH-956	11/1/30	120	12.5	0.24	0.00E+00	0.00E+00	5.40E-02	4.00E-03	4.04E+00	3.50E-01	2.39E+03	5.19E-01	2.50E-02	6.65E+00	1.25E-15	6.44E-01	1.88E-04	1.60E-02	8.00E-03
BATCH-957	11/10/30	101	10.5	0.24	0.00E+00	0.00E+00	7.50E-02	5.00E-03	5.64E+00	5.78E-01	2.02E+03	1.10E+00	3.60E-02	7.64E+00	1.85E-15	7.28E-01	1.78E-04	1.20E-02	8.25E-03
BATCH-958	11/14/30	58	6.1	0.24	0.00E+00	0.00E+00	2.10E-02	2.00E-03	1.53E+00	5.67E-02	5.84E+02	1.13E-01	1.30E-02	2.18E+00	8.28E-16	1.58E-01	1.31E-04	2.80E-02	1.75E-03
BATCH-959	11/20/30	123	12.8	0.24	0.00E+00	0.00E+00	9.20E-02	6.00E-03	6.87E+00	7.05E-01	2.46E+03	1.34E+00	4.40E-02	9.32E+00	2.26E-15	8.88E-01	2.17E-04	1.40E-02	1.00E-02
BATCH-960	11/21/30	101	10.6	0.24	0.00E+00	0.00E+00	7.60E-02	5.00E-03	5.65E+00	5.80E-01	2.03E+03	1.10E+00	3.60E-02	7.66E+00	1.86E-15	7.30E-01	1.78E-04	1.20E-02	8.25E-03
BATCH-961	12/2/30	58	6.0	0.24	0.00E+00	0.00E+00	1.80E-02	2.00E-03	1.31E+00	5.31E-02	4.83E+02	8.50E-02	1.00E-02	1.81E+00	6.34E-16	1.35E-01	9.97E-05	2.00E-02	1.75E-03
BATCH-962	12/3/30	99	10.3	0.24	0.00E+00	0.00E+00	3.80E-02	4.00E-03	2.80E+00	1.12E-01	1.10E+03	2.02E-01	2.30E-02	3.94E+00	1.44E-15	2.89E-01	2.26E-04	4.70E-02	3.50E-03
BATCH-963	12/8/30	20	2.1	0.24	0.00E+00	0.00E+00	6.00E-03	6.30E-04	4.15E-01	1.53E-02	1.58E+02	3.10E-02	4.00E-03	5.90E-01	2.24E-16	4.30E-02	3.53E-05	8.00E-03	5.00E-04
BATCH-964	12/11/30	100	10.4	0.24	0.00E+00	0.00E+00	4.90E-02	5.00E-03	3.64E+00	1.57E-01	1.75E+03	3.05E-01	2.90E-02	4.72E+00	1.86E-15	3.33E-01	2.74E-04	5.80E-02	4.00E-03
BATCH-965	12/14/30	108	11.3	0.24	0.00E+00	0.00E+00	4.10E-02	4.00E-03	3.03E+00	1.47E-01	1.55E+03	2.74E-01	2.40E-02	4.19E+00	1.49E-15	3.17E-01	2.23E-04	4.50E-02	3.75E-03
BATCH-966	12/21/30	104	10.9	0.24	0.00E+00	0.00E+00	7.80E-02	5.00E-03	5.82E+00	5.99E-01	2.09E+03	1.14E+00	3.70E-02	7.89E+00	1.91E-15	7.52E-01	1.84E-04	1.20E-02	8.50E-03
BATCH-967	12/26/30	20	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.77E-04	3.44E-01	1.44E-02	1.27E+02	2.20E-02	3.00E-03	4.76E-01	1.67E-16	3.60E-02	5.00E-05	5.00E-03	5.00E-04
BATCH-968	12/28/30	162	16.9	0.24	0.00E+00	0.00E+00	1.21E-01	8.00E-03	9.02E+00	9.26E-01	3.23E+03	1.76E+00	5.80E-02	1.22E+01	2.96E-15	1.17E+00	2.84E-04	1.90E-02	1.30E-02
BATCH-969	1/1/31	54	5.6	0.24	0.00E+00	0.00E+00	1.80E-02	2.00E-03	1.37E+00	5.49E-02	5.27E+02	9.90E-02	1.10E-02	1.94E+00	3.57E-16	1.35E-01	8.66E-05	2.30E-02	1.75E-03
BATCH-970	1/7/31	60	6.2	0.24	0.00E+00	0.00E+00	2.70E-02	3.00E-03	2.00E+00	8.64E-02	9.45E+02	1.69E-01	1.50E-02	2.61E+00	5.18E-16	1.76E-01	1.18E-04	3.20E-02	2.25E-03
BATCH-971	1/14/31	61	6.4	0.24	0.00E+00	0.00E+00	2.10E-02	2.00E-03	1.58E+00	7.74E-02	7.96E+02	1.44E-01	1.20E-02	2.20E+00	3.93E-16	1.59E-01	9.13E-05	2.40E-02	2.00E-03
BATCH-972	1/14/31	162	16.8	0.24	0.00E+00	0.00E+00	1.21E-01	7.00E-03	8.95E+00	9.24E-01	3.23E+03	1.76E+00	5.50E-02	1.22E+01	1.49E-15	1.11E+00	2.21E-04	1.90E-02	1.30E-02
BATCH-973	1/20/31	106	11.0	0.24	0.00E+00	0.00E+00	3.70E-02	3.00E-03	2.73E+00	1.79E-01	1.97E+03	3.57E-01	2.10E-02	4.02E+00	6.46E-16	3.15E-01	1.42E-04	3.50E-02	3.50E-03
BATCH-974	1/31/31	18	1.9	0.24	0.00E+00	0.00E+00	4.00E-03	4.24E-04	3.30E-01	1.35E-02	1.27E+02	2.40E-02	3.00E-03	4.67E-01	8.60E-17	3.30E-02	2.09E-05	6.00E-03	5.00E-04
BATCH-975	2/1/31	22	2.3	0.24	0.00E+00	0.00E+00	8.00E-03	7.61E-04	6.04E-01	2.61E-02	2.85E+02	5.10E-02	5.00E-03	7.88E-01	1.57E-16	5.30E-02	3.57E-05	1.00E-02	7.50E-04
BATCH-976	2/2/31	130	13.5	0.24	0.00E+00	0.00E+00	9.00E-02	5.00E-03	6.65E+00	6.62E-01	2.59E+03	1.23E+00	3.90E-02	9.17E+00	1.09E-15	8.45E-01	1.67E-04	1.40E-02	1.00E-02
BATCH-977	2/3/31	23	2.4	0.24	0.00E+00	0.00E+00	6.00E-03	5.74E-04	4.71E-01	2.34E-02	2.38E+02	4.30E-02	4.00E-03	6.58E-01	1.18E-16	4.80E-02	2.73E-05	7.00E-03	5.00E-04
BATCH-978	2/6/31	59	6.2	0.24	0.00E+00	0.00E+00	1.90E-02	2.00E-03	1.40E+00	9.18E-02	1.01E+03	1.83E-01	1.10E-02	2.06E+00	3.31E-16	1.61E-01	7.29E-05	1.80E-02	1.75E-03
BATCH-979	2/12/31	161	16.8	0.24	0.00E+00	0.00E+00	5.90E-02	3.00E-03	4.36E+00	2.40E-01	1.42E+03	2.04E-01	1.60E-02	6.68E+00	5.85E-16	7.09E-01	1.26E-04	7.00E-03	9.00E-03

Appendix A Nominal ILAW inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-931	6/2/30	141	14.7	0.24	3.89E-08	4.22E+02	2.44E+02	2.10E+02	1.09E+00	5.70E-02	8.61E-06	7.79E-06	9.63E-04	3.18E-04	1.49E-04	6.28E-04	2.40E-02	1.32E-01	3.70E-02
BATCH-932	6/5/30	155	16.1	0.24	4.16E-08	4.63E+02	3.70E+02	3.00E+02	1.61E+00	8.30E-02	1.10E-05	1.18E-05	1.00E-03	4.58E-04	2.13E-04	8.97E-04	3.50E-02	1.92E-01	5.30E-02
BATCH-933	6/17/30	19	2.0	0.24	1.16E-09	5.65E+01	9.40E-02	7.80E-05	3.00E-03	2.73E-04	1.39E-07	3.44E-09	1.25E-05	5.08E-06	1.28E-06	8.94E-06	2.19E-04	1.00E-03	2.58E-04
BATCH-934	6/19/30	154	16.1	0.24	4.16E-08	4.63E+02	3.69E+02	3.00E+02	1.61E+00	8.30E-02	1.10E-05	1.18E-05	1.00E-03	4.58E-04	2.13E-04	8.97E-04	3.50E-02	1.92E-01	5.30E-02
BATCH-935	6/21/30	121	12.6	0.24	3.25E-08	3.63E+02	2.89E+02	2.40E+02	1.26E+00	6.50E-02	8.60E-06	9.21E-06	1.00E-03	3.58E-04	1.67E-04	7.01E-04	2.80E-02	1.50E-01	4.20E-02
BATCH-936	7/4/30	58	6.0	0.24	4.77E-09	1.73E+02	4.52E-01	4.39E-04	2.00E-02	2.00E-03	5.64E-07	1.63E-08	5.47E-05	2.31E-05	5.06E-06	4.01E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-937	7/5/30	121	12.6	0.24	3.26E-08	3.63E+02	2.89E+02	2.40E+02	1.26E+00	6.50E-02	8.61E-06	9.22E-06	1.00E-03	3.59E-04	1.67E-04	7.02E-04	2.80E-02	1.50E-01	4.20E-02
BATCH-938	7/10/30	154	16.1	0.24	4.14E-08	4.62E+02	3.68E+02	3.00E+02	1.60E+00	8.20E-02	1.10E-05	1.17E-05	1.00E-03	4.56E-04	2.13E-04	8.94E-04	3.50E-02	1.91E-01	5.30E-02
BATCH-939	7/18/30	130	13.5	0.24	4.47E-08	3.89E+02	6.27E+02	4.60E+02	2.48E+00	1.16E-01	1.41E-05	2.00E-05	1.00E-03	3.98E-04	3.42E-04	9.18E-04	4.30E-02	2.35E-01	6.90E-02
BATCH-940	7/26/30	100	10.4	0.24	3.97E-08	3.00E+02	6.56E+02	4.70E+02	2.52E+00	1.15E-01	1.35E-05	2.09E-05	7.04E-04	3.14E-04	3.52E-04	7.98E-04	4.10E-02	2.21E-01	6.70E-02
BATCH-941	8/1/30	128	13.3	0.24	5.07E-08	3.83E+02	8.38E+02	5.90E+02	3.22E+00	1.47E-01	1.72E-05	2.67E-05	8.99E-04	4.01E-04	4.49E-04	1.00E-03	5.20E-02	2.82E-01	8.50E-02
BATCH-942	8/6/30	19	2.0	0.24	1.13E-09	5.65E+01	1.07E-01	1.04E-04	5.00E-03	4.07E-04	1.33E-07	3.84E-09	1.29E-05	5.46E-06	1.20E-06	9.46E-06	3.08E-04	2.00E-03	3.87E-04
BATCH-943	8/8/30	100	10.4	0.24	3.98E-08	3.00E+02	6.57E+02	4.70E+02	2.53E+00	1.15E-01	1.35E-05	2.09E-05	7.05E-04	3.15E-04	3.52E-04	7.99E-04	4.10E-02	2.21E-01	6.70E-02
BATCH-944	8/14/30	128	13.3	0.24	5.06E-08	3.83E+02	8.37E+02	5.90E+02	3.22E+00	1.47E-01	1.72E-05	2.67E-05	8.98E-04	4.01E-04	4.49E-04	1.00E-03	5.20E-02	2.82E-01	8.50E-02
BATCH-945	8/19/30	112	11.7	0.24	4.44E-08	3.36E+02	7.34E+02	5.20E+02	2.82E+00	1.29E-01	1.51E-05	2.34E-05	7.87E-04	3.52E-04	3.94E-04	8.93E-04	4.60E-02	2.47E-01	7.50E-02
BATCH-946	8/28/30	88	9.2	0.24	3.51E-08	2.65E+02	5.80E+02	4.10E+02	2.23E+00	1.02E-01	1.19E-05	1.85E-05	6.21E-04	2.78E-04	3.11E-04	7.05E-04	3.60E-02	1.95E-01	5.90E-02
BATCH-947	8/31/30	162	16.9	0.24	5.32E-08	4.87E+02	3.66E+02	2.60E+02	1.42E+00	6.50E-02	1.09E-05	1.17E-05	5.69E-04	2.25E-04	2.18E-04	5.52E-04	2.60E-02	1.43E-01	4.20E-02
BATCH-948	9/6/30	148	15.4	0.24	4.35E-08	4.44E+02	2.64E+02	2.00E+02	1.16E+01	6.00E-03	5.12E-06	8.41E-07	2.66E-04	7.97E-05	4.34E-05	1.76E-04	6.00E-03	3.50E-02	1.00E-02
BATCH-949	9/17/30	116	12.1	0.24	3.41E-08	3.48E+02	2.06E+01	2.00E+02	9.20E-02	4.00E-03	4.02E-06	6.63E-07	2.08E-04	6.26E-05	3.41E-05	1.38E-04	5.00E-03	2.70E-02	8.00E-03
BATCH-950	9/22/30	148	15.4	0.24	4.35E-08	4.43E+02	2.64E+01	2.00E+02	1.16E+01	6.00E-03	5.12E-06	8.41E-07	2.66E-04	7.97E-05	4.34E-05	1.76E-04	6.00E-03	3.50E-02	1.00E-02
BATCH-951	9/29/30	130	13.5	0.24	3.82E-08	3.89E+02	2.32E+01	2.00E+02	1.02E+01	5.00E-03	4.49E-06	7.40E-07	2.33E-04	6.99E-05	3.81E-05	1.55E-04	6.00E-03	3.10E-02	9.00E-03
BATCH-952	10/7/30	108	11.2	0.24	1.35E-08	3.23E+02	9.80E+01	7.00E+03	3.97E+01	1.90E+02	2.96E-06	3.12E-06	1.83E-04	6.86E-05	5.77E-05	1.59E-04	7.00E-03	3.90E-02	1.20E-02
BATCH-953	10/13/30	158	16.5	0.24	4.65E-08	4.74E+02	2.79E+01	2.00E+03	1.23E+01	6.00E-03	5.47E-06	8.89E-07	2.84E-04	8.51E-05	4.62E-05	1.88E-04	7.00E-03	3.70E-02	1.00E-02
BATCH-954	10/19/30	130	13.5	0.24	3.82E-08	3.89E+02	2.28E+01	2.00E+03	1.01E+01	5.00E-03	4.49E-06	7.26E-07	2.33E-04	6.96E-05	3.79E-05	1.54E-04	6.00E-03	3.00E-02	8.00E-03
BATCH-955	10/29/30	114	11.8	0.24	1.36E-08	3.40E+02	7.24E+01	6.00E-03	3.03E+01	1.50E-02	2.63E-06	2.31E-06	1.89E-04	6.60E-05	4.52E-05	1.45E-04	6.00E-03	3.30E-02	1.00E-02
BATCH-956	11/1/30	120	12.5	0.24	3.30E-08	3.59E+02	1.59E+01	4.00E-03	2.16E+01	2.10E-02	4.30E-06	5.08E-07	4.85E-04	1.12E-04	4.27E-05	2.08E-04	6.00E-03	3.40E-02	8.00E-03
BATCH-957	11/10/30	101	10.5	0.24	2.34E-08	3.03E+02	2.90E+00	9.00E-03	4.38E+01	5.10E-02	3.96E-06	9.59E-08	9.68E-04	1.92E-04	5.20E-05	3.11E-04	8.00E-03	4.10E-02	8.00E-03
BATCH-958	11/14/30	58	6.1	0.24	6.68E-09	1.74E+02	4.83E+01	4.00E-03	1.96E+01	1.00E-02	1.46E-06	1.54E-06	9.02E-05	3.38E-05	2.85E-05	3.79E-04	1.90E-02	9.00E-03	6.00E-03
BATCH-959	11/20/30	123	12.8	0.24	2.85E-08	3.69E+02	3.53E+00	1.10E-02	5.34E+01	6.20E-02	4.83E-06	1.17E-07	1.00E-03	2.34E-04	6.34E-05	3.79E-04	4.10E-02	5.00E-02	1.00E-02
BATCH-960	11/21/30	101	10.6	0.24	2.34E-08	3.04E+02	2.90E+00	9.00E-03	4.40E+01	5.10E-02	3.98E-06	9.62E-08	9.71E-04	1.92E-04	5.22E-05	3.12E-04	8.00E-03	4.10E-02	9.00E-03
BATCH-961	12/2/30	58	6.0	0.24	6.34E-09	1.74E+02	3.38E+01	3.00E-03	1.41E+01	7.00E-03	1.23E-06	1.08E-06	8.80E-05	3.08E-05	2.11E-05	6.75E-05	3.00E-03	1.50E-02	4.00E-03
BATCH-962	12/3/30	99	10.3	0.24	1.25E-08	2.97E+02	8.01E+01	6.00E-03	3.24E+01	1.60E-02	2.56E-06	2.55E-06	1.83E-04	6.55E-05	4.87E-05	1.46E-04	6.00E-03	3.50E-02	1.00E-02
BATCH-963	12/8/30	20	2.1	0.24	1.81E-09	6.10E+01	1.31E+01	9.86E-04	5.30E-02	3.00E-03	3.95E-07	4.17E-07	2.44E-05	9.16E-06	7.70E-06	2.13E-05	9.65E-04	5.00E-03	2.00E-03
BATCH-964	12/11/30	100	10.4	0.24	1.21E-08	3.00E+02	9.80E+01	8.00E-03	4.32E+01	2.30E-02	2.92E-06	3.12E-06	2.91E-04	9.29E-05	6.00E-05	1.95E-04	8.00E-03	4.40E-02	1.20E-02
BATCH-965	12/14/30	108	11.3	0.24	1.28E-08	3.24E+02	7.53E+01	6.00E-03	3.39E+01	1.90E-02	2.64E-06	2.40E-06	2.46E-04	7.57E-05	4.93E-05	1.60E-04	7.00E-03	3.60E-02	1.00E-02
BATCH-966	12/21/30	104	10.9	0.24	2.41E-08	3.13E+02	2.98E+00	9.00E-03	4.53E+01	5.20E-02	4.09E-06	9.86E-08	1.00E-03	1.98E-04	5.38E-05	3.21E-04	8.00E-03	4.30E-02	9.00E-03
BATCH-967	12/26/30	20	2.1	0.24	1.67E-09	6.01E+01	8.90E+00	6.96E-04	3.70E-02	2.00E-03	3.24E-07	2.84E-07	2.32E-05	8.12E-06	5.56E-06	1.78E-05	7.54E-04	4.00E-03	1.00E-03
BATCH-968	12/28/30	162	16.9	0.24	3.74E-08	4.85E+02	4.61E+00	1.40E-02	7.02E+01	8.10E-02	6.34E-06	1.53E-07	2.00E-03	3.07E-04	8.33E-05	4.97E-04	1.20E-02	6.60E-02	1.40E-02
BATCH-969	1/1/31	54	5.6	0.24	4.39E-09	1.62E+02	3.91E+01	3.00E-03	1.47E+01	7.00E-03	1.26E-06	1.22E-06	8.13E-05	3.22E-05	2.39E-05	7.20E-05	3.00E-03	1.70E-02	5.00E-03
BATCH-970	1/7/31	60	6.2	0.24	4.77E-09	1.79E+02	5.38E+01	4.00E-03	2.20E+01	1.10E-02	1.62E-06	1.67E-06	1.45E-04	5.14E-05	3.32E-05	1.08E-04	4.00E-03	2.40E-02	7.00E-03
BATCH-971	1/14/31	61	6.4	0.24	4.81E-09	1.84E+02	3.92E+01	3.00E-03	1.64E+01	9.00E-03	1.39E-06	1.22E-06	1.17E-04	3.99E-05	2.59E-05	8.39E-05	3.00E-03	1.90E-02	5.00E-03
BATCH-972	1/14/31	162	16.8	0.24	2.67E-08	4.84E+02	4.57E+00	1.30E-02	6.47E+01	7.00E-02	6.33E-06	1.48E-07	1.00E-03	3.06E-04	8.32E-05	4.97E-04	1.20E-02	6.60E-02	1.40E-02
BATCH-973	1/20/31	106	11.0	0.24	8.86E-09	3.17E+02	5.52E+01	5.00E-03	2.79E+01	1.70E-02	2.41E-06	1.72E-06	2.54E-04	7.24E-05	4.31E-05	1.45E-04	5.00E-03	3.00E-02	8.00E-03
BATCH-974	1/31/31	18	1.9	0.24	1.06E-09	5.44E+01	9.43E+00	6.81E-04	3.50E-02	2.00E-03	3.04E-07	2.93E-07	1.95E-05	7.77E-06	5.77E-06	1.74E-05	7.58E-04	4.00E-03	1.00E-03
BATCH-975	2/1/31	22	2.3	0.24	1.44E-09	6.68E+01	1.62E+01	1.00E-03	6.70E-02	3.00E-03	4.88E-07	5.05E-07	4.39E-05	1.55E-05	1.00E-05	3.26E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-976	2/2/31	130	13.5	0.24	2.27E-08	3.89E+02	3.23E+00	9.00E-03	4.43E+01	4.80E-02	5.12E-06	1.04E-07	1.00E-03	2.21E-04	6.11E-05	3.62E-04	9.00E-03	4.70E-02	1.00E-02
BATCH-977	2/3/31	23	2.4	0.24	1.44E-09	6.77E+01	1.17E+01	9.49E-04	4.90E-02	3.00E-03	4.14E-07	3.65E-07	3.48E-05	1.19E-05	7.73E-06	2.51E-05	1.00E-03	6.00E-03	2.00E-03
BATCH-978	2/6/31	59	6.2	0.24	4.54E-09	1.77E+02	2.83E+01	3.00E-03	1.43E+01	9.00E-03	1.23E-06	8.80E-07	1.30E-04	3.71E-05	2.21E-05	7.44E-05	3.00E-03	1.50E-02	4.00E-03
BATCH-979	2/12/31	161	16.8	0.24	3.69E-08	4.82E+02	8.23E+01	6.21E-05	3.00E-03	1.59E-04	6.57E-06	2.55E-08	4.55E-04	9.20E-05	3.46E-05	1.85E-04	3.00E-03	1.40E-02	3.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-931	6/2/30	141	14.7	0.24	2.00E-03	9.50E-04	3.30E-02	3.10E-02	3.90E-02	1.44E+00	2.40E-01	1.95E+00	4.88E-01	3.27E-27	1.50E-05	7.59E-05	1.95E-04	1.00E-03	3.47E-11
BATCH-932	6/5/30	155	16.1	0.24	2.00E-03	1.00E-03	4.60E-02	4.50E-02	5.60E-02	2.09E+00	3.52E-01	2.85E+00	7.21E-01	4.34E-27	2.22E-05	1.10E-04	2.56E-04	1.00E-03	7.10E-12
BATCH-933	6/17/30	19	2.0	0.24	1.08E-05	4.49E-06	3.23E-04	1.12E-04	2.46E-04	6.00E-03	9.15E-04	2.70E-02	2.00E-03	5.58E-29	5.30E-08	5.87E-07	3.53E-06	3.37E-05	3.32E-12
BATCH-934	6/19/30	154	16.1	0.24	2.00E-03	1.00E-03	4.60E-02	4.50E-02	5.60E-02	2.09E+00	3.52E-01	2.85E+00	7.20E-01	4.33E-27	2.22E-05	1.10E-04	2.55E-04	1.00E-03	7.10E-12
BATCH-935	6/21/30	121	12.6	0.24	2.00E-03	1.00E-03	3.60E-02	3.50E-02	4.40E-02	1.63E+00	2.75E-01	2.23E+00	5.63E-01	3.39E-27	1.74E-05	8.62E-05	2.00E-04	1.00E-03	5.62E-12
BATCH-936	7/4/30	58	6.0	0.24	6.88E-05	2.62E-05	1.00E-03	5.35E-04	2.00E-03	2.80E-02	4.00E-03	1.74E-01	8.00E-03	2.31E-28	2.58E-07	3.65E-06	1.49E-05	1.80E-04	2.50E-11
BATCH-937	7/5/30	121	12.6	0.24	2.00E-03	1.00E-03	3.60E-02	3.50E-02	4.40E-02	1.63E+00	2.76E-01	2.24E+00	5.64E-01	3.39E-27	1.74E-05	8.63E-05	2.00E-04	1.00E-03	5.57E-12
BATCH-938	7/10/30	154	16.1	0.24	2.00E-03	1.00E-03	4.60E-02	4.50E-02	5.60E-02	2.08E+00	3.51E-01	2.84E+00	7.18E-01	4.32E-27	2.21E-05	1.10E-04	2.55E-04	1.00E-03	7.07E-12
BATCH-939	7/18/30	130	13.5	0.24	3.00E-03	2.00E-03	6.90E-02	7.60E-02	7.50E-02	3.50E+00	5.90E-01	4.08E+00	1.21E+00	7.19E-27	3.74E-05	1.54E-04	4.28E-04	2.00E-03	3.66E-12
BATCH-940	7/26/30	100	10.4	0.24	3.00E-03	2.00E-03	7.00E-02	7.90E-02	7.40E-02	3.65E+00	6.15E-01	4.06E+00	1.26E+00	7.48E-27	3.90E-05	1.52E-04	4.46E-04	3.00E-03	1.57E-12
BATCH-941	8/1/30	128	13.3	0.24	3.00E-03	3.00E-03	9.00E-02	1.01E-01	9.40E-02	4.66E+00	7.86E-01	5.18E+00	1.61E+00	9.55E-27	4.98E-05	1.94E-04	5.69E-04	3.00E-03	2.00E-12
BATCH-942	8/6/30	19	2.0	0.24	1.63E-05	6.20E-06	2.96E-04	1.26E-04	3.70E-04	7.00E-03	1.00E-03	4.10E-02	2.00E-03	5.47E-29	6.09E-08	8.62E-07	3.51E-06	4.25E-05	5.90E-12
BATCH-943	8/8/30	100	10.4	0.24	3.00E-03	2.00E-03	7.00E-02	7.90E-02	7.40E-02	3.66E+00	6.16E-01	4.06E+00	1.26E+00	7.49E-27	3.90E-05	1.52E-04	4.46E-04	3.00E-03	1.57E-12
BATCH-944	8/14/30	128	13.3	0.24	3.00E-03	3.00E-03	8.90E-02	1.01E-01	9.40E-02	4.66E+00	7.85E-01	5.18E+00	1.61E+00	9.54E-27	4.97E-05	1.94E-04	5.69E-04	3.00E-03	2.00E-12
BATCH-945	8/19/30	112	11.7	0.24	3.00E-03	2.00E-03	7.80E-02	8.80E-02	8.20E-02	4.09E+00	6.89E-01	4.54E+00	1.41E+00	8.37E-27	4.36E-05	1.70E-04	4.99E-04	3.00E-03	1.75E-12
BATCH-946	8/28/30	88	9.2	0.24	2.00E-03	2.00E-03	6.20E-02	7.00E-02	6.50E-02	3.23E+00	5.44E-01	3.58E+00	1.11E+00	6.61E-27	3.44E-05	1.34E-04	3.94E-04	2.00E-03	1.38E-12
BATCH-947	8/31/30	162	16.9	0.24	2.00E-03	1.00E-03	4.70E-02	4.60E-02	4.60E-02	2.19E+00	3.63E-01	2.37E+00	7.33E-01	5.29E-27	2.27E-05	8.85E-05	3.23E-04	2.00E-03	1.47E-12
BATCH-948	9/6/30	148	15.4	0.24	4.07E-04	1.93E-04	1.40E-02	6.00E-03	1.00E-02	3.45E-01	5.10E-02	2.98E-01	9.10E-02	2.78E-06	2.19E-05	8.60E-06	9.23E-05	5.55E-04	6.80E-13
BATCH-949	9/17/30	116	12.1	0.24	3.20E-04	1.51E-04	1.10E-02	5.00E-03	8.00E-03	2.71E-01	4.00E-02	2.34E-01	7.20E-02	2.19E-06	1.41E-27	2.78E-06	1.09E-05	1.18E-04	7.07E-04	8.66E-13
BATCH-950	9/22/30	148	15.4	0.24	4.07E-04	1.93E-04	1.40E-02	6.00E-03	1.00E-02	3.45E-01	5.00E-02	2.98E-01	9.10E-02	1.80E-27	2.78E-06	1.09E-05	1.18E-04	7.07E-04	7.60E-13
BATCH-951	9/29/30	130	13.5	0.24	3.57E-04	1.69E-04	1.20E-02	5.00E-03	8.00E-03	3.03E-01	4.40E-02	2.61E-01	8.00E-02	1.58E-27	2.44E-06	9.61E-06	1.03E-04	6.20E-04	7.60E-13
BATCH-952	10/7/30	108	11.2	0.24	4.72E-04	3.35E-04	1.20E-02	1.20E-02	1.30E-02	5.80E-01	9.60E-02	6.70E-01	1.95E-01	1.36E-27	6.03E-06	2.56E-05	8.25E-05	4.82E-04	1.84E-11
BATCH-953	10/13/30	158	16.5	0.24	4.34E-04	2.05E-04	1.40E-02	6.00E-03	1.00E-02	3.67E-01	5.40E-02	3.16E-01	9.70E-02	1.92E-27	2.96E-06	1.16E-05	1.26E-04	7.54E-04	9.26E-13
BATCH-954	10/19/30	130	13.5	0.24	3.56E-04	1.68E-04	1.20E-02	5.00E-03	8.00E-03	3.01E-01	4.40E-02	2.59E-01	7.90E-02	1.57E-27	2.42E-06	9.52E-06	1.03E-04	6.19E-04	7.61E-13
BATCH-955	10/29/30	114	11.8	0.24	3.94E-04	2.63E-04	1.00E-02	9.00E-03	1.00E-02	4.43E-01	7.30E-02	5.27E-01	1.47E-01	4.54E-06	2.02E-05	6.78E-05	3.98E-04	1.52E-11	
BATCH-956	11/1/30	120	12.5	0.24	3.48E-04	1.59E-04	1.10E-02	5.00E-03	8.00E-03	2.46E-01	3.70E-02	4.82E-01	7.10E-02	5.88E-27	2.28E-05	4.89E-04	1.10E-02	1.13E-12	
BATCH-957	11/10/30	101	10.5	0.24	3.33E-04	1.42E-04	8.00E-03	3.00E-03	8.00E-03	1.44E-01	2.50E-02	9.10E-01	5.60E-02	1.41E-26	4.83E-05	1.00E-03	3.00E-02	1.83E-12	
BATCH-958	11/14/30	58	6.1	0.24	2.33E-04	1.65E-04	6.00E-03	6.00E-03	6.00E-03	2.86E-01	4.80E-02	3.30E-01	6.80E-02	2.97E-06	1.26E-05	4.07E-05	2.38E-04	9.09E-12	
BATCH-959	11/20/30	123	12.8	0.24	4.07E-04	1.73E-04	1.00E-02	4.00E-03	1.00E-02	1.76E-01	3.00E-02	1.11E+00	6.80E-02	1.72E-26	1.77E-06	5.89E-05	1.00E-03	3.70E-02	2.23E-12
BATCH-960	11/21/30	101	10.6	0.24	3.34E-04	1.42E-04	8.00E-03	3.00E-03	8.00E-03	1.45E-01	2.50E-02	9.13E-01	5.60E-02	1.41E-26	1.45E-06	4.85E-05	1.00E-03	3.00E-02	1.83E-12
BATCH-961	12/2/30	58	6.0	0.24	1.84E-04	1.23E-04	5.00E-03	4.00E-03	5.00E-03	2.07E-01	3.40E-02	2.46E-01	6.90E-02	5.18E-28	2.12E-06	9.44E-06	3.16E-05	1.86E-04	7.08E-12
BATCH-962	12/3/30	99	10.3	0.24	4.14E-04	2.84E-04	1.10E-02	1.00E-02	1.10E-02	4.79E-01	8.00E-02	5.54E-01	1.61E-01	1.27E-27	4.97E-06	2.11E-05	8.09E-05	6.82E-04	6.67E-13
BATCH-963	12/8/30	20	2.1	0.24	6.30E-05	4.47E-05	2.00E-03	2.00E-03	2.00E-03	7.70E-02	1.30E-02	8.90E-02	2.60E-02	1.82E-28	8.04E-07	3.41E-06	1.10E-05	6.44E-05	2.46E-12
BATCH-964	12/11/30	100	10.4	0.24	5.08E-04	3.49E-04	1.20E-02	1.20E-02	1.30E-02	5.70E-01	9.60E-02	7.43E-01	1.96E-01	2.44E-27	6.03E-06	2.94E-05	1.79E-04	3.00E-03	1.01E-12
BATCH-965	12/14/30	108	11.3	0.24	4.09E-04	2.76E-04	1.00E-02	1.00E-02	1.10E-02	4.56E-01	7.60E-02	5.91E-01	1.54E-01	2.31E-27	4.75E-06	2.36E-05	1.73E-04	3.00E-03	7.60E-13
BATCH-966	12/21/30	104	10.9	0.24	3.44E-04	1.46E-04	8.00E-03	4.00E-03	8.00E-03	1.49E-01	2.50E-02	9.40E-01	5.80E-02	1.46E-26	1.50E-06	4.99E-05	1.00E-03	3.10E-02	1.89E-12
BATCH-967	12/26/30	20	2.1	0.24	4.85E-05	3.24E-05	1.00E-03	1.00E-03	1.00E-03	5.50E-02	9.00E-03	6.50E-02	1.80E-02	1.37E-28	5.59E-07	2.49E-06	8.34E-06	4.90E-05	1.87E-12
BATCH-968	12/28/30	162	16.9	0.24	5.34E-04	2.27E-04	1.30E-02	5.00E-03	1.30E-02	2.31E-01	3.90E-02	1.46E+00	8.90E-02	2.26E-26	2.32E-06	7.74E-05	2.00E-03	4.80E-02	2.93E-12
BATCH-969	1/1/31	54	5.6	0.24	2.03E-04	1.40E-04	5.00E-03	5.00E-03	5.00E-03	2.35E-01	3.90E-02	2.72E-01	7.50E-02	1.33E-28	2.44E-06	1.04E-05	3.88E-05	3.23E-04	3.28E-13
BATCH-970	1/7/31	60	6.2	0.24	2.81E-04	1.93E-04	7.00E-03	7.00E-03	7.00E-03	3.15E-01	5.30E-02	4.10E-01	1.03E-01	2.86E-28	3.33E-06	1.62E-05	9.66E-05	2.00E-03	5.56E-13
BATCH-971	1/14/31	61	6.4	0.24	2.15E-04	1.45E-04	5.00E-03	5.00E-03	6.00E-03	2.40E-01	4.00E-02	3.10E-01	7.70E-02	2.57E-28	2.50E-06	1.24E-05	8.86E-05	2.00E-03	3.99E-13
BATCH-972	1/14/31	162	16.8	0.24	5.33E-04	2.27E-04	1.30E-02	5.00E-03	1.30E-02	2.30E-01	3.90E-02	1.45E+00	8.50E-02	4.79E-27	2.31E-06	7.73E-05	2.00E-03	4.70E-02	2.93E-12
BATCH-973	1/20/31	106	11.0	0.24	3.25E-04	2.15E-04	9.00E-03	8.00E-03	9.00E-03	3.56E-01	5.90E-02	5.39E-01	1.15E-01	7.79E-28	3.69E-06	2.32E-05	2.91E-04	6.00E-03	5.88E-13
BATCH-974	1/31/31	18	1.9	0.24	4.91E-05	3.37E-05	1.00E-03	1.00E-03	1.00E-03	5.70E-02	9.00E-03	6.60E-02	1.80E-02	3.21E-29	5.89E-07	2.50E-06	9.36E-06	7.78E-05	7.91E-14
BATCH-975	2/1/31	22	2.3	0.24	8.49E-05	5.84E-05	2.00E-03	2.00E-03	2.00E-03	9.50E-02	1.60E-02	1.24E-01	3.10E-02	8.64E-29	1.01E-06	4.91E-06	2.92E-05	4.91E-04	1.68E-13
BATCH-976	2/2/31	130	13.5	0.24	3.79E-04	1.63E-04	1.00E-02	4.00E-03	9.00E-03	1.85E-01	3.00E-02	1.00E+00	6.40E-02	3.32E-27	1.76E-06	5.32E-05	1.00E-03	3.20E-02	1.67E-10
BATCH-977	2/3/31	23	2.4	0.24	6.42E-05	4.33E-05	2.00E-03	2.00E-03	2.00E-03	7.20E-02	1.20E-02	9.30E-02	2.30E-02	7.68E-29	7.46E-07	3.70E-06	2.65E-05	4.64E-04	1.19E-13
BATCH-978	2/6/31	59	6.2	0.24	1.67E-04	1.10E-04	4.00E-03	4.00E-03	4.00E-03	1.82E-01	3.00E-02	2.76E-01	5.90E-02	3.99E-28	1.89E-06	1.19E-05	1.49E-04	3.00E-03	3.01E-13
BATCH-979	2/12/31	161	16.8	0.24	1.18E-04	6.55E-05	1.20E-02	3.00E-03	3.00E-03	2.31E-01	3.00E-02	5.50E-02	4.70E-02	2.87E-28	1.45E-06	2.03E-06	8.55E-05	5.33E-04	1.38E-09

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-931	6/2/30	141	14.7	0.24	2.45E-06	1.98E+02	6.11E-11	9.76E-09	3.90E-11	5.12E-45	8.00E-03	5.06E+00	1.41E-10	1.20E-02	1.98E+01	0.00E+00	8.46E-08	6.55E+00	5.39E-05
BATCH-932	6/5/30	155	16.1	0.24	5.00E-03	2.57E+02	2.26E-11	3.77E-09	1.86E-11	1.66E-47	1.00E-02	6.88E+00	1.54E-10	7.00E-03	1.76E+01	0.00E+00	1.84E-04	9.25E+00	8.09E-05
BATCH-933	6/17/30	19	2.0	0.24	3.20E+01	0.00E+00	1.05E-12	4.13E-09	6.20E-13	6.20E-48	1.00E-03	2.09E-01	2.49E-12	8.05E-04	8.83E-01	0.00E+00	1.07E+00	0.00E+00	2.56E-08
BATCH-934	6/19/30	154	16.1	0.24	4.00E-03	2.57E+02	2.26E-11	3.77E-09	1.85E-11	2.86E-42	1.00E-02	6.88E+00	1.54E-10	7.00E-03	1.76E+01	0.00E+00	1.49E-04	9.25E+00	8.09E-05
BATCH-935	6/21/30	121	12.6	0.24	1.36E-09	2.01E+02	1.78E-11	2.96E-09	1.46E-11	1.30E-47	8.00E-03	5.38E+00	1.21E-10	5.00E-03	1.38E+01	0.00E+00	4.97E-11	7.23E+00	5.39E-05
BATCH-936	7/4/30	58	6.0	0.24	1.39E+02	0.00E+00	1.00E-11	2.39E-09	5.90E-12	1.37E-43	4.00E-03	1.35E+00	1.08E-11	3.00E-03	3.41E+00	0.00E+00	4.18E+00	0.00E+00	1.45E-07
BATCH-937	7/5/30	121	12.6	0.24	1.44E-09	2.01E+02	1.77E-11	2.95E-09	1.45E-11	3.00E-48	8.00E-03	5.39E+00	1.21E-10	5.00E-03	1.38E+01	0.00E+00	4.95E-11	7.24E+00	5.39E-05
BATCH-938	7/10/30	154	16.1	0.24	5.00E-03	2.56E+02	2.25E-11	3.75E-09	1.85E-11	9.14E-52	1.00E-02	6.86E+00	1.54E-10	7.00E-03	1.76E+01	0.00E+00	1.57E-04	9.22E+00	8.09E-05
BATCH-939	7/18/30	130	13.5	0.24	2.37E-06	3.05E+02	8.27E-12	1.47E-09	8.82E-12	7.55E-51	1.00E-02	3.21E+00	7.06E-11	7.00E-03	1.98E+01	0.00E+00	8.38E-08	1.17E+01	1.08E-04
BATCH-940	7/26/30	100	10.4	0.24	8.65E-13	2.83E+02	5.34E-13	2.10E-10	3.12E-12	8.22E-51	9.00E-03	1.08E+00	2.24E-11	6.00E-03	1.79E+01	0.00E+00	3.16E-14	1.12E+01	1.08E-04
BATCH-941	8/1/30	128	13.3	0.24	2.18E-06	3.62E+02	6.79E-13	2.68E-10	3.98E-12	1.42E-45	1.20E-02	1.38E+00	2.86E-11	7.00E-03	2.29E+01	0.00E+00	7.42E-08	1.42E+01	1.62E-04
BATCH-942	8/6/30	19	2.0	0.24	3.29E+01	0.00E+00	2.37E-12	5.64E-10	1.39E-12	3.24E-44	1.00E-03	3.18E-01	2.55E-12	6.62E-04	8.04E-01	0.00E+00	9.88E-01	0.00E+00	3.42E-08
BATCH-943	8/8/30	100	10.4	0.24	9.09E-13	2.83E+02	5.34E-13	2.10E-10	3.12E-12	1.90E-51	9.00E-03	1.08E+00	2.24E-11	6.00E-03	1.79E+01	0.00E+00	3.13E-14	1.12E+01	1.08E-04
BATCH-944	8/14/30	128	13.3	0.24	2.35E-06	3.61E+02	6.78E-13	2.67E-10	3.97E-12	4.54E-55	1.20E-02	1.38E+00	2.86E-11	7.00E-03	2.29E+01	0.00E+00	7.81E-08	1.42E+01	1.62E-04
BATCH-945	8/19/30	112	11.7	0.24	1.34E-09	3.17E+02	5.89E-13	2.34E-10	3.48E-12	4.27E-54	1.00E-02	1.21E+00	2.50E-11	6.00E-03	2.00E+01	0.00E+00	4.74E-11	1.25E+01	1.35E-04
BATCH-946	8/28/30	88	9.2	0.24	6.19E-16	2.50E+02	4.62E-13	1.84E-10	2.75E-12	5.88E-54	8.00E-03	9.50E-01	1.97E-11	5.00E-03	1.58E+01	0.00E+00	2.26E-17	9.86E+00	1.08E-04
BATCH-947	8/31/30	162	16.9	0.24	4.00E-03	2.42E+02	5.78E-13	2.44E-07	2.69E-12	4.21E-48	7.00E-03	2.30E+00	2.23E-11	2.60E-02	3.29E+01	0.00E+00	1.29E-04	7.50E+00	5.39E-05
BATCH-948	9/6/30	148	15.4	0.24	1.22E-09	1.25E+02	4.07E-13	3.28E-07	1.42E-12	7.93E-49	3.00E-03	2.34E+00	1.41E-11	3.10E-02	3.16E+01	0.00E+00	4.13E-11	2.16E+00	5.01E-06
BATCH-949	9/17/30	116	12.1	0.24	6.45E-16	9.79E+01	3.19E-13	2.58E-07	1.11E-12	1.35E-54	3.00E-03	1.84E+00	1.11E-11	2.40E-02	2.48E+01	0.00E+00	2.23E-17	1.70E+00	3.95E-06
BATCH-950	9/22/30	148	15.4	0.24	1.31E-09	1.25E+02	4.07E-13	3.28E-07	1.41E-12	2.53E-58	3.00E-03	2.34E+00	1.41E-11	3.10E-02	3.16E+01	0.00E+00	4.35E-11	2.16E+00	5.01E-06
BATCH-951	9/29/30	130	13.5	0.24	8.51E-13	1.09E+02	3.57E-13	2.88E-07	1.24E-12	2.71E-57	3.00E-03	2.05E+00	1.24E-11	2.70E-02	2.77E+01	0.00E+00	3.01E-14	1.90E+00	4.40E-06
BATCH-952	10/7/30	108	11.2	0.24	3.12E+02	0.00E+00	2.86E-11	4.53E-09	1.71E-11	2.92E-42	1.00E-02	2.01E+00	3.29E-11	6.00E-03	7.86E+00	0.00E+00	1.68E+01	0.00E+00	1.78E-05
BATCH-953	10/13/30	158	16.5	0.24	2.23E-06	1.33E+02	4.34E-13	3.51E-07	1.51E-12	2.19E-51	3.00E-03	2.50E+00	1.51E-11	3.30E-02	3.38E+01	0.00E+00	6.70E-08	2.30E+00	5.30E-06
BATCH-954	10/19/30	130	13.5	0.24	7.69E-13	1.09E+02	3.57E-13	2.89E-07	1.24E-12	5.01E-52	3.00E-03	2.06E+00	1.24E-11	2.70E-02	2.78E+01	0.00E+00	2.61E-14	1.89E+00	4.33E-06
BATCH-955	10/29/30	114	11.8	0.24	3.16E+02	0.00E+00	2.40E-11	2.22E-08	1.45E-11	7.88E-43	9.00E-03	2.64E+00	3.23E-11	6.00E-03	8.17E+00	0.00E+00	1.51E+01	0.00E+00	1.32E-05
BATCH-956	11/1/30	120	12.5	0.24	7.45E-13	1.28E+02	4.86E-13	1.91E-07	1.97E-12	1.44E-61	3.00E-03	2.45E+00	1.64E-11	2.00E-02	2.25E+01	0.00E+00	2.48E-14	1.82E+00	3.21E-06
BATCH-957	11/10/30	101	10.5	0.24	5.91E-16	1.63E+02	7.35E-13	6.91E-09	3.37E-12	1.88E-60	2.00E-03	3.22E+00	2.42E-11	8.00E-03	1.27E+01	0.00E+00	2.09E-17	1.69E+00	1.10E-06
BATCH-958	11/14/30	58	6.1	0.24	1.54E+02	0.00E+00	1.41E-11	2.23E-09	8.45E-12	1.45E-42	5.00E-03	9.90E-01	1.63E-11	3.00E-03	3.88E+00	0.00E+00	8.29E+00	0.00E+00	8.78E-06
BATCH-959	11/20/30	123	12.8	0.24	1.27E-09	1.99E+02	8.96E-13	8.38E-09	4.10E-12	1.25E-54	3.00E-03	3.92E+00	2.95E-11	1.00E-02	1.54E+01	0.00E+00	3.81E-11	2.06E+00	1.34E-06
BATCH-960	11/21/30	101	10.6	0.24	5.32E-16	1.64E+02	7.37E-13	6.93E-09	3.38E-12	3.47E-55	2.00E-03	3.23E+00	2.43E-11	8.00E-03	1.27E+01	0.00E+00	1.81E-17	1.69E+00	1.10E-06
BATCH-961	12/2/30	58	6.0	0.24	1.48E+02	0.00E+00	1.12E-11	1.03E-08	6.77E-12	3.68E-43	4.00E-03	1.23E+00	1.50E-11	3.00E-03	3.81E+00	0.00E+00	7.03E+00	0.00E+00	6.16E-06
BATCH-962	12/3/30	99	10.3	0.24	2.60E+02	0.00E+00	1.34E-12	5.04E-08	1.52E-12	4.97E-53	7.00E-03	2.22E+00	1.26E-11	6.00E-03	7.42E+00	0.00E+00	1.48E+01	0.00E+00	1.46E-05
BATCH-963	12/8/30	20	2.1	0.24	4.16E+01	0.00E+00	3.81E-12	6.04E-10	2.29E-12	3.91E-43	1.00E-03	2.68E-01	4.40E-12	7.38E-04	1.05E+00	0.00E+00	2.24E+00	0.00E+00	2.37E-06
BATCH-964	12/11/30	100	10.4	0.24	2.51E+02	0.00E+00	2.20E-12	1.95E-08	2.36E-12	8.32E-49	6.00E-03	2.70E+00	1.91E-11	4.00E-03	6.20E+00	0.00E+00	1.82E+01	0.00E+00	1.79E-05
BATCH-965	12/14/30	108	11.3	0.24	2.88E+02	0.00E+00	1.32E-12	4.15E-08	1.68E-12	1.47E-43	8.00E-03	2.56E+00	1.36E-11	5.00E-03	7.39E+00	0.00E+00	1.67E+01	0.00E+00	1.37E-05
BATCH-966	12/21/30	104	10.9	0.24	8.53E-13	1.69E+02	7.59E-13	6.93E-09	3.48E-12	8.38E-58	2.00E-03	3.33E+00	2.50E-11	8.00E-03	1.31E+01	0.00E+00	2.56E-14	1.75E+00	1.13E-06
BATCH-967	12/26/30	20	2.1	0.24	3.89E+01	0.00E+00	2.95E-12	2.73E-09	1.79E-12	9.69E-44	1.00E-03	3.25E-01	3.97E-12	7.71E-04	1.01E+00	0.00E+00	1.85E+00	0.00E+00	1.62E-06
BATCH-968	12/28/30	162	16.9	0.24	7.00E-03	2.62E+02	1.18E-12	1.07E-08	5.39E-12	6.78E-47	4.00E-03	5.15E+00	3.87E-11	1.30E-02	2.03E+01	0.00E+00	3.89E-04	2.70E+00	1.75E-06
BATCH-969	1/1/31	54	5.6	0.24	1.28E+02	0.00E+00	6.58E-13	2.48E-08	7.46E-13	2.45E-53	3.00E-03	1.09E+00	6.21E-12	3.00E-03	3.65E+00	0.00E+00	7.28E+00	0.00E+00	7.17E-06
BATCH-970	1/7/31	60	6.2	0.24	1.39E+02	0.00E+00	1.22E-12	1.08E-08	1.31E-12	4.60E-49	3.00E-03	1.49E+00	1.06E-11	2.00E-03	3.43E+00	0.00E+00	1.01E+01	0.00E+00	9.98E-06
BATCH-971	1/14/31	61	6.4	0.24	1.52E+02	0.00E+00	6.92E-13	2.18E-08	8.81E-13	7.72E-44	4.00E-03	1.35E+00	7.15E-12	3.00E-03	3.88E+00	0.00E+00	8.76E+00	0.00E+00	7.22E-06
BATCH-972	1/14/31	162	16.8	0.24	7.00E-03	2.61E+02	1.18E-12	1.07E-08	5.38E-12	1.62E-47	4.00E-03	5.15E+00	3.87E-11	1.30E-02	2.02E+01	0.00E+00	3.10E-04	2.70E+00	1.75E-06
BATCH-973	1/20/31	106	11.0	0.24	2.61E+02	0.00E+00	2.34E-13	3.50E-08	1.08E-12	6.36E-49	7.00E-03	2.17E+00	8.17E-12	5.00E-03	7.25E+00	0.00E+00	1.47E+01	0.00E+00	1.02E-05
BATCH-974	1/31/31	18	1.9	0.24	3.09E+01	0.00E+00	1.59E-13	5.98E-09	1.80E-13	5.90E-54	8.19E-04	2.63E-01	1.50E-12	6.69E-04	8.81E-01	0.00E+00	1.76E+00	0.00E+00	1.73E-06
BATCH-975	2/1/31	22	2.3	0.24	4.20E+01	0.00E+00	3.68E-13	3.26E-09	3.95E-13	1.39E-49	9.91E-04	4.50E-01	3.19E-12	6.00E-04	1.04E+00	0.00E+00	3.04E+00	0.00E+00	2.99E-06
BATCH-976	2/2/31	130	13.5	0.24	3.34E-06	1.96E+02	3.48E-10	5.56E-08	1.58E-10	3.14E-50	3.00E-03	3.65E+00	1.26E-10	1.10E-02	1.77E+01	0.00E+00	1.80E-07	2.03E+00	1.23E-06
BATCH-977	2/3/31	23	2.4	0.24	4.53E+01	0.00E+00	2.07E-13	6.52E-09	2.63E-13	2.31E-44	1.00E-03	4.02E-01	2.14E-12	8.37E-04	1.16E+00	0.00E+00	2.62E+00	0.00E+00	2.16E-06
BATCH-978	2/6/31	59	6.2	0.24	1.34E+02	0.00E+00	1.20E-13	1.79E-08	5.54E-13	3.26E-49	4.00E-03	1.11E+00	4.16E-12	3.00E-03	3.71E+00	0.00E+00	7.55E+00	0.00E+00	5.22E-06
BATCH-979	2/12/31	161	16.8	0.24	3.43E-06	1.45E+02	2.92E-09	4.05E-07	1.38E-09	8.55E-51	6.67E-04	1.02E+00	8.34E-10	2.00E-02	3.22E+01	0.00E+00	1.64E-07	1.49E+00	2.67E-07

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-931	6/2/30	141	14.7	0.24	1.69E-12	7.26E+01	2.91E+00	0.00E+00	0.00E+00	4.00E-04	1.15E+01	2.55E-05	1.22E-10	1.57E-09	1.13E-01	6.30E-11	2.41E+03	0.00E+00	2.81E+00
BATCH-932	6/5/30	155	16.1	0.24	2.08E-12	8.87E+01	4.16E+00	0.00E+00	0.00E+00	4.00E-04	1.33E+01	3.71E-06	1.63E-10	6.63E-10	1.51E-01	4.08E-13	2.64E+03	0.00E+00	4.23E+00
BATCH-933	6/17/30	19	2.0	0.24	7.58E-15	1.78E+00	4.90E-02	0.00E+00	0.00E+00	1.13E-05	3.79E-01	1.96E-06	4.71E-13	2.93E-11	2.00E-03	1.75E-11	3.22E+02	0.00E+00	3.00E-03
BATCH-934	6/19/30	154	16.1	0.24	2.08E-12	8.86E+01	4.15E+00	0.00E+00	0.00E+00	4.00E-04	1.33E+01	3.71E-06	1.63E-10	6.63E-10	1.51E-01	3.80E-13	2.64E+03	0.00E+00	4.23E+00
BATCH-935	6/21/30	121	12.6	0.24	1.63E-12	6.93E+01	3.25E+00	0.00E+00	0.00E+00	4.00E-04	1.04E+01	2.96E-06	1.27E-10	5.21E-10	1.18E-01	3.39E-13	2.07E+03	0.00E+00	3.30E+00
BATCH-936	7/4/30	58	6.0	0.24	7.00E-14	7.77E+00	2.50E-01	0.00E+00	0.00E+00	5.81E-05	1.64E+00	6.41E-06	4.10E-12	2.46E-10	1.00E-02	9.88E-12	1.26E-10	9.88E+02	1.60E-02
BATCH-937	7/5/30	121	12.6	0.24	1.63E-12	6.94E+01	3.25E+00	0.00E+00	0.00E+00	4.00E-04	1.04E+01	2.92E-06	1.28E-10	5.20E-10	1.18E-01	2.23E-13	2.07E+03	0.00E+00	3.31E+00
BATCH-938	7/10/30	154	16.1	0.24	2.07E-12	8.83E+01	4.14E+00	0.00E+00	0.00E+00	4.00E-04	1.32E+01	3.70E-06	1.62E-10	6.60E-10	1.50E-01	2.39E-13	2.63E+03	0.00E+00	4.21E+00
BATCH-939	7/18/30	130	13.5	0.24	1.99E-12	8.01E+01	2.72E+00	0.00E+00	0.00E+00	2.00E-04	1.01E+01	3.57E-06	7.99E-11	2.41E-10	1.08E-01	1.09E-11	2.22E+03	0.00E+00	2.57E+00
BATCH-940	7/26/30	100	10.4	0.24	1.66E-12	6.48E+01	1.68E+00	0.00E+00	0.00E+00	1.15E-04	7.24E+00	3.00E-06	3.06E-11	1.38E-11	7.40E-02	1.42E-11	1.71E+03	0.00E+00	1.44E+00
BATCH-941	8/1/30	128	13.3	0.24	2.12E-12	8.27E+01	2.14E+00	0.00E+00	0.00E+00	1.47E-04	9.24E+00	3.83E-06	3.90E-11	1.75E-11	9.40E-02	1.81E-11	2.18E+03	0.00E+00	1.84E+00
BATCH-942	8/6/30	19	2.0	0.24	1.65E-14	1.84E+00	5.90E-02	0.00E+00	0.00E+00	1.37E-05	3.88E-01	1.52E-06	9.69E-13	5.81E-11	2.00E-03	2.99E-11	3.22E+02	0.00E+00	4.00E-03
BATCH-943	8/8/30	100	10.4	0.24	1.67E-12	6.49E+01	1.68E+00	0.00E+00	0.00E+00	1.16E-04	7.25E+00	3.00E-06	3.06E-11	1.39E-11	7.40E-02	1.42E-11	1.71E+03	0.00E+00	1.45E+00
BATCH-944	8/14/30	128	13.3	0.24	2.12E-12	8.26E+01	2.14E+00	0.00E+00	0.00E+00	1.47E-04	9.23E+00	3.82E-06	3.90E-11	1.75E-11	9.40E-02	1.81E-11	2.18E+03	0.00E+00	1.84E+00
BATCH-945	8/19/30	112	11.7	0.24	1.86E-12	7.25E+01	1.88E+00	0.00E+00	0.00E+00	1.29E-04	8.10E+00	3.35E-06	3.42E-11	1.52E-11	8.20E-02	1.59E-11	1.91E+03	0.00E+00	1.62E+00
BATCH-946	8/28/30	88	9.2	0.24	1.47E-12	5.72E+01	1.48E+00	0.00E+00	0.00E+00	1.02E-04	6.39E+00	2.65E-06	2.70E-11	1.19E-11	6.50E-02	1.25E-11	1.51E+03	0.00E+00	1.27E+00
BATCH-947	8/31/30	162	16.9	0.24	1.47E-12	7.51E+01	1.44E+00	0.00E+00	0.00E+00	2.00E-04	1.18E+01	1.66E-06	2.83E-11	2.26E-11	8.00E-02	1.23E-11	2.78E+03	0.00E+00	8.47E-01
BATCH-948	9/6/30	148	15.4	0.24	8.00E-13	5.52E+01	7.44E-01	0.00E+00	0.00E+00	4.00E-04	1.08E+01	1.04E-07	1.64E-11	2.08E-11	5.60E-02	6.49E-12	2.53E+03	0.00E+00	1.13E-01
BATCH-949	9/17/30	116	12.1	0.24	6.27E-13	4.33E+01	5.84E-01	0.00E+00	0.00E+00	2.00E-04	8.48E+00	8.22E-08	1.28E-11	1.63E-11	4.40E-02	5.09E-12	1.98E+03	0.00E+00	8.90E-02
BATCH-950	9/22/30	148	15.4	0.24	7.99E-13	5.52E+01	7.44E+01	0.00E+00	0.00E+00	4.00E-04	1.08E+01	1.04E-07	1.64E-11	2.08E-11	5.60E-02	6.49E-12	2.53E+03	0.00E+00	1.13E-01
BATCH-951	9/29/30	130	13.5	0.24	7.02E-13	4.84E+01	6.53E-01	0.00E+00	0.00E+00	2.00E-04	9.49E+00	9.17E-08	1.44E-11	1.83E-11	4.90E-02	5.69E-12	2.22E+03	0.00E+00	1.00E-01
BATCH-952	10/7/30	108	11.2	0.24	4.83E-13	2.03E+01	8.82E-01	0.00E+00	0.00E+00	7.56E-05	3.10E+00	1.43E-05	1.94E-11	7.07E-10	2.30E-02	3.93E-11	1.84E+03	0.00E+00	3.74E-01
BATCH-953	10/13/30	158	16.5	0.24	8.54E-13	5.90E+01	7.95E-01	0.00E+00	0.00E+00	4.00E-04	1.16E+01	1.10E-07	1.75E-11	2.22E-11	6.00E-02	6.93E-12	2.70E+03	0.00E+00	1.20E-01
BATCH-954	10/19/30	130	13.5	0.24	7.02E-13	4.84E+01	6.53E-01	0.00E+00	0.00E+00	2.00E-04	9.50E+00	8.97E-08	1.44E-11	1.83E-11	4.90E-02	5.69E-12	2.22E+03	0.00E+00	9.90E-02
BATCH-955	10/29/30	114	11.8	0.24	4.55E-13	2.06E+01	9.76E-01	0.00E+00	0.00E+00	9.07E-05	3.35E+00	1.16E-05	2.15E-11	5.97E-10	2.50E-02	3.17E-11	1.94E+03	0.00E+00	4.13E-01
BATCH-956	11/1/30	120	12.5	0.24	1.09E-12	4.68E+01	1.50E+00	0.00E+00	0.00E+00	2.00E-04	9.99E+00	1.49E-06	2.13E-11	1.82E-11	4.70E-02	9.03E-12	2.05E+03	0.00E+00	9.10E-01
BATCH-957	11/10/30	101	10.5	0.24	1.83E-12	4.40E+01	3.12E+00	0.00E+00	0.00E+00	2.00E-04	1.10E+07	4.15E-06	3.45E-11	1.81E-11	4.20E-02	1.54E-11	1.73E+03	0.00E+00	2.46E+00
BATCH-958	11/14/30	58	6.1	0.24	2.38E-13	1.00E+01	4.35E-01	0.00E+00	0.00E+00	3.73E-05	1.53E+00	7.05E-06	9.58E-12	3.49E-10	1.20E-02	1.94E-11	9.92E+02	0.00E+00	1.94E-01
BATCH-959	11/20/30	123	12.8	0.24	2.23E-12	5.37E+01	3.81E+00	0.00E+00	0.00E+00	4.00E-04	1.34E+01	5.07E-06	4.21E-11	2.21E-11	5.10E-02	1.88E-11	2.10E+03	0.00E+00	3.00E+00
BATCH-960	11/21/30	101	10.6	0.24	1.83E-12	4.41E+01	3.13E+00	0.00E+00	0.00E+00	2.00E-04	1.10E+07	4.17E-06	3.46E-11	1.82E-11	4.20E-02	1.55E-11	1.73E+03	0.00E+00	2.47E+00
BATCH-961	12/2/30	58	6.0	0.24	2.12E-13	9.60E+00	4.55E-01	0.00E+00	0.00E+00	4.23E-05	1.56E+00	5.42E-06	1.00E-11	2.79E-10	1.20E-02	1.48E-11	9.91E+02	0.00E+00	1.92E-01
BATCH-962	12/3/30	99	10.3	0.24	3.93E-13	1.91E+01	8.90E-01	0.00E+00	0.00E+00	8.38E-05	3.09E+00	5.10E-07	1.42E-11	4.04E-11	2.30E-02	2.35E-12	1.69E+03	0.00E+00	3.92E-01
BATCH-963	12/8/30	20	2.1	0.24	6.44E-14	2.71E+00	1.18E-01	0.00E+00	0.00E+00	1.01E-05	4.14E-01	1.91E-06	2.59E-12	9.43E-11	3.00E-03	5.24E-12	3.48E+02	0.00E+00	5.00E-02
BATCH-964	12/11/30	100	10.4	0.24	5.53E-13	2.12E-01	1.30E+00	0.00E+00	0.00E+00	9.22E-05	3.47E+00	9.91E-07	2.17E-11	6.46E-11	2.80E-02	3.09E-12	1.71E+03	0.00E+00	7.44E-01
BATCH-965	12/14/30	108	11.3	0.24	5.03E-13	2.05E+01	1.17E+00	0.00E+00	0.00E+00	9.47E-05	3.58E+00	8.15E-07	1.59E-11	3.93E-11	2.40E-02	3.34E-12	1.85E+03	0.00E+00	5.66E-01
BATCH-966	12/21/30	104	10.9	0.24	1.89E-12	4.55E+01	3.23E+00	0.00E+00	0.00E+00	2.00E-04	1.13E+01	4.29E-06	3.56E-11	1.87E-11	4.30E-02	1.60E-11	1.78E+03	0.00E+00	2.54E+00
BATCH-967	12/26/30	20	2.1	0.24	5.60E-14	2.53E+00	1.20E-01	0.00E+00	0.00E+00	1.12E-05	4.12E-01	1.43E-06	2.64E-12	7.34E-11	3.00E-03	3.90E-12	3.42E+02	0.00E+00	5.10E-02
BATCH-968	12/28/30	162	16.9	0.24	2.93E-12	7.04E+01	5.00E+00	0.00E+00	0.00E+00	4.00E-04	1.75E+01	6.65E-06	5.52E-11	2.91E-11	6.70E-02	2.47E-11	2.76E+03	0.00E+00	3.94E+00
BATCH-969	1/1/31	54	5.6	0.24	1.93E-13	9.42E+00	4.37E-01	0.00E+00	0.00E+00	4.12E-05	1.52E+00	2.51E-07	7.00E-12	1.99E-11	1.20E-02	1.16E-12	9.26E+02	0.00E+00	1.93E-01
BATCH-970	1/7/31	60	6.2	0.24	3.06E-13	1.17E+01	7.19E-01	0.00E+00	0.00E+00	5.10E-05	1.92E+00	5.48E-07	1.20E-11	3.57E-11	1.50E-02	1.71E-12	1.02E+03	0.00E+00	4.11E-01
BATCH-971	1/14/31	61	6.4	0.24	2.64E-13	1.08E+01	6.14E-01	0.00E+00	0.00E+00	4.97E-05	1.88E+00	4.28E-07	8.36E-12	2.06E-11	1.30E-02	1.76E-12	1.05E+03	0.00E+00	2.97E-01
BATCH-972	1/14/31	162	16.8	0.24	2.93E-12	7.03E+01	4.99E+00	0.00E+00	0.00E+00	4.00E-04	1.75E+01	6.65E-06	5.52E-11	2.90E-11	6.70E-02	2.47E-11	2.76E+03	0.00E+00	3.93E+00
BATCH-973	1/20/31	106	11.0	0.24	5.89E-13	1.98E+01	1.27E+00	0.00E+00	0.00E+00	9.67E-05	3.93E+00	1.10E-05	1.12E-11	6.91E-12	2.00E-02	4.95E-12	1.81E+03	0.00E+00	6.30E-01
BATCH-974	1/31/31	18	1.9	0.24	4.67E-14	2.27E+00	1.06E-01	0.00E+00	0.00E+00	9.94E-06	3.66E-01	6.05E-08	1.69E-12	4.79E-12	3.00E-03	2.79E-13	3.10E+02	0.00E+00	4.60E-02
BATCH-975	2/1/31	22	2.3	0.24	9.24E-14	3.54E+00	2.17E-01	0.00E+00	0.00E+00	1.54E-05	5.79E-01	1.66E-07	3.63E-12	1.08E-11	5.00E-03	5.16E-13	3.80E+02	0.00E+00	1.24E-01
BATCH-976	2/2/31	130	13.5	0.24	3.41E-12	5.48E+01	3.59E+00	0.00E+00	0.00E+00	4.00E-04	1.34E+01	5.36E-06	1.51E-10	9.32E-09	4.80E-02	4.70E-11	2.22E+03	0.00E+00	2.78E+00
BATCH-977	2/3/31	23	2.4	0.24	7.89E-14	3.22E+00	1.83E-01	0.00E+00	0.00E+00	1.49E-05	5.62E-01	1.28E-07	2.50E-12	6.17E-12	4.00E-03	5.24E-13	3.85E+02	0.00E+00	8.90E-02
BATCH-978	2/6/31	59	6.2	0.24	3.02E-13	1.01E+01	6.48E-01	0.00E+00	0.00E+00	4.95E-05	2.01E+00	5.63E-07	5.72E-12	3.54E-12	1.00E-02	2.54E-12	1.01E+03	0.00E+00	3.23E-01
BATCH-979	2/12/31	161	16.8	0.24	1.18E-11	5.58E+01	1.42E+00	0.00E+00	0.00E+00	9.58E-05	1.20E+01	6.81E-06	9.48E-10	7.82E-08	2.00E-02	2.53E-10	2.75E+03	0.00E+00	7.30E-01

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-931	6/2/30	141	14.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E-02	6.04E+01	4.25E-12	6.45E+00	4.93E+01	6.80E-02	1.50E-16	0.00E+00	3.50E-02	2.20E-08	2.60E-02
BATCH-932	6/5/30	155	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	6.81E+01	2.51E-12	8.56E+00	5.50E+01	8.70E-02	2.08E-14	0.00E+00	5.20E-02	2.96E-08	3.30E-02
BATCH-933	6/17/30	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.07E-04	3.27E+00	5.85E-14	2.93E+00	1.62E+00	1.00E-03	2.58E-16	0.00E+00	4.44E-05	2.03E-10	4.22E-04
BATCH-934	6/19/30	154	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	6.81E+01	2.51E-12	8.55E+00	5.50E+01	8.70E-02	1.73E-14	0.00E+00	5.20E-02	2.96E-08	3.30E-02
BATCH-935	6/21/30	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.90E-02	5.33E+01	1.97E-12	6.69E+00	4.30E+01	6.80E-02	5.35E-17	0.00E+00	4.00E-02	2.32E-08	2.60E-02
BATCH-936	7/4/30	58	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.45E+01	5.61E-13	1.54E+01	7.10E+00	5.00E-03	1.52E-15	0.00E+00	3.13E-04	1.15E-09	2.00E-03
BATCH-937	7/5/30	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.90E-02	5.34E+01	1.97E-12	6.70E+00	4.31E+01	6.80E-02	5.35E-17	0.00E+00	4.10E-02	2.32E-08	2.60E-02
BATCH-938	7/10/30	154	16.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	6.79E+01	2.50E-12	8.53E+00	5.48E+01	8.70E-02	6.80E-17	0.00E+00	5.20E-02	2.95E-08	3.30E-02
BATCH-939	7/18/30	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-01	7.43E+01	9.00E-13	8.68E+00	5.10E+01	9.00E-02	1.13E-12	0.00E+00	8.80E-02	1.07E-08	3.10E-02
BATCH-940	7/26/30	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-01	6.65E+01	3.50E-14	7.51E+00	4.19E+01	7.90E-02	1.49E-12	0.00E+00	9.30E-02	5.79E-10	2.60E-02
BATCH-941	8/1/30	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-01	8.49E+01	4.44E-14	9.58E+00	5.36E+01	1.00E-01	1.90E-12	0.00E+00	1.18E-01	7.36E-10	3.30E-02
BATCH-942	8/6/30	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.43E+00	1.33E-13	3.65E+00	1.68E+00	1.00E-03	3.59E-16	0.00E+00	7.39E-05	2.71E-10	4.37E-04
BATCH-943	8/8/30	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-01	6.66E+01	3.51E-14	7.51E+00	4.20E+01	7.90E-02	1.49E-12	0.00E+00	9.30E-02	5.80E-10	2.60E-02
BATCH-944	8/14/30	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-01	8.48E+01	4.44E-14	9.57E+00	5.35E+01	1.00E-01	1.90E-12	0.00E+00	1.18E-01	7.35E-10	3.30E-02
BATCH-945	8/19/30	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-01	7.44E+01	3.83E-14	8.40E+00	4.69E+01	8.80E-02	1.67E-12	0.00E+00	1.04E-01	6.38E-10	2.90E-02
BATCH-946	8/28/30	88	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-02	5.87E+01	2.99E-14	6.63E+00	3.70E+01	6.90E-02	1.32E-12	0.00E+00	8.20E-02	4.99E-10	2.30E-02
BATCH-947	8/31/30	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-02	7.76E+01	3.65E-14	6.65E+00	5.84E+01	7.60E-02	1.28E-12	0.00E+00	5.20E-02	3.87E-09	3.00E-02
BATCH-948	9/6/30	148	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	5.72E+01	2.51E-14	3.62E+00	4.89E+01	4.60E-02	6.61E-13	0.00E+00	4.00E-03	4.82E-09	2.20E-02
BATCH-949	9/17/30	116	12.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-02	4.49E+01	1.97E-14	2.84E+00	3.83E+01	3.60E-02	5.18E-13	0.00E+00	3.00E-03	3.78E-09	1.70E-02
BATCH-950	9/22/30	148	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	5.72E+01	2.51E-14	3.62E+00	4.88E+01	4.60E-02	6.61E-13	0.00E+00	4.00E-03	4.82E-09	2.20E-02
BATCH-951	9/29/30	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	5.02E+01	2.20E-14	3.18E+00	4.28E+01	4.00E-02	5.80E-13	0.00E+00	3.00E-03	4.23E-09	1.90E-02
BATCH-952	10/7/30	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	3.59E+01	1.66E-12	3.38E+01	1.65E+01	2.00E-02	1.87E-13	0.00E+00	1.80E-02	2.81E-09	7.00E-03
BATCH-953	10/13/30	158	16.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	6.11E+01	2.68E-14	3.87E+00	5.22E+01	4.90E-02	7.06E-13	0.00E+00	4.00E-03	5.15E-09	2.30E-02
BATCH-954	10/19/30	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	5.02E+01	2.20E-14	3.18E+00	4.29E+01	4.00E-02	5.80E-13	0.00E+00	3.00E-03	4.23E-09	1.90E-02
BATCH-955	10/29/30	114	11.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.51E+01	1.43E-12	3.35E+01	1.70E+01	1.90E-02	1.41E-13	0.00E+00	1.40E-02	3.59E-09	7.00E-03
BATCH-956	11/1/30	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	4.43E+01	3.05E-14	4.02E+00	3.82E+01	7.80E-02	9.30E-13	0.00E+00	3.00E-03	2.87E-09	1.50E-02
BATCH-957	11/10/30	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	3.33E+01	4.69E-14	5.63E+00	2.94E+01	1.49E-01	1.60E-12	0.00E+00	2.00E-03	2.86E-10	8.00E-03
BATCH-958	11/14/30	58	6.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.77E+01	8.18E-13	1.67E+01	8.14E+00	1.00E-02	9.22E-14	0.00E+00	9.00E-03	1.39E-09	4.00E-03
BATCH-959	11/20/30	123	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	4.06E+01	5.72E-14	6.86E+00	3.59E+01	1.81E-01	1.95E-12	0.00E+00	3.00E-03	3.48E-10	9.00E-03
BATCH-960	11/21/30	101	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	3.34E+01	4.71E-14	5.64E+00	2.95E+01	1.49E-01	1.61E-12	0.00E+00	2.00E-03	2.87E-10	8.00E-03
BATCH-961	12/2/30	58	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.64E+01	6.69E-13	1.56E+01	7.94E+00	9.00E-03	6.56E-14	0.00E+00	6.00E-03	1.67E-09	3.00E-03
BATCH-962	12/3/30	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.09E+01	1.43E-13	2.48E+01	1.53E+01	2.00E-02	2.43E-13	0.00E+00	1.50E-02	2.39E-09	7.00E-03
BATCH-963	12/8/30	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.79E+00	2.21E-13	4.51E+00	2.20E+00	3.00E-03	2.50E-14	0.00E+00	2.00E-03	3.75E-10	9.73E-04
BATCH-964	12/11/30	100	10.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	3.26E+01	2.38E-13	2.08E+01	1.53E+01	3.10E-02	3.19E-13	0.00E+00	1.80E-02	3.06E-09	7.00E-03
BATCH-965	12/14/30	108	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.50E+01	1.39E-13	2.76E+01	1.61E+01	3.00E-02	3.46E-13	0.00E+00	1.40E-02	2.19E-09	7.00E-03
BATCH-966	12/21/30	104	10.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	3.44E+01	4.85E-14	5.81E+00	3.04E+01	1.54E-01	1.65E-12	0.00E+00	2.00E-03	2.93E-10	8.00E-03
BATCH-967	12/26/30	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	4.32E+00	1.76E-13	4.12E+00	2.09E+00	2.00E-03	1.73E-14	0.00E+00	2.00E-03	4.41E-10	9.18E-04
BATCH-968	12/28/30	162	16.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	5.33E+01	7.52E-14	9.01E+00	4.71E+01	2.38E-01	2.56E-12	0.00E+00	3.00E-03	4.54E-10	1.20E-02
BATCH-969	1/1/31	54	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.52E+01	7.04E-14	1.22E+01	7.53E+00	1.00E-02	1.19E-13	0.00E+00	7.00E-03	1.18E-09	4.00E-03
BATCH-970	1/7/31	60	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.80E+01	1.32E-13	1.15E+01	8.49E+00	1.70E-02	1.77E-13	0.00E+00	1.00E-02	1.69E-09	4.00E-03
BATCH-971	1/14/31	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.84E+01	7.29E-14	1.45E+01	8.45E+00	1.60E-02	1.82E-13	0.00E+00	7.00E-03	1.15E-09	4.00E-03
BATCH-972	1/14/31	162	16.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	5.33E+01	7.51E-14	9.00E+00	4.70E+01	2.38E-01	2.56E-12	0.00E+00	3.00E-03	4.53E-10	1.20E-02
BATCH-973	1/20/31	106	11.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	3.71E+01	1.49E-14	2.57E+01	1.56E+01	4.10E-02	5.14E-13	0.00E+00	9.00E-03	5.96E-10	6.00E-03
BATCH-974	1/31/31	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.67E+00	1.70E-14	2.95E+00	1.82E+00	2.00E-03	2.88E-14	0.00E+00	2.00E-03	2.84E-10	8.84E-04
BATCH-975	2/1/31	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.44E+00	3.98E-14	3.47E+00	2.57E+00	5.00E-03	5.34E-14	0.00E+00	3.00E-03	5.11E-10	1.00E-03
BATCH-976	2/2/31	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	4.32E+01	1.37E-12	6.51E+00	3.82E+01	1.65E-01	2.05E-12	0.00E+00	2.00E-03	4.41E-09	9.00E-03
BATCH-977	2/3/31	23	2.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.50E+00	2.18E-14	4.34E+00	2.52E+00	5.00E-03	5.42E-14	0.00E+00	2.00E-03	3.43E-10	1.00E-03
BATCH-978	2/6/31	59	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.90E+01	7.61E-15	1.32E+01	7.97E+00	2.10E-02	2.63E-13	0.00E+00	5.00E-03	3.05E-10	3.00E-03
BATCH-979	2/12/31	161	16.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	5.60E+01	1.11E-11	2.90E+00	4.99E+01	1.80E-02	2.46E-12	0.00E+00	2.20E-04	3.44E-08	2.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-980	2/16/31	189	19.7	0.24	0.00E+00	0.00E+00	7.00E-02	4.00E-03	5.13E+00	2.82E-01	1.66E+03	2.39E-01	1.80E-02	7.86E+00	6.88E-16	8.35E-01	1.48E-04	8.00E-03	1.05E-02
BATCH-981	3/1/31	189	19.7	0.24	0.00E+00	0.00E+00	7.00E-02	4.00E-03	5.13E+00	2.82E-01	1.66E+03	2.39E-01	1.80E-02	7.85E+00	6.83E-16	8.34E-01	1.48E-04	8.00E-03	1.05E-02
BATCH-982	3/8/31	189	19.7	0.24	0.00E+00	0.00E+00	7.00E-02	4.00E-03	5.12E+00	2.82E-01	1.66E+03	2.39E-01	1.80E-02	7.85E+00	6.87E-16	8.34E-01	1.48E-04	8.00E-03	1.05E-02
BATCH-983	3/21/31	21	2.2	0.24	0.00E+00	0.00E+00	5.00E-03	4.39E-04	3.88E-01	2.52E-02	2.79E+02	5.10E-02	3.00E-03	5.70E-01	9.17E-17	4.50E-02	2.02E-05	5.00E-03	5.00E-04
BATCH-984	3/23/31	127	13.2	0.24	0.00E+00	0.00E+00	4.70E-02	2.00E-03	3.44E+00	1.89E-01	1.12E+03	1.61E-01	1.20E-02	5.27E+00	4.62E-16	5.60E-01	9.92E-05	5.00E-03	7.00E-03
BATCH-985	3/28/31	141	14.7	0.24	0.00E+00	0.00E+00	5.20E-02	3.00E-03	3.82E+00	2.10E-01	1.24E+03	1.78E-01	1.40E-02	5.85E+00	5.12E-16	6.21E-01	1.10E-04	6.00E-03	7.75E-03
BATCH-986	4/5/31	148	15.4	0.24	0.00E+00	0.00E+00	1.30E-01	1.00E-02	9.60E+00	3.33E-01	2.95E+03	4.06E-01	4.80E-02	1.06E+01	1.97E-15	8.59E-01	3.91E-04	8.80E-02	1.13E-02
BATCH-987	4/12/31	146	15.2	0.24	0.00E+00	0.00E+00	1.45E-01	1.10E-02	1.07E+01	3.55E-01	2.92E+03	4.50E-01	5.40E-02	1.15E+01	2.26E-15	8.95E-01	4.47E-04	1.05E-01	1.18E-02
BATCH-988	4/21/31	166	17.3	0.24	0.00E+00	0.00E+00	1.64E-01	1.30E-02	1.22E+01	4.02E-01	3.31E+03	5.11E-01	6.20E-02	1.30E+01	2.56E-15	1.02E+00	5.08E-04	1.19E-01	1.33E-02
BATCH-989	4/27/31	146	15.2	0.24	0.00E+00	0.00E+00	1.45E-01	1.10E-02	1.07E+01	3.54E-01	2.92E+03	4.50E-01	5.40E-02	1.14E+01	2.25E-15	8.94E-01	4.47E-04	1.05E-01	1.18E-02
BATCH-990	5/9/31	98	10.2	0.24	0.00E+00	0.00E+00	9.70E-02	8.00E-03	7.19E+00	2.38E-01	1.96E+03	3.02E-01	3.60E-02	7.68E+00	1.51E-15	6.00E-01	3.00E-04	7.00E-02	7.75E-03
BATCH-991	5/13/31	109	11.4	0.24	0.00E+00	0.00E+00	1.08E-01	8.00E-03	7.99E+00	2.64E-01	2.18E+03	3.35E-01	4.10E-02	8.54E+00	1.68E-15	6.67E-01	3.33E-04	7.80E-02	8.75E-03
BATCH-992	5/19/31	128	13.3	0.24	0.00E+00	0.00E+00	1.27E-01	1.00E-02	9.39E+00	3.11E-01	2.56E+03	3.94E-01	4.80E-02	1.00E+01	1.99E-15	7.83E-01	3.92E-04	9.20E-02	1.03E-02
BATCH-993	5/24/31	133	13.8	0.24	0.00E+00	0.00E+00	1.50E-01	1.20E-02	1.11E+01	2.97E-01	2.65E+03	4.39E-01	5.10E-02	1.08E+01	2.29E-15	8.99E-01	4.15E-04	1.03E-01	1.03E-02
BATCH-994	6/2/31	152	15.9	0.24	0.00E+00	0.00E+00	1.75E-01	1.40E-02	1.30E+01	3.38E-01	3.04E+03	5.08E-01	5.80E-02	1.24E+01	2.66E-15	1.04E+00	4.77E-04	1.19E-01	1.18E-02
BATCH-995	6/7/31	134	14.0	0.24	0.00E+00	0.00E+00	1.54E-01	1.20E-02	1.14E+01	2.97E-01	2.68E+03	4.47E-01	5.10E-02	1.10E+01	2.34E-15	9.19E-01	4.20E-04	1.05E-01	1.03E-02
BATCH-996	6/18/31	110	11.4	0.24	0.00E+00	0.00E+00	3.40E-02	2.00E-03	2.49E+00	2.14E-01	2.19E+03	3.84E-01	1.40E-02	3.30E+00	4.26E-16	3.00E-01	7.01E-05	9.00E-03	3.50E-03
BATCH-997	6/21/31	101	10.5	0.24	0.00E+00	0.00E+00	2.50E-02	1.00E-03	1.83E+00	1.29E-01	1.27E+03	2.03E-01	9.00E-03	2.45E+00	3.08E-16	2.29E-01	5.58E-05	7.00E-03	2.75E-03
BATCH-998	6/30/31	118	12.3	0.24	0.00E+00	0.00E+00	1.36E-01	1.00E-02	1.01E+01	2.62E-01	2.36E+03	3.93E-01	4.50E-02	9.64E+00	2.06E-15	8.09E-01	3.70E-04	9.20E-02	9.00E-03
BATCH-999	7/2/31	120	12.5	0.24	0.00E+00	0.00E+00	1.37E-01	1.10E-02	1.02E+01	2.65E-01	2.39E+03	3.99E-01	4.60E-02	9.77E+00	2.09E-15	8.19E-01	3.75E-04	9.30E-02	9.25E-03
BATCH-1000	7/12/31	137	14.2	0.24	0.00E+00	0.00E+00	1.57E-01	1.20E-02	1.16E+01	3.02E-01	2.73E+03	4.55E-01	5.20E-02	1.12E+01	2.38E-15	9.36E-01	4.28E-04	1.07E-01	1.05E-02
BATCH-1001	7/15/31	120	12.5	0.24	0.00E+00	0.00E+00	1.38E-01	1.10E-02	1.02E+01	2.66E-01	2.40E+03	4.00E-01	4.60E-02	9.81E+00	2.10E-15	8.23E-01	3.77E-04	9.40E-02	9.25E-03
BATCH-1002	7/26/31	60	6.2	0.24	0.00E+00	0.00E+00	1.70E-02	1.00E-03	1.25E+00	1.07E-01	1.17E+03	1.92E-01	7.00E-03	1.66E+00	2.13E-16	1.50E-01	3.51E-05	4.00E-03	1.75E-03
BATCH-1003	7/27/31	60	6.2	0.24	0.00E+00	0.00E+00	1.30E-02	8.15E-04	9.94E-01	7.02E-02	6.92E+02	1.10E-01	5.00E-03	1.33E+00	1.66E-16	1.24E-01	3.03E-05	4.00E-03	1.50E-03
BATCH-1004	8/2/31	108	11.2	0.24	0.00E+00	0.00E+00	8.00E-02	5.00E-03	5.91E+00	1.97E-01	1.67E+03	2.36E-01	2.60E-02	6.27E+00	9.89E-16	5.45E-01	2.09E-04	4.30E-02	7.00E-03
BATCH-1005	8/3/31	118	12.3	0.24	0.00E+00	0.00E+00	4.50E-02	2.00E-03	3.25E+00	1.75E-01	6.24E+02	1.38E-01	1.20E-02	4.36E+00	2.09E-16	4.06E-01	1.01E-04	8.00E-03	6.25E-03
BATCH-1006	8/13/31	135	14.0	0.24	0.00E+00	0.00E+00	5.20E-02	2.00E-03	3.72E+00	2.00E-01	7.13E+02	1.57E-01	1.40E-02	4.99E+00	2.39E-16	4.64E-01	1.16E-04	9.00E-03	7.00E-03
BATCH-1007	8/15/31	119	12.4	0.24	0.00E+00	0.00E+00	4.50E-02	2.00E-03	3.28E+00	1.76E-01	6.28E+02	1.39E-01	1.30E-02	4.39E+00	2.11E-16	4.09E-01	1.02E-04	8.00E-03	6.25E-03
BATCH-1008	8/27/31	21	2.2	0.24	0.00E+00	0.00E+00	5.00E-03	2.82E-04	3.50E-01	2.97E-02	3.30E+02	5.40E-02	2.00E-03	4.65E-01	5.99E-17	4.20E-02	9.86E-06	1.00E-03	5.00E-04
BATCH-1009	8/28/31	20	2.1	0.24	0.00E+00	0.00E+00	4.00E-03	2.15E-04	2.62E-01	1.80E-02	1.82E+02	2.90E-02	1.00E-03	3.50E-01	4.41E-17	3.30E-02	7.97E-06	1.00E-03	5.00E-04
BATCH-1010	8/30/31	122	12.8	0.24	0.00E+00	0.00E+00	3.90E-02	3.00E-03	2.86E+00	9.81E-02	9.11E+02	1.19E-01	1.30E-02	3.18E+00	5.49E-16	2.78E-01	1.06E-04	2.30E-02	3.50E-03
BATCH-1011	8/30/31	120	12.5	0.24	0.00E+00	0.00E+00	3.60E-02	2.60E-03	2.62E+00	9.18E-02	8.05E+02	1.09E-01	1.20E-02	2.92E+00	4.78E-16	2.55E-01	9.62E-05	2.00E-02	3.25E-03
BATCH-1012	9/12/31	118	12.3	0.24	0.00E+00	0.00E+00	3.50E-02	2.00E-03	2.59E+00	9.00E-02	7.94E+02	1.07E-01	1.20E-02	2.87E+00	4.71E-16	2.52E-01	9.42E-05	2.00E-02	3.25E-03
BATCH-1013	9/12/31	117	12.2	0.24	0.00E+00	0.00E+00	4.50E-02	2.00E-03	3.22E+00	1.73E-01	6.16E+02	1.36E-01	1.25E-02	4.32E+00	2.06E-16	4.02E-01	1.00E-04	8.00E-03	6.25E-03
BATCH-1014	9/24/31	186	19.4	0.24	0.00E+00	0.00E+00	7.10E-02	3.00E-03	5.13E+00	2.75E-01	9.75E+02	2.17E-01	2.00E-02	6.88E+00	3.28E-16	6.41E-01	1.60E-04	1.20E-02	9.75E-03
BATCH-1015	9/24/31	186	19.4	0.24	0.00E+00	0.00E+00	7.10E-02	3.00E-03	5.12E+00	2.75E-01	9.81E+02	2.17E-01	2.00E-02	6.87E+00	3.28E-16	6.40E-01	1.60E-04	1.20E-02	9.75E-03
BATCH-1016	10/14/31	59	6.2	0.24	0.00E+00	0.00E+00	1.70E-02	1.00E-03	1.27E+00	4.41E-02	4.04E+02	5.30E-02	6.00E-03	1.41E+00	2.44E-16	1.23E-01	4.73E-05	1.00E-02	1.50E-03
BATCH-1017	10/14/31	60	6.3	0.24	0.00E+00	0.00E+00	1.60E-02	1.00E-03	1.21E+00	4.23E-02	3.71E+02	5.00E-02	5.00E-03	1.35E+00	2.20E-16	1.18E-01	4.44E-05	9.00E-03	1.35E-03
BATCH-1018	10/20/31	118	12.3	0.24	0.00E+00	0.00E+00	3.80E-02	3.00E-03	2.77E+00	9.27E-02	8.11E+02	1.12E-01	1.30E-02	2.95E+00	4.93E-16	2.50E-01	1.03E-04	2.20E-02	3.25E-03
BATCH-1019	10/20/31	60	6.3	0.24	0.00E+00	0.00E+00	1.60E-02	1.00E-03	1.21E+00	4.23E-02	3.71E+02	5.00E-02	5.00E-03	1.34E+00	2.20E-16	1.18E-01	4.40E-05	9.00E-03	1.50E-03
BATCH-1020	10/27/31	151	15.7	0.24	0.00E+00	0.00E+00	6.50E-02	2.00E-03	4.62E+00	2.18E-01	2.43E+02	1.20E-01	1.40E-02	4.46E+00	7.83E-17	3.49E-01	1.16E-04	8.00E-03	7.25E-03
BATCH-1021	11/2/31	150	15.6	0.24	0.00E+00	0.00E+00	5.90E-02	2.00E-03	4.24E+00	2.21E-01	6.70E+02	1.63E-01	1.50E-02	5.31E+00	2.23E-16	4.79E-01	1.28E-04	9.00E-03	7.75E-03
BATCH-1022	11/12/31	21	2.1	0.24	0.00E+00	0.00E+00	5.00E-03	3.31E-04	3.41E-01	1.17E-02	1.08E+02	1.40E-02	2.00E-03	3.78E-01	6.52E-17	3.30E-02	1.27E-05	3.00E-03	5.00E-04
BATCH-1023	11/14/31	21	2.2	0.24	0.00E+00	0.00E+00	4.00E-03	3.07E-04	3.26E-01	1.17E-02	1.00E+02	1.40E-02	1.00E-03	3.63E-01	5.95E-17	3.20E-02	1.20E-05	2.00E-03	5.00E-04
BATCH-1024	11/17/31	21	2.2	0.24	0.00E+00	0.00E+00	4.00E-03	3.07E-04	3.26E-01	1.17E-02	1.00E+02	1.30E-02	1.00E-03	3.61E-01	5.93E-17	3.20E-02	1.19E-05	2.00E-03	5.00E-04
BATCH-1025	11/18/31	61	6.3	0.24	0.00E+00	0.00E+00	1.80E-02	1.00E-03	1.31E+00	4.41E-02	3.83E+02	5.30E-02	6.00E-03	1.39E+00	2.32E-16	1.18E-01	4.83E-05	1.00E-02	1.50E-03
BATCH-1026	11/19/31	122	12.8	0.24	0.00E+00	0.00E+00	5.20E-02	1.00E-03	3.76E+00	1.76E-01	1.97E+02	9.80E-02	1.10E-02	3.63E+00	6.36E-17	2.84E-01	9.46E-05	6.00E-03	5.75E-03
BATCH-1027	11/24/31	173	18.1	0.24	0.00E+00	0.00E+00	7.40E-02	2.00E-03	5.32E+00	2.50E-01	2.79E+02	1.39E-01	1.60E-02	5.14E+00	8.99E-17	4.02E-01	1.34E-04	9.00E-03	8.25E-03
BATCH-1028	12/2/31	122	12.7	0.24	0.00E+00	0.00E+00	5.20E-02	1.00E-03	3.74E+00	1.76E-01	1.97E+02	9.70E-02	1.10E-02	3.61E+00	6.33E-17	2.82E-01	9.40E-05	6.00E-03	5.75E-03

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00
Fraction Remaining After Volatization Losses																			
BATCH-980	2/16/31	189	19.7	0.24	4.35E-08	5.67E+02	9.68E-01	6.49E-05	3.00E-03	1.44E-04	7.74E-06	3.00E-08	5.35E-04	1.08E-04	4.07E-05	2.17E-04	3.00E-03	1.70E-02	3.00E-03
BATCH-981	3/1/31	189	19.7	0.24	4.34E-08	5.67E+02	9.69E-01	6.51E-05	3.00E-03	1.44E-04	7.73E-06	3.00E-08	5.35E-04	1.08E-04	4.07E-05	2.17E-04	3.00E-03	1.70E-02	3.00E-03
BATCH-982	3/8/31	189	19.7	0.24	4.34E-08	5.66E+02	9.67E-01	6.49E-05	3.00E-03	1.44E-04	7.73E-06	3.00E-08	5.35E-04	1.08E-04	4.07E-05	2.17E-04	3.00E-03	1.70E-02	3.00E-03
BATCH-983	3/21/31	21	2.2	0.24	1.26E-09	6.27E+01	7.84E+00	7.74E-04	4.00E-02	2.00E-03	3.42E-07	2.44E-07	3.60E-05	1.03E-05	6.12E-06	2.06E-05	7.68E-04	4.00E-03	1.00E-03
BATCH-984	3/23/31	127	13.2	0.24	2.91E-08	3.80E+02	6.49E-01	4.95E-05	3.00E-03	1.28E-04	5.19E-06	2.01E-08	3.59E-04	7.26E-05	2.73E-05	1.46E-04	2.00E-03	1.10E-02	2.00E-03
BATCH-985	3/28/31	141	14.7	0.24	3.23E-08	4.22E+02	7.19E-01	4.83E-05	3.00E-03	1.07E-04	5.76E-06	2.23E-08	3.98E-04	8.05E-05	3.03E-05	1.62E-04	2.00E-03	1.20E-02	3.00E-03
BATCH-986	4/6/31	148	15.4	0.24	2.90E-08	4.42E+02	1.42E+02	1.00E-02	5.19E-01	2.20E-02	7.70E-06	4.42E-06	8.55E-04	2.35E-04	1.01E-04	4.60E-04	1.60E-02	8.70E-02	2.30E-02
BATCH-987	4/12/31	146	15.2	0.24	2.77E-08	4.38E+02	1.71E+02	1.20E-02	6.25E-01	2.70E-02	7.99E-06	5.33E-06	9.42E-04	2.66E-04	1.15E-04	5.18E-04	1.90E-02	1.02E-01	2.80E-02
BATCH-988	4/21/31	166	17.3	0.24	3.14E-08	4.97E+02	1.95E+02	1.40E-02	7.10E-01	3.00E-02	9.06E-06	6.05E-06	1.00E-03	3.01E-04	1.31E-04	5.88E-04	2.10E-02	1.16E-01	3.10E-02
BATCH-989	4/27/31	146	15.2	0.24	2.76E-08	4.37E+02	1.71E+02	1.20E-02	6.25E-01	2.70E-02	7.98E-06	5.33E-06	9.40E-04	2.65E-04	1.15E-04	5.18E-04	1.90E-02	1.02E-01	2.80E-02
BATCH-990	5/9/31	98	10.2	0.24	1.86E-08	2.94E+02	1.15E+02	8.00E-03	4.19E-01	1.80E-02	5.36E-06	3.57E-06	6.31E-04	1.78E-04	7.72E-05	3.48E-04	1.20E-02	6.80E-02	1.80E-02
BATCH-991	5/13/31	109	11.4	0.24	2.06E-08	3.26E+02	1.28E+02	9.00E-03	4.66E-01	2.00E-02	5.95E-06	3.97E-06	7.02E-04	1.98E-04	8.58E-05	3.86E-04	1.40E-02	7.60E-02	2.10E-02
BATCH-992	5/19/31	128	13.3	0.24	2.42E-08	3.83E+02	1.50E+02	1.10E-02	5.48E-01	2.30E-02	6.99E-06	4.67E-06	8.24E-04	2.33E-04	1.01E-04	4.54E-04	1.60E-02	8.90E-02	2.40E-02
BATCH-993	5/24/31	133	13.8	0.24	2.55E-08	3.98E+02	1.70E+02	1.10E-02	6.01E-01	2.50E-02	7.76E-06	5.29E-06	8.84E-04	2.28E-04	1.09E-04	4.57E-04	1.20E-02	6.80E-02	2.50E-02
BATCH-994	6/2/31	152	15.9	0.24	2.93E-08	4.56E+02	1.97E+02	1.30E-02	6.95E-01	2.90E-02	8.97E-06	6.14E-06	1.00E-03	2.60E-04	1.26E-04	5.23E-04	1.40E-02	7.50E-02	2.90E-02
BATCH-995	6/7/31	134	14.0	0.24	2.58E-08	4.02E+02	1.74E+02	1.20E-02	6.12E-01	2.60E-02	7.90E-06	5.40E-06	8.97E-04	2.29E-04	1.11E-04	4.60E-04	1.20E-02	6.60E-02	2.50E-02
BATCH-996	6/18/31	110	11.4	0.24	8.56E-09	3.29E+02	8.13E+00	3.00E-03	1.56E-01	1.50E-02	1.97E-06	2.54E-07	3.45E-04	7.78E-05	2.35E-05	1.32E-04	3.00E-03	1.80E-02	4.00E-03
BATCH-997	6/21/31	101	10.5	0.24	8.27E-09	3.01E+02	8.27E+00	2.00E-03	8.60E-02	7.00E-03	1.75E-06	2.58E-07	2.24E-04	5.09E-05	1.70E-05	9.09E-05	2.00E-03	1.20E-02	3.00E-03
BATCH-998	6/30/31	118	12.3	0.24	2.27E-08	3.54E+02	1.53E+02	1.00E-02	5.39E-01	2.30E-02	6.96E-06	4.76E-06	7.89E-04	2.01E-04	9.76E-05	4.05E-04	1.10E-02	5.80E-02	2.20E-02
BATCH-999	7/2/31	120	12.5	0.24	2.30E-08	3.58E+02	1.55E+02	1.00E-02	5.46E-01	2.30E-02	7.04E-06	4.82E-06	7.99E-04	2.04E-04	1.13E-04	4.69E-04	1.20E-02	5.90E-02	2.30E-02
BATCH-1000	7/12/31	137	14.2	0.24	2.63E-08	4.09E+02	1.77E+02	1.20E-02	6.23E-01	2.60E-02	8.05E-06	5.50E-06	9.13E-04	2.33E-04	9.93E-05	4.12E-04	1.10E-02	5.90E-02	2.30E-02
BATCH-1001	7/15/31	120	12.5	0.24	2.31E-08	3.60E+02	1.56E+02	1.00E-02	5.48E-01	2.30E-02	7.08E-06	4.84E-06	8.03E-04	2.05E-04	1.18E-05	6.60E-05	2.00E-03	9.00E-03	2.00E-03
BATCH-1002	7/26/31	60	6.2	0.24	4.29E-09	1.79E+02	4.07E+00	2.00E-03	7.80E-02	8.00E-03	9.87E-07	1.27E-07	1.73E-04	3.90E-05	2.76E-05	4.94E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-1003	7/27/31	60	6.2	0.24	4.50E-09	1.79E+02	4.50E+00	9.45E-04	4.70E-02	4.00E-03	9.52E-07	1.40E-07	1.22E-04	2.76E-05	9.22E-06	4.94E-05	5.00E-03	2.90E-02	1.10E-02
BATCH-1004	8/2/31	108	11.2	0.24	2.06E-08	3.23E+02	6.83E+01	5.00E-03	2.49E-01	1.10E-02	4.34E-06	2.13E-06	4.31E-04	1.09E-04	5.47E-05	2.21E-04	5.00E-03	2.90E-02	3.00E-03
BATCH-1005	8/3/31	118	12.3	0.24	2.22E-08	3.53E+02	4.91E+00	7.79E-04	3.50E-02	2.00E-03	2.77E-06	1.54E-07	1.88E-04	4.52E-05	2.61E-05	9.67E-05	2.00E-03	9.00E-03	4.00E-03
BATCH-1006	8/13/31	135	14.0	0.24	2.54E-08	4.04E+02	5.60E+00	8.90E-04	4.00E-02	2.00E-03	3.17E-06	1.76E-07	2.15E-04	5.17E-05	2.99E-05	1.11E-04	2.00E-03	1.00E-02	4.00E-03
BATCH-1007	8/15/31	119	12.4	0.24	2.24E-08	3.55E+02	4.94E+00	7.84E-04	3.60E-02	2.00E-03	2.79E-06	1.55E-07	1.89E-04	4.56E-05	2.63E-05	9.74E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-1008	8/27/31	21	2.2	0.24	1.20E-09	6.38E+01	1.14E+00	4.49E-04	2.20E-02	1.00E-03	2.77E-07	3.57E-08	4.85E-05	1.09E-05	3.30E-06	1.85E-05	4.70E-04	3.00E-03	5.69E-04
BATCH-1009	8/28/31	20	2.1	0.24	1.18E-09	6.14E+01	1.18E+00	2.49E-04	1.20E-02	1.00E-03	2.51E-07	3.69E-08	3.20E-05	7.27E-06	2.43E-06	1.30E-05	3.20E-04	2.00E-03	4.03E-04
BATCH-1010	8/30/31	122	12.8	0.24	1.02E-08	3.67E+02	3.60E+01	2.00E-03	1.29E-01	5.00E-03	2.46E-06	1.12E-06	2.47E-04	6.27E-05	2.79E-05	1.25E-04	3.00E-03	1.90E-02	6.00E-03
BATCH-1011	8/30/31	120	12.5	0.24	9.70E-09	3.58E+02	3.14E+01	2.00E-03	1.14E-01	5.00E-03	2.20E-06	9.75E-07	2.18E-04	5.53E-05	2.52E-05	1.10E-04	3.00E-03	1.70E-02	5.00E-03
BATCH-1012	9/12/31	118	12.3	0.24	9.55E-09	3.54E+02	3.08E+01	2.00E-03	1.11E-01	5.00E-03	2.17E-06	9.57E-07	2.13E-04	5.38E-05	2.47E-05	1.08E-04	3.00E-03	1.60E-02	5.00E-03
BATCH-1013	9/12/31	117	12.2	0.24	2.20E-08	3.50E+02	4.76E+00	7.65E-04	3.50E-02	2.00E-03	2.74E-06	1.50E-07	1.86E-04	4.47E-05	2.58E-05	9.56E-05	2.00E-03	9.00E-03	3.00E-03
BATCH-1014	9/24/31	186	19.4	0.24	3.51E-08	5.58E+02	7.59E+00	1.00E-03	5.50E-02	3.00E-03	4.37E-06	2.39E-07	2.96E-04	7.13E-05	4.12E-05	1.53E-04	3.00E-03	1.40E-02	5.00E-03
BATCH-1015	9/24/31	186	19.4	0.24	3.51E-08	5.57E+02	7.58E+00	1.00E-03	5.50E-02	3.00E-03	4.37E-06	2.38E-07	2.96E-04	7.12E-05	4.12E-05	1.52E-04	3.00E-03	1.40E-02	5.00E-03
BATCH-1016	10/14/31	59	6.2	0.24	4.54E-09	1.78E+02	1.60E+01	1.00E-03	5.70E-02	2.00E-03	1.09E-06	4.98E-07	1.10E-04	2.78E-05	1.24E-05	5.53E-05	2.00E-03	8.00E-03	3.00E-03
BATCH-1017	10/14/31	60	6.3	0.24	4.47E-09	1.80E+02	1.45E+01	1.00E-03	5.20E-02	2.00E-03	1.01E-06	4.50E-07	1.00E-04	2.55E-05	1.16E-05	5.09E-05	1.00E-03	8.00E-03	2.00E-03
BATCH-1018	10/20/31	118	12.3	0.24	9.05E-09	3.54E+02	3.51E+01	2.00E-03	1.28E-01	5.00E-03	2.04E-06	1.09E-06	2.13E-04	5.56E-05	2.67E-05	1.12E-04	3.00E-03	1.70E-02	6.00E-03
BATCH-1019	10/20/31	60	6.3	0.24	4.47E-09	1.81E+02	1.44E+01	9.95E-04	5.20E-02	2.00E-03	1.01E-06	4.47E-07	9.98E-05	2.52E-05	1.16E-05	5.03E-05	1.00E-03	7.00E-03	2.00E-03
BATCH-1020	10/27/31	151	15.7	0.24	1.29E-08	4.51E+02	1.79E+00	1.00E-03	5.50E-02	3.00E-03	1.87E-06	6.00E-08	3.66E-04	9.93E-05	3.46E-05	1.68E-04	3.00E-03	1.70E-02	1.90E-02
BATCH-1021	11/2/31	150	15.6	0.24	2.49E-08	4.50E+02	5.16E+00	1.00E-03	4.70E-02	2.00E-03	3.16E-06	1.63E-07	2.67E-04	6.67E-05	3.35E-05	1.33E-04	2.00E-03	1.30E-02	8.00E-03
BATCH-1022	11/12/31	21	2.1	0.24	1.22E-09	6.17E+01	4.29E+00	2.94E-04	1.50E-02	6.51E-04	2.93E-07	1.33E-07	2.93E-05	7.45E-06	3.32E-06	1.48E-05	4.16E-04	2.00E-03	7.01E-04
BATCH-1023	11/14/31	21	2.2	0.24	1.21E-09	6.26E+01	3.90E+00	2.68E-04	1.40E-02	6.00E-04	2.74E-07	1.21E-07	2.71E-05	6.88E-06	3.14E-06	1.37E-05	3.77E-04	2.00E-03	6.51E-04
BATCH-1024	11/17/31	21	2.2	0.24	1.20E-09	6.26E+01	3.88E+00	2.68E-04	1.40E-02	5.94E-04	2.73E-07	1.21E-07	2.69E-05	6.78E-06	3.12E-06	1.36E-05	3.63E-04	2.00E-03	6.44E-04
BATCH-1025	11/18/31	61	6.3	0.24	4.27E-09	1.82E+02	1.65E+01	1.00E-03	6.00E-02	3.00E-03	9.64E-07	5.14E-07	1.00E-04	2.62E-05	1.26E-05	5.27E-05	1.00E-03	8.00E-03	3.00E-03
BATCH-1026	11/19/31	122	12.8	0.24	1.05E-08	3.67E+02	1.45E+00	1.00E-03	4.50E-02	3.00E-03	1.52E-06	4.87E-08	2.97E-04	8.08E-05	2.81E-05	1.37E-04	3.00E-03	1.40E-02	1.60E-02
BATCH-1027	11/24/31	173	18.1	0.24	1.48E-08	5.19E+02	2.06E+00	2.00E-03	6.30E-02	4.00E-03	2.15E-06	6.90E-08	4.21E-04	1.14E-04	3.98E-05	1.94E-04	4.00E-03	1.90E-02	2.20E-02
BATCH-1028	12/2/31	122	12.7	0.24	1.04E-08	3.65E+02	1.45E+00	1.00E-03	4.40E-02	3.00E-03	1.51E-06	4.85E-08	2.96E-04	8.03E-05	2.79E-05	1.36E-04	2.00E-03	1.40E-02	1.60E-02

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m^3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-980	2/16/31	189	19.7	0.24	1.39E-04	7.70E-05	1.40E-02	4.00E-03	3.00E-03	2.72E-01	3.60E-02	6.40E-02	5.50E-02	3.35E-28	1.70E-06	2.34E-06	9.95E-05	5.99E-04	1.63E-09
BATCH-981	3/1/31	189	19.7	0.24	1.39E-04	7.69E-05	1.40E-02	4.00E-03	3.00E-03	2.72E-01	3.60E-02	6.40E-02	5.50E-02	3.35E-28	1.70E-06	2.34E-06	9.95E-05	5.99E-04	1.63E-09
BATCH-982	3/8/31	189	19.7	0.24	1.38E-04	7.69E-05	1.40E-02	4.00E-03	3.00E-03	2.72E-01	3.60E-02	6.40E-02	5.50E-02	3.35E-28	1.70E-06	2.34E-06	9.94E-05	5.98E-04	1.63E-09
BATCH-983	3/21/31	21	2.2	0.24	4.61E-05	3.05E-05	1.00E-03	1.00E-03	1.00E-03	5.10E-02	8.00E-03	7.70E-02	1.60E-02	1.11E-28	5.24E-07	3.28E-06	4.13E-05	8.84E-04	8.34E-14
BATCH-984	3/23/31	127	13.2	0.24	9.31E-05	5.17E-05	9.00E-03	3.00E-03	2.00E-03	1.83E-01	2.40E-02	4.40E-02	3.70E-02	2.27E-28	1.14E-06	1.61E-06	6.75E-05	4.23E-04	1.09E-09
BATCH-985	3/28/31	141	14.7	0.24	1.03E-04	5.73E-05	1.00E-02	3.00E-03	2.00E-03	2.03E-01	2.70E-02	4.80E-02	4.10E-02	2.50E-28	1.27E-06	1.74E-06	7.41E-05	4.46E-04	1.21E-09
BATCH-986	4/6/31	148	15.4	0.24	9.61E-04	5.94E-04	2.50E-02	1.90E-02	2.40E-02	9.43E-01	1.54E-01	1.02E+00	2.94E-01	4.98E-28	9.49E-06	3.79E-05	1.37E-04	7.92E-04	2.30E-10
BATCH-987	4/12/31	146	15.2	0.24	1.00E-03	7.04E-04	2.80E-02	2.30E-02	2.90E-02	1.09E+00	1.80E-01	1.22E+00	3.46E-01	5.44E-28	1.12E-05	4.54E-05	1.49E-04	8.55E-04	1.95E-12
BATCH-988	4/21/31	166	17.3	0.24	1.00E-03	7.99E-04	3.20E-02	2.60E-02	3.30E-02	1.24E+00	2.05E-01	1.39E+00	3.92E-01	6.17E-28	1.27E-05	5.15E-05	1.69E-04	9.70E-04	1.27E-12
BATCH-989	4/27/31	146	15.2	0.24	1.00E-03	7.03E-04	2.80E-02	2.30E-02	2.90E-02	1.09E+00	1.80E-01	1.22E+00	3.45E-01	5.43E-28	1.12E-05	4.53E-05	1.48E-04	8.54E-04	1.95E-12
BATCH-990	5/9/31	98	10.2	0.24	7.62E-04	4.72E-04	1.90E-02	1.50E-02	1.90E-02	7.32E-01	1.21E-01	8.20E-01	2.32E-01	3.65E-28	7.49E-06	3.04E-05	9.96E-05	5.73E-04	1.58E-12
BATCH-991	5/13/31	109	11.4	0.24	8.47E-04	5.24E-04	2.10E-02	1.70E-02	2.20E-02	8.14E-01	1.34E-01	9.11E-01	2.58E-01	4.05E-28	8.32E-06	3.38E-05	1.11E-04	6.37E-04	1.67E-12
BATCH-992	5/19/31	128	13.3	0.24	9.95E-04	6.16E-04	2.40E-02	2.00E-02	2.50E-02	9.56E-01	1.58E-01	1.07E+00	3.03E-01	4.76E-28	9.78E-06	3.97E-05	1.30E-04	7.48E-04	1.11E-12
BATCH-993	5/24/31	133	13.8	0.24	9.89E-04	6.28E-04	2.70E-02	2.30E-02	2.70E-02	1.19E+00	1.88E-01	1.09E+00	3.47E-01	5.38E-28	1.12E-05	4.05E-05	1.47E-04	8.45E-04	1.06E-10
BATCH-994	6/2/31	152	15.9	0.24	1.00E-03	7.19E-04	3.10E-02	2.70E-02	3.10E-02	1.39E+00	2.19E-01	1.25E+00	4.03E-01	6.23E-28	1.30E-05	4.64E-05	1.71E-04	9.79E-04	1.35E-10
BATCH-995	6/7/31	134	14.0	0.24	9.94E-04	6.33E-04	2.80E-02	2.40E-02	2.80E-02	1.23E+00	1.93E-01	1.10E+00	3.55E-01	5.49E-28	1.14E-05	4.09E-05	1.50E-04	8.62E-04	1.19E-10
BATCH-996	6/18/31	110	11.4	0.24	1.61E-04	7.86E-05	4.00E-03	2.00E-03	4.00E-03	1.05E-01	1.70E-02	3.46E-01	3.40E-02	1.00E-27	1.01E-06	1.76E-05	3.96E-04	9.00E-03	7.70E-11
BATCH-997	6/21/31	101	10.5	0.24	1.14E-04	6.03E-05	4.00E-03	2.00E-03	3.00E-03	9.90E-02	1.50E-02	1.92E-01	2.90E-02	4.87E-28	8.94E-07	9.18E-06	1.88E-04	4.00E-03	1.75E-10
BATCH-998	6/30/31	118	12.3	0.24	8.75E-04	5.57E-04	2.40E-02	2.10E-02	2.40E-02	1.08E+00	1.70E-01	9.67E-01	3.12E-01	4.83E-28	1.01E-05	3.60E-05	1.32E-04	7.59E-04	1.05E-10
BATCH-999	7/2/31	120	12.5	0.24	8.86E-04	5.64E-04	2.50E-02	2.10E-02	2.50E-02	1.09E+00	1.72E-01	9.80E-01	3.16E-01	4.89E-28	1.02E-05	3.64E-05	1.34E-04	7.68E-04	1.06E-10
BATCH-1000	7/12/31	137	14.2	0.24	1.00E-03	6.45E-04	2.80E-02	2.40E-02	2.80E-02	1.25E+00	1.97E-01	1.12E+00	3.61E-01	5.59E-28	1.16E-05	4.16E-05	1.53E-04	8.78E-04	1.21E-10
BATCH-1001	7/15/31	120	12.5	0.24	8.91E-04	5.67E-04	2.50E-02	2.10E-02	2.50E-02	1.10E+00	1.73E-01	9.84E-01	3.18E-01	4.91E-28	1.02E-05	3.66E-05	1.34E-04	7.72E-04	1.07E-10
BATCH-1002	7/26/31	60	6.2	0.24	8.08E-05	3.94E-05	2.00E-03	1.00E-03	2.00E-03	5.20E-02	9.00E-03	1.74E-01	1.70E-02	5.02E-28	5.07E-07	8.79E-06	1.98E-04	5.00E-03	3.86E-11
BATCH-1003	7/27/31	60	6.2	0.24	6.18E-05	3.28E-05	2.00E-03	1.00E-03	2.00E-03	5.40E-02	8.00E-03	1.04E-01	1.60E-02	2.65E-28	4.86E-07	4.99E-06	1.02E-04	2.00E-03	9.48E-11
BATCH-1004	8/2/31	108	11.2	0.24	4.40E-04	2.70E-04	1.40E-02	1.30E-02	1.20E-02	5.75E-01	8.80E-02	4.53E-01	1.56E-01	2.98E-28	5.04E-06	1.68E-05	8.23E-05	4.77E-04	4.53E-11
BATCH-1005	8/3/31	118	12.3	0.24	1.30E-04	6.03E-05	7.00E-03	9.00E-03	3.00E-03	2.27E-01	3.00E-02	7.50E-02	4.80E-02	1.85E-28	1.46E-06	2.72E-06	5.24E-05	3.10E-04	7.47E-14
BATCH-1006	8/13/31	135	14.0	0.24	1.49E-04	6.89E-05	8.00E-03	1.00E-02	4.00E-03	2.59E-01	3.50E-02	8.50E-02	5.50E-02	2.12E-28	1.67E-06	3.11E-06	5.99E-05	3.54E-04	7.46E-14
BATCH-1007	8/15/31	119	12.4	0.24	1.31E-04	6.07E-05	7.00E-03	9.00E-03	3.00E-03	2.28E-01	3.10E-02	7.50E-02	4.80E-02	1.87E-28	1.47E-06	2.74E-06	5.27E-05	3.12E-04	7.44E-14
BATCH-1008	8/27/31	21	2.2	0.24	2.27E-05	1.11E-05	6.26E-04	3.12E-04	5.57E-04	1.50E-02	2.00E-03	4.90E-02	5.00E-03	1.41E-28	1.42E-07	2.47E-06	5.56E-05	1.00E-03	1.08E-11
BATCH-1009	8/28/31	20	2.1	0.24	1.63E-05	8.62E-06	5.62E-04	2.75E-04	4.00E-04	1.40E-02	2.00E-03	2.70E-02	4.00E-03	6.96E-29	1.28E-07	1.31E-06	2.68E-05	6.08E-04	2.50E-11
BATCH-1010	8/30/31	122	12.8	0.24	2.37E-04	1.47E-04	7.00E-03	5.00E-03	6.00E-03	2.72E-01	4.30E-02	2.48E-01	7.90E-02	1.50E-28	2.54E-06	9.22E-06	4.17E-05	2.43E-04	1.72E-10
BATCH-1011	8/30/31	120	12.5	0.24	2.10E-04	1.29E-04	7.00E-03	5.00E-03	6.00E-03	2.47E-01	3.90E-02	2.17E-01	7.10E-02	1.37E-28	2.26E-06	8.06E-06	3.81E-05	2.22E-04	1.29E-10
BATCH-1012	9/12/31	118	12.3	0.24	2.04E-04	1.26E-04	6.00E-03	5.00E-03	5.00E-03	2.44E-01	3.80E-02	2.11E-01	6.90E-02	1.35E-28	2.23E-06	7.84E-06	3.76E-05	2.19E-04	1.29E-10
BATCH-1013	9/12/31	117	12.2	0.24	1.29E-04	5.94E-05	7.00E-03	9.00E-03	3.00E-03	2.24E-01	3.00E-02	7.30E-02	4.70E-02	1.83E-28	1.44E-06	2.67E-06	5.18E-05	3.06E-04	3.84E-16
BATCH-1014	9/24/31	186	19.4	0.24	2.05E-04	9.47E-05	1.00E-02	1.40E-02	5.00E-03	3.57E-01	4.80E-02	1.17E-01	7.50E-02	2.92E-28	2.30E-06	4.27E-06	8.26E-05	4.89E-04	2.55E-15
BATCH-1015	9/24/31	186	19.4	0.24	2.05E-04	9.46E-05	1.00E-02	1.40E-02	5.00E-03	3.57E-01	4.80E-02	1.17E-01	7.50E-02	2.92E-28	2.29E-06	4.26E-06	8.25E-05	4.88E-04	4.77E-15
BATCH-1016	10/14/31	59	6.2	0.24	1.05E-04	6.54E-05	3.00E-03	2.00E-03	3.00E-03	1.21E-01	1.90E-02	1.10E-01	3.50E-02	6.65E-29	1.13E-06	4.09E-06	1.85E-05	1.08E-04	7.66E-11
BATCH-1017	10/14/31	60	6.3	0.24	9.67E-05	5.96E-05	3.00E-03	2.00E-03	3.00E-03	1.14E-01	1.80E-02	1.00E-01	3.30E-02	6.31E-29	1.04E-06	3.71E-06	1.76E-05	1.02E-04	5.93E-11
BATCH-1018	10/20/31	118	12.3	0.24	2.29E-04	1.41E-04	7.00E-03	6.00E-03	6.00E-03	2.72E-01	4.20E-02	2.39E-01	7.80E-02	1.40E-28	2.49E-06	8.87E-06	3.86E-05	2.23E-04	1.51E-11
BATCH-1019	10/20/31	60	6.3	0.24	9.53E-05	5.88E-05	3.00E-03	2.00E-03	3.00E-03	1.14E-01	1.80E-02	9.90E-02	3.20E-02	6.30E-29	1.04E-06	3.66E-06	1.76E-05	1.02E-04	6.04E-11
BATCH-1020	10/27/31	151	15.7	0.24	6.90E-04	1.88E-04	4.00E-03	2.00E-02	2.00E-02	5.15E-01	5.90E-02	1.20E-01	7.10E-02	1.10E-28	2.04E-06	3.47E-06	2.39E-05	1.53E-04	5.64E-12
BATCH-1021	11/2/31	150	15.6	0.24	2.81E-04	1.01E-04	7.00E-03	1.30E-02	8.00E-03	3.38E-01	4.30E-02	1.00E-01	6.30E-02	2.08E-28	1.89E-06	3.44E-06	5.71E-05	3.41E-04	1.25E-12
BATCH-1022	11/12/31	21	2.1	0.24	2.82E-05	1.75E-05	8.64E-04	6.39E-04	7.43E-04	3.20E-02	5.00E-03	3.00E-02	9.00E-03	1.78E-29	3.02E-07	1.10E-06	4.97E-06	2.89E-05	2.05E-11
BATCH-1023	11/14/31	21	2.2	0.24	2.61E-05	1.61E-05	8.10E-04	6.42E-04	6.90E-04	3.10E-02	5.00E-03	2.70E-02	9.00E-03	1.70E-29	2.82E-07	1.00E-06	4.74E-06	2.76E-05	1.60E-11
BATCH-1024	11/17/31	21	2.2	0.24	2.57E-05	1.59E-05	8.06E-04	6.42E-04	6.84E-04	3.10E-02	5.00E-03	2.70E-02	9.00E-03	1.70E-29	2.81E-07	9.87E-07	4.73E-06	2.75E-05	1.63E-11
BATCH-1025	11/18/31	61	6.3	0.24	1.08E-04	6.64E-05	3.00E-03	3.00E-03	3.00E-03	1.28E-01	2.00E-02	1.13E-01	3.70E-02	6.60E-29	1.18E-06	4.19E-06	1.82E-05	1.05E-04	7.11E-12
BATCH-1026	11/19/31	122	12.8	0.24	5.61E-04	1.53E-04	3.00E-03	1.60E-02	1.60E-02	4.18E-01	4.80E-02	9.80E-02	5.80E-02	8.94E-29	1.66E-06	2.82E-06	1.94E-05	1.25E-04	4.59E-12
BATCH-1027	11/24/31	173	18.1	0.24	7.94E-04	2.17E-04	4.00E-03	2.30E-02	2.30E-02	5.92E-01	6.80E-02	1.38E-01	8.20E-02	1.26E-28	2.35E-06	4.00E-06	2.74E-05	1.76E-04	6.49E-12
BATCH-1028	12/2/31	122	12.7	0.24	5.58E-04	1.52E-04	3.00E-03	1.60E-02	1.60E-02	4.16E-01	4.80E-02	9.70E-02	5.70E-02	8.89E-29	1.65E-06	2.81E-06	1.93E-05	1.24E-04	4.56E-12

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-980	2/16/31	189	19.7	0.24	5.00E-03	1.71E+02	3.44E-09	4.77E-07	1.62E-09	8.96E-58	7.84E-04	1.19E+00	9.82E-10	2.40E-02	3.79E+01	0.00E+00	2.67E-04	1.75E+00	3.13E-07
BATCH-981	3/1/31	189	19.7	0.24	9.00E-03	1.71E+02	3.43E-09	4.77E-07	1.62E-09	2.94E-53	7.83E-04	1.19E+00	9.82E-10	2.40E-02	3.79E+01	0.00E+00	6.43E-04	1.75E+00	3.14E-07
BATCH-982	3/8/31	189	19.7	0.24	9.00E-03	1.71E+02	3.43E-09	4.76E-07	1.62E-09	4.81E-48	7.83E-04	1.19E+00	9.81E-10	2.40E-02	3.79E+01	0.00E+00	5.46E-04	1.75E+00	3.13E-07
BATCH-983	3/21/31	21	2.2	0.24	3.71E+01	0.00E+00	3.32E-14	4.96E-09	1.53E-13	9.02E-50	1.00E-03	3.08E-01	1.16E-12	7.39E-04	1.03E+00	0.00E+00	2.09E+00	0.00E+00	1.45E-06
BATCH-984	3/23/31	127	13.2	0.24	2.23E-09	1.15E+02	2.30E-09	3.20E-07	1.09E-09	2.09E-53	5.27E-04	8.02E-01	6.58E-10	1.60E-02	2.54E+01	0.00E+00	1.20E-10	1.17E+00	2.11E-07
BATCH-985	3/28/31	141	14.7	0.24	2.06E-09	1.27E+02	2.56E-09	3.55E-07	1.21E-09	5.12E-54	5.83E-04	8.89E-01	7.31E-10	1.80E-02	2.82E+01	0.00E+00	9.80E-11	1.30E+00	2.33E-07
BATCH-986	4/6/31	148	15.4	0.24	2.07E-06	1.96E+02	4.86E-10	7.59E-08	2.29E-10	3.95E-61	3.00E-03	3.85E+00	1.44E-10	1.40E-02	2.38E+01	0.00E+00	1.18E-07	4.31E+00	2.65E-05
BATCH-987	4/12/31	146	15.2	0.24	4.57E-06	2.08E+02	7.18E-12	1.10E-08	3.02E-12	1.51E-56	4.00E-03	4.44E+00	8.13E-12	1.30E-02	2.24E+01	0.00E+00	3.30E-07	4.91E+00	2.70E-05
BATCH-988	4/21/31	166	17.3	0.24	7.00E-03	2.36E+02	6.15E-12	1.23E-08	2.48E-12	1.69E-53	5.00E-03	5.04E+00	8.65E-12	1.50E-02	2.54E+01	0.00E+00	3.92E-04	5.57E+00	2.70E-05
BATCH-989	4/27/31	146	15.2	0.24	4.85E-06	2.08E+02	7.18E-12	1.10E-08	3.01E-12	2.47E-51	4.00E-03	4.43E+00	8.12E-12	1.30E-02	2.24E+01	0.00E+00	2.80E-07	4.90E+00	2.70E-05
BATCH-990	5/9/31	98	10.2	0.24	1.70E-12	1.39E+02	5.39E-12	7.48E-09	2.29E-12	1.60E-56	3.00E-03	2.98E+00	5.61E-12	9.00E-03	1.50E+01	0.00E+00	9.17E-14	3.29E+00	2.14E-05
BATCH-991	5/13/31	109	11.4	0.24	1.41E-12	1.55E+02	5.79E-12	8.29E-09	2.46E-12	3.52E-57	3.00E-03	3.31E+00	6.18E-12	1.00E-02	1.67E+01	0.00E+00	6.73E-14	3.66E+00	2.38E-05
BATCH-992	5/19/31	128	13.3	0.24	1.21E-09	1.82E+02	5.03E-12	9.49E-09	2.04E-12	2.30E-54	4.00E-03	3.89E+00	6.76E-12	1.20E-02	1.96E+01	0.00E+00	6.86E-11	4.30E+00	2.70E-05
BATCH-993	5/24/31	133	13.8	0.24	2.30E-09	1.76E+02	1.11E-11	1.90E-08	1.15E-11	7.60E-60	3.00E-03	2.15E+00	1.29E-10	1.50E-02	2.08E+01	0.00E+00	1.66E-10	4.66E+00	2.70E-05
BATCH-994	6/2/31	152	15.9	0.24	3.55E-06	2.01E+02	1.36E-11	2.30E-08	1.45E-11	8.65E-57	3.00E-03	2.22E+00	1.64E-10	1.70E-02	2.39E+01	0.00E+00	2.00E-07	5.38E+00	2.70E-05
BATCH-995	6/7/31	134	14.0	0.24	2.81E-09	1.77E+02	1.20E-11	2.02E-08	1.28E-11	1.43E-54	3.00E-03	1.95E+00	1.45E-10	1.50E-02	2.10E+01	0.00E+00	1.63E-10	4.74E+00	2.70E-05
BATCH-996	6/18/31	110	11.4	0.24	2.26E+02	0.00E+00	1.61E-10	2.50E-08	7.72E-11	6.19E-48	3.00E-03	2.45E+00	5.41E-11	4.00E-03	6.78E+00	0.00E+00	1.46E+01	0.00E+00	1.70E-06
BATCH-997	6/21/31	101	10.5	0.24	2.41E+02	0.00E+00	3.68E-10	5.24E-08	1.74E-10	1.44E-48	3.00E-03	1.68E+00	1.09E-10	4.00E-03	6.67E+00	0.00E+00	1.33E+01	0.00E+00	1.64E-06
BATCH-998	6/30/31	118	12.3	0.24	7.95E-13	1.55E+02	1.05E-11	1.78E-08	1.13E-11	1.52E-67	3.00E-03	1.72E+00	1.27E-10	1.30E-02	1.85E+01	0.00E+00	4.52E-14	4.17E+00	2.70E-05
BATCH-999	7/2/31	120	12.5	0.24	1.50E-12	1.57E+02	1.07E-11	1.81E-08	1.14E-11	4.94E-63	3.00E-03	1.74E+00	1.29E-10	1.40E-02	1.88E+01	0.00E+00	1.08E-13	4.22E+00	2.70E-05
BATCH-1000	7/12/31	137	14.2	0.24	2.02E-09	1.80E+02	1.22E-11	2.06E-08	1.30E-11	4.92E-60	3.00E-03	1.99E+00	1.48E-10	1.50E-02	2.14E+01	0.00E+00	1.14E-10	4.82E+00	2.70E-05
BATCH-1001	7/15/31	120	12.5	0.24	1.82E-12	1.58E+02	1.07E-11	1.81E-08	1.15E-11	9.25E-58	3.00E-03	1.75E+00	1.30E-10	1.40E-02	1.88E+01	0.00E+00	1.05E-13	4.24E+00	2.70E-05
BATCH-1002	7/26/31	60	6.2	0.24	1.13E+02	0.00E+00	8.08E-11	1.25E-08	3.87E-11	3.10E-48	2.00E-03	1.23E+00	2.71E-11	2.00E-03	3.40E+00	0.00E+00	7.31E+00	0.00E+00	8.53E-07
BATCH-1003	7/27/31	60	6.2	0.24	1.31E+02	0.00E+00	2.00E-10	2.85E-08	9.46E-11	7.84E-49	2.00E-03	9.11E-01	5.91E-11	2.00E-03	3.73E+00	0.00E+00	7.23E+00	0.00E+00	8.89E-07
BATCH-1004	8/2/31	108	11.2	0.24	5.21E-16	1.15E+02	4.55E-12	1.00E-08	4.86E-12	9.95E-71	1.70E-02	9.16E-01	5.58E-11	1.50E-02	1.78E+01	0.00E+00	2.96E-17	2.46E+00	1.26E-05
BATCH-1005	8/3/31	118	12.3	0.24	1.05E-15	9.91E+01	7.57E-15	4.84E-09	8.33E-15	3.46E-66	3.20E-02	3.64E-01	1.69E-12	1.90E-02	2.03E+01	0.00E+00	7.56E-17	1.37E+00	8.92E-07
BATCH-1006	8/13/31	135	14.0	0.24	1.24E-12	1.13E+02	7.58E-15	5.54E-09	8.37E-15	3.00E-63	3.70E-02	4.16E-01	1.92E-12	2.20E-02	2.32E+01	0.00E+00	6.97E-14	1.57E+00	1.02E-06
BATCH-1007	8/15/31	119	12.4	0.24	1.26E-15	9.99E+01	7.55E-15	4.88E-09	8.30E-15	6.41E-61	3.20E-02	3.66E-01	1.70E-12	1.90E-02	2.05E+01	0.00E+00	7.28E-17	1.38E+00	8.98E-07
BATCH-1008	8/27/31	21	2.2	0.24	3.17E+01	0.00E+00	2.27E-11	3.51E-09	1.09E-11	8.70E-49	4.77E-04	3.44E-01	7.61E-12	5.89E-04	9.53E-01	0.00E+00	2.05E+00	0.00E+00	2.39E-07
BATCH-1009	8/28/31	20	2.1	0.24	3.44E+01	0.00E+00	5.25E-11	7.50E-09	2.49E-11	2.06E-49	4.03E-04	2.40E-01	1.56E-11	6.08E-04	9.82E-01	0.00E+00	1.90E+00	0.00E+00	2.34E-07
BATCH-1010	8/30/31	122	12.8	0.24	3.15E+02	0.00E+00	3.38E-10	5.01E-08	1.61E-10	6.53E-59	1.20E-02	1.80E+00	1.12E-10	6.00E-03	8.60E+00	0.00E+00	1.62E+01	0.00E+00	6.69E-06
BATCH-1011	8/30/31	120	12.5	0.24	3.20E+02	0.00E+00	2.48E-10	3.74E-08	1.18E-10	2.11E-54	1.80E-02	1.50E+00	8.54E-11	6.00E-03	8.24E+00	0.00E+00	1.60E+01	0.00E+00	5.82E-06
BATCH-1012	9/12/31	118	12.3	0.24	3.18E+02	0.00E+00	2.46E-10	3.73E-08	1.17E-10	3.43E-49	1.90E-02	1.42E+00	8.66E-11	6.00E-03	8.13E+00	0.00E+00	1.61E+01	0.00E+00	5.70E-06
BATCH-1013	9/12/31	117	12.2	0.24	8.71E-16	9.82E+01	1.13E-16	4.79E-09	3.59E-16	2.12E-66	3.20E-02	3.59E-01	1.59E-12	1.90E-02	2.01E+01	0.00E+00	4.91E-17	1.36E+00	8.64E-07
BATCH-1014	9/24/31	186	19.4	0.24	6.00E-03	1.57E+02	4.41E-15	7.64E-09	2.59E-15	1.63E-52	5.10E-02	5.73E-01	2.53E-12	3.00E-02	3.21E+01	0.00E+00	3.83E-04	2.17E+00	1.38E-06
BATCH-1015	9/24/31	186	19.4	0.24	6.00E-03	1.56E+02	9.11E-15	7.63E-09	4.80E-15	3.51E-53	5.10E-02	5.72E-01	2.53E-12	3.00E-02	3.20E+01	0.00E+00	3.24E-04	2.16E+00	1.38E-06
BATCH-1016	10/14/31	59	6.2	0.24	1.40E+02	0.00E+00	1.50E-10	2.22E-08	7.13E-11	2.90E-59	5.00E-03	7.99E-01	4.99E-11	3.00E-03	3.82E+00	0.00E+00	7.21E+00	0.00E+00	2.97E-06
BATCH-1017	10/14/31	60	6.3	0.24	1.47E+02	0.00E+00	1.14E-10	1.73E-08	5.43E-11	9.72E-55	8.00E-03	6.93E-01	3.94E-11	3.00E-03	3.80E+00	0.00E+00	7.40E+00	0.00E+00	2.68E-06
BATCH-1018	10/20/31	118	12.3	0.24	3.19E+02	0.00E+00	1.90E-12	4.15E-09	1.76E-12	1.08E-54	2.50E-02	1.54E+00	1.90E-11	6.00E-03	7.74E+00	0.00E+00	1.57E+01	0.00E+00	6.49E-06
BATCH-1019	10/20/31	60	6.3	0.24	1.49E+02	0.00E+00	1.15E-10	1.74E-08	5.47E-11	1.60E-49	9.00E-03	6.62E-01	4.05E-11	3.00E-03	3.80E+00	0.00E+00	7.50E+00	0.00E+00	2.67E-06
BATCH-1020	10/27/31	151	15.7	0.24	2.82E-06	1.70E+02	1.25E-14	2.52E-10	3.36E-14	1.69E-56	8.30E-02	1.09E+00	6.68E-13	3.20E-02	1.61E+01	0.00E+00	1.56E-07	3.05E+00	3.37E-07
BATCH-1021	11/2/31	150	15.6	0.24	2.71E-06	1.36E+02	2.87E-15	4.85E-09	7.79E-15	7.43E-56	5.00E-02	6.01E-01	1.74E-12	2.60E-02	2.37E+01	0.00E+00	1.75E-07	2.03E+00	9.39E-07
BATCH-1022	11/12/31	21	2.1	0.24	3.75E+01	0.00E+00	4.02E-11	5.96E-09	1.91E-11	7.76E-60	1.00E-03	2.14E-01	1.34E-11	6.71E-04	1.02E+00	0.00E+00	2.00E+00	0.00E+00	7.24E-07
BATCH-1023	11/14/31	21	2.2	0.24	3.98E+01	0.00E+00	3.08E-11	4.66E-09	1.46E-11	2.62E-55	2.00E-03	1.87E-01	1.06E-11	7.25E-04	1.03E+00	0.00E+00	2.00E+00	0.00E+00	7.19E-07
BATCH-1024	11/17/31	21	2.2	0.24	4.01E+01	0.00E+00	3.10E-11	4.70E-09	1.47E-11	4.32E-50	2.00E-03	1.79E-01	1.09E-11	7.30E-04	1.02E+00	0.00E+00	2.02E+00	0.00E+00	7.39E-07
BATCH-1025	11/18/31	61	6.3	0.24	1.51E+02	0.00E+00	8.95E-13	1.96E-09	8.32E-13	5.08E-55	1.20E-02	7.24E-01	8.97E-12	3.00E-03	3.65E+00	0.00E+00	7.39E+00	0.00E+00	3.06E-06
BATCH-1026	11/19/31	122	12.8	0.24	1.66E-09	1.38E+02	1.02E-14	2.02E-10	2.73E-14	9.97E-60	6.70E-02	8.88E-01	5.43E-13	2.60E-02	1.31E+01	0.00E+00	9.20E-11	2.48E+00	2.74E-07
BATCH-1027	11/24/31	173	18.1	0.24	6.00E-03	1.95E+02	2.10E-14	2.87E-10	4.18E-14	1.28E-63	9.50E-02	1.26E+00	7.70E-13	3.70E-02	1.85E+01	0.00E+00	3.19E-04	3.51E+00	3.88E-07
BATCH-1028	12/2/31	122	12.7	0.24	1.61E-09	1.37E+02	1.01E-14	2.04E-10	2.72E-14	4.41E-59	6.70E-02	8.82E-01	5.40E-13	2.60E-02	1.30E+01	0.00E+00	1.04E-10	2.47E+00	2.73E-07

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-980	2/16/31	189	19.7	0.24	1.39E-11	6.57E+01	1.67E+00	0.00E+00	0.00E+00	1.13E-04	1.41E+01	8.01E-06	1.12E-09	9.21E-08	2.30E-02	2.97E-10	3.23E+03	0.00E+00	8.57E-01
BATCH-981	3/1/31	189	19.7	0.24	1.39E-11	6.57E+01	1.67E+00	0.00E+00	0.00E+00	1.12E-04	1.41E+01	8.01E-06	1.12E-09	9.20E-08	2.30E-02	2.97E-10	3.23E+03	0.00E+00	8.57E-01
BATCH-982	3/8/31	189	19.7	0.24	1.39E-11	6.56E+01	1.67E+00	0.00E+00	0.00E+00	1.12E-04	1.41E+01	8.00E-06	1.12E-09	9.20E-08	2.30E-02	2.97E-10	3.23E+03	0.00E+00	8.56E-01
BATCH-983	3/21/31	21	2.2	0.24	8.35E-14	2.81E+00	1.79E-01	0.00E+00	0.00E+00	1.37E-05	5.57E-01	1.56E-07	1.58E-12	9.81E-13	3.00E-03	7.03E-13	3.58E+02	0.00E+00	8.90E-02
BATCH-984	3/23/31	127	13.2	0.24	9.33E-12	4.40E+01	1.12E+00	0.00E+00	0.00E+00	7.56E-05	9.44E+00	5.37E-06	7.48E-10	6.17E-08	1.70E-02	1.99E-10	2.17E+03	0.00E+00	5.76E-01
BATCH-985	3/28/31	141	14.7	0.24	1.04E-11	4.89E+01	1.25E+00	0.00E+00	0.00E+00	8.38E-05	1.05E+01	5.96E-06	8.31E-10	6.85E-08	1.70E-02	2.21E-10	2.41E+03	0.00E+00	6.38E-01
BATCH-986	4/6/31	148	15.4	0.24	1.96E-12	6.50E+01	3.03E+00	0.00E+00	0.00E+00	2.00E-04	1.24E+01	4.81E-06	1.81E-10	1.32E-08	7.40E-02	4.17E-11	2.52E+03	0.00E+00	2.58E+00
BATCH-987	4/12/31	146	15.2	0.24	1.61E-14	6.73E+01	3.38E+00	0.00E+00	0.00E+00	2.00E-04	1.26E+01	4.45E-06	2.96E-11	3.53E-10	8.50E-02	1.53E-13	2.50E+03	0.00E+00	2.97E+00
BATCH-988	4/21/31	166	17.3	0.24	1.02E-14	7.64E+01	3.83E+00	0.00E+00	0.00E+00	4.00E-04	1.43E+01	5.05E-06	3.30E-11	3.47E-10	9.60E-02	1.32E-16	2.83E+03	0.00E+00	3.37E+00
BATCH-989	4/27/31	146	15.2	0.24	1.61E-14	6.73E+01	3.37E+00	0.00E+00	0.00E+00	2.00E-04	1.26E+01	4.45E-06	2.96E-11	3.53E-10	8.50E-02	1.53E-13	2.49E+03	0.00E+00	2.97E+00
BATCH-990	5/9/31	98	10.2	0.24	1.31E-14	4.51E+01	2.26E+00	0.00E+00	0.00E+00	1.80E-04	8.43E+00	2.98E-06	2.00E-11	2.52E-10	5.70E-02	1.52E-13	1.67E+03	0.00E+00	1.99E+00
BATCH-991	5/13/31	109	11.4	0.24	1.38E-14	5.02E+01	2.51E+00	0.00E+00	0.00E+00	2.00E-04	9.36E+00	3.32E-06	2.22E-11	2.75E-10	6.30E-02	1.52E-13	1.86E+03	0.00E+00	2.22E+00
BATCH-992	5/19/31	128	13.3	0.24	8.98E-15	5.89E+01	2.95E+00	0.00E+00	0.00E+00	2.00E-04	1.10E+01	3.89E-06	2.55E-11	2.76E-10	7.40E-02	2.44E-14	2.18E+03	0.00E+00	2.60E+00
BATCH-993	5/24/31	133	13.8	0.24	2.52E-12	7.30E+01	3.37E+00	0.00E+00	0.00E+00	4.00E-04	9.32E+00	6.43E-05	4.10E-10	6.40E-09	3.80E-02	2.29E-09	2.27E+03	0.00E+00	3.69E+00
BATCH-994	6/2/31	152	15.9	0.24	3.23E-12	8.54E+01	3.91E+00	0.00E+00	0.00E+00	6.00E-04	1.04E+01	8.19E-05	5.23E-10	8.17E-09	2.94E-02	2.94E-09	2.60E+03	0.00E+00	3.25E+00
BATCH-995	6/7/31	134	14.0	0.24	2.84E-12	7.52E+01	3.44E+00	0.00E+00	0.00E+00	6.00E-04	9.18E+00	7.21E-05	4.60E-10	7.20E-09	3.30E-02	2.59E-09	2.29E+03	0.00E+00	9.55E-01
BATCH-996	6/18/31	110	11.4	0.24	1.24E-12	2.00E+01	1.65E+00	0.00E+00	0.00E+00	1.04E-04	4.71E+00	1.90E-06	6.46E-11	4.33E-09	1.80E-02	1.89E-11	1.87E+03	0.00E+00	5.76E-01
BATCH-997	6/21/31	101	10.5	0.24	1.75E-12	1.63E+01	1.12E+00	0.00E+00	0.00E+00	6.28E-05	3.63E+00	1.65E-06	1.26E-10	9.86E-09	1.20E-02	3.40E-11	1.72E+03	0.00E+00	2.86E+00
BATCH-998	6/30/31	118	12.3	0.24	2.50E-12	6.62E+01	3.03E+00	0.00E+00	0.00E+00	4.00E-04	8.08E+00	6.35E-05	4.05E-10	6.33E-09	2.90E-02	2.28E-09	2.02E+03	0.00E+00	2.90E+00
BATCH-999	7/2/31	120	12.5	0.24	2.53E-12	6.70E+01	3.07E+00	0.00E+00	0.00E+00	4.00E-04	8.18E+00	6.43E-05	4.10E-10	6.42E-09	3.00E-02	2.31E-09	2.04E+03	0.00E+00	3.31E+00
BATCH-1000	7/12/31	137	14.2	0.24	2.90E-12	7.66E+01	3.50E+00	0.00E+00	0.00E+00	6.00E-04	9.34E+00	7.35E-05	4.69E-10	7.33E-09	3.40E-02	2.63E-09	2.33E+03	0.00E+00	2.91E+00
BATCH-1001	7/15/31	120	12.5	0.24	2.55E-12	6.74E+01	3.08E+00	0.00E+00	0.00E+00	4.00E-04	8.22E+00	6.46E-05	4.12E-10	6.45E-09	3.00E-02	2.32E-09	2.05E+03	0.00E+00	4.79E-01
BATCH-1002	7/26/31	60	6.2	0.24	6.22E-13	1.00E+01	8.28E-01	0.00E+00	0.00E+00	5.19E-05	2.36E+00	9.51E-07	3.24E-11	2.17E-09	9.00E-03	9.47E-12	1.02E+03	0.00E+00	3.13E-01
BATCH-1003	7/27/31	60	6.2	0.24	9.50E-13	8.87E+00	6.11E-01	0.00E+00	0.00E+00	3.41E-05	1.97E+00	8.96E-07	6.82E-11	5.36E-09	7.00E-03	1.85E-11	1.02E+02	0.00E+00	1.40E+00
BATCH-1004	8/2/31	108	11.2	0.24	1.08E-12	5.30E+01	1.44E+00	0.00E+00	0.00E+00	2.00E-04	7.66E+00	3.49E-05	1.75E-10	2.74E-09	1.90E-02	9.82E-10	1.84E+03	0.00E+00	3.44E-01
BATCH-1005	8/3/31	118	12.3	0.24	2.06E-15	5.05E+01	2.77E-01	0.00E+00	0.00E+00	1.22E-04	8.63E+00	1.56E-05	2.97E-13	9.04E-12	1.40E-02	1.61E-12	2.01E+03	0.00E+00	3.93E-01
BATCH-1006	8/13/31	135	14.0	0.24	2.09E-15	5.77E+01	3.16E-01	0.00E+00	0.00E+00	1.40E-04	9.87E+00	1.79E-05	2.99E-13	9.69E-12	1.60E-02	1.61E-12	2.30E+03	0.00E+00	3.46E-01
BATCH-1007	8/15/31	119	12.4	0.24	2.05E-15	5.09E+01	2.79E-01	0.00E+00	0.00E+00	1.23E-04	8.69E+00	1.57E-05	2.97E-13	9.06E-12	1.40E-02	1.61E-12	2.03E+03	0.00E+00	1.34E-01
BATCH-1008	8/27/31	21	2.2	0.24	1.75E-13	2.82E+00	2.33E-01	0.00E+00	0.00E+00	1.46E-05	6.62E-01	2.67E-07	9.09E-12	6.09E-10	3.00E-03	2.66E-12	3.63E+02	0.00E+00	8.20E-02
BATCH-1009	8/28/31	20	2.1	0.24	2.50E-13	2.34E+00	1.61E-01	0.00E+00	0.00E+00	8.97E-06	5.20E-01	2.36E-07	1.80E-11	1.41E-09	2.00E-03	4.86E-12	3.50E+02	0.00E+00	7.37E-01
BATCH-1010	8/30/31	122	12.8	0.24	1.67E-12	2.22E+01	1.29E+00	0.00E+00	0.00E+00	9.46E-05	3.79E+00	9.18E-06	1.61E-10	9.81E-09	1.50E-02	3.03E-10	2.09E+03	0.00E+00	6.49E-01
BATCH-1011	8/30/31	120	12.5	0.24	1.28E-12	2.16E+01	1.17E+00	0.00E+00	0.00E+00	8.99E-05	3.62E+00	9.33E-06	1.28E-10	7.33E-09	1.30E-02	2.77E-10	2.04E+03	0.00E+00	6.41E-01
BATCH-1012	9/12/31	118	12.3	0.24	1.31E-12	2.15E+01	1.16E+00	0.00E+00	0.00E+00	9.18E-05	3.53E+00	1.02E-05	1.33E-10	7.37E-09	1.20E-02	3.09E-10	2.02E+03	0.00E+00	6.41E-01
BATCH-1013	9/12/31	117	12.2	0.24	2.83E-16	5.00E+01	2.72E-01	0.00E+00	0.00E+00	1.21E-04	8.55E+00	1.54E-05	1.04E-14	4.52E-12	1.40E-02	2.38E-15	1.99E+03	0.00E+00	3.39E-01
BATCH-1014	9/24/31	186	19.4	0.24	4.81E-16	7.98E+01	4.34E-01	0.00E+00	0.00E+00	1.93E-04	1.36E+01	2.46E-05	1.80E-14	7.32E-12	2.20E-02	2.47E-15	3.18E+03	0.00E+00	5.41E-01
BATCH-1015	9/24/31	186	19.4	0.24	4.91E-16	7.97E+01	4.34E-01	0.00E+00	0.00E+00	1.93E-04	1.36E+01	2.46E-05	1.94E-14	7.43E-12	2.20E-02	2.80E-15	3.17E+03	0.00E+00	5.40E-01
BATCH-1016	10/14/31	59	6.2	0.24	7.40E-13	9.86E+00	5.75E-01	0.00E+00	0.00E+00	4.20E-05	1.68E+00	4.08E-06	7.16E-11	4.36E-09	7.00E-03	1.35E-10	1.01E+03	0.00E+00	3.27E-01
BATCH-1017	10/14/31	60	6.3	0.24	5.90E-13	9.98E+00	5.39E-01	0.00E+00	0.00E+00	4.14E-05	1.67E+00	4.30E-06	5.89E-11	3.38E-09	6.00E-03	1.28E-10	1.03E+03	0.00E+00	2.99E-01
BATCH-1018	10/20/31	118	12.3	0.24	3.58E-13	2.30E+01	1.18E+00	0.00E+00	0.00E+00	1.04E-04	3.54E+00	1.21E-05	6.00E-11	9.28E-10	1.30E-02	3.25E-10	2.02E+03	0.00E+00	6.82E-01
BATCH-1019	10/20/31	60	6.3	0.24	6.11E-13	1.00E+01	5.40E-01	0.00E+00	0.00E+00	4.29E-05	1.65E+00	4.75E-06	6.19E-11	3.45E-09	6.00E-03	1.44E-10	1.03E+03	0.00E+00	3.00E-01
BATCH-1020	10/27/31	151	15.7	0.24	4.55E-16	1.11E+02	1.39E-01	0.00E+00	0.00E+00	1.00E-03	1.19E+01	1.81E-04	2.76E-13	7.61E-14	1.40E-02	3.44E-11	2.57E+03	0.00E+00	8.21E-01
BATCH-1021	11/2/31	150	15.6	0.24	3.82E-16	7.46E+01	3.03E-01	0.00E+00	0.00E+00	4.00E-04	1.12E+01	5.54E-05	7.12E-14	4.54E-12	1.70E-02	7.61E-12	2.56E+03	0.00E+00	5.21E-01
BATCH-1022	11/12/31	21	2.1	0.24	1.98E-13	2.64E+00	1.54E-01	0.00E+00	0.00E+00	1.13E-05	4.51E+01	1.09E-06	1.92E-11	1.17E-09	2.00E-03	3.61E-11	3.52E+02	0.00E+00	8.80E-02
BATCH-1023	11/14/31	21	2.2	0.24	1.59E-13	2.69E+00	1.45E-01	0.00E+00	0.00E+00	1.12E-05	4.45E+01	1.16E-06	1.59E-11	9.12E-10	2.00E-03	3.45E-11	3.57E+02	0.00E+00	8.10E-02
BATCH-1024	11/17/31	21	2.2	0.24	1.65E-13	2.71E+00	1.46E-01	0.00E+00	0.00E+00	1.16E-05	4.51E+01	1.28E-06	1.67E-11	9.29E-10	2.00E-03	3.89E-11	3.57E+02	0.00E+00	8.10E-02
BATCH-1025	11/18/31	61	6.3	0.24	1.69E-13	1.08E+01	5.56E-01	0.00E+00	0.00E+00	4.92E-05	1.67E+00	5.69E-06	2.83E-11	4.38E-10	6.00E-03	1.53E-10	1.04E+03	0.00E+00	3.22E-01
BATCH-1026	11/19/31	122	12.8	0.24	3.70E-16	9.03E+01	1.13E-01	0.00E+00	0.00E+00	8.00E-04	9.71E+00	1.47E-04	2.24E-13	5.90E-14	1.10E-02	2.80E-11	2.09E+03	0.00E+00	6.67E-01
BATCH-1027	11/24/31	173	18.1	0.24	5.56E-16	1.28E+02	1.60E-01	0.00E+00	0.00E+00	1.20E-03	1.37E+01	2.08E-04	3.20E-13	2.76E-13	1.60E-02	3.96E-11	2.96E+03	0.00E+00	9.44E-01
BATCH-1028	12/2/31	122	12.7	0.24	3.68E-16	8.98E+01	1.13E-01	0.00E+00	0.00E+00	8.00E-04	9.65E+00	1.46E-04	2.22E-13	6.13E-14	1.10E-02	2.78E-11	2.98E+03	0.00E+00	6.63E-01

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUND)	OH-	Pb+2	PO4-3	Se+6	SI+4	SO4-2	Sr+2	Tc+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-980	2/16/31	189	19.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	6.59E+01	1.31E-11	3.41E+00	5.88E+01	2.10E-02	2.90E-12	0.00E+00	2.58E-04	4.06E-08	3.00E-03
BATCH-981	3/1/31	189	19.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	6.59E+01	1.31E-11	3.40E+00	5.88E+01	2.10E-02	2.90E-12	0.00E+00	2.58E-04	4.05E-08	3.00E-03
BATCH-982	3/8/31	189	19.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	6.58E+01	1.31E-11	3.40E+00	5.87E+01	2.10E-02	2.89E-12	0.00E+00	2.57E-04	4.05E-08	3.00E-03
BATCH-983	3/21/31	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	5.26E+00	2.11E-15	3.65E+00	2.21E+00	6.00E-03	7.30E-14	0.00E+00	1.00E-03	8.45E-11	8.40E-04
BATCH-984	3/23/31	127	13.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.42E+01	8.75E-12	2.28E+00	3.94E+01	1.40E-02	1.94E-12	0.00E+00	1.74E-04	2.72E-08	2.00E-03
BATCH-985	3/28/31	141	14.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.90E+01	9.72E-12	2.53E+00	4.38E+01	1.60E-02	2.16E-12	0.00E+00	1.92E-04	3.02E-08	2.00E-03
BATCH-986	4/6/31	148	15.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	5.72E+01	1.83E-12	4.79E+00	4.97E+01	5.30E-02	4.07E-13	0.00E+00	2.00E-02	5.85E-09	1.10E-02
BATCH-987	4/12/31	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-02	5.79E+01	6.71E-15	5.21E+00	5.01E+01	6.00E-02	1.49E-15	0.00E+00	2.40E-02	2.18E-10	1.30E-02
BATCH-988	4/21/31	166	17.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-02	6.57E+01	3.95E-19	5.90E+00	5.68E+01	6.80E-02	1.37E-17	0.00E+00	2.80E-02	2.24E-10	1.50E-02
BATCH-989	4/27/31	146	15.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-02	5.78E+01	6.70E-15	5.20E+00	5.00E+01	6.00E-02	1.49E-15	0.00E+00	2.40E-02	2.18E-10	1.30E-02
BATCH-990	5/9/31	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-02	3.88E+01	6.69E-15	3.49E+00	3.36E+01	4.00E-02	1.48E-15	0.00E+00	1.60E-02	1.53E-10	9.00E-03
BATCH-991	5/13/31	109	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-02	4.31E+01	6.68E-15	3.88E+00	3.73E+01	4.50E-02	1.48E-15	0.00E+00	1.80E-02	1.68E-10	1.00E-02
BATCH-992	5/19/31	128	13.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-02	5.07E+01	1.07E-15	4.56E+00	4.38E+01	5.30E-02	2.37E-16	0.00E+00	2.10E-02	1.76E-10	1.20E-02
BATCH-993	5/24/31	133	13.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-02	7.83E+01	2.22E-12	4.20E+00	4.14E+01	4.00E-02	2.81E-10	0.00E+00	2.90E-02	1.53E-08	2.30E-02
BATCH-994	6/2/31	152	15.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	9.34E+01	2.84E-12	4.75E+00	4.70E+01	4.50E-02	3.60E-10	0.00E+00	3.40E-02	1.96E-08	2.80E-02
BATCH-995	6/7/31	134	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	8.22E+01	2.51E-12	4.18E+00	4.14E+01	3.90E-02	3.17E-10	0.00E+00	3.00E-02	1.72E-08	2.50E-02
BATCH-996	6/18/31	110	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.73E+01	6.27E-13	2.35E+01	1.55E+01	5.10E-02	6.51E-13	0.00E+00	2.00E-03	2.00E-09	3.00E-03
BATCH-997	6/21/31	101	10.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	3.38E+01	1.40E-12	3.03E+01	1.40E+01	2.60E-02	5.38E-13	0.00E+00	2.00E-03	4.38E-09	2.00E-03
BATCH-998	6/30/31	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	7.24E+01	2.20E-12	3.68E+00	3.64E+01	3.50E-02	2.79E-10	0.00E+00	2.60E-02	1.52E-08	2.20E-02
BATCH-999	7/2/31	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	7.33E+01	2.23E-12	3.73E+00	3.69E+01	3.50E-02	2.83E-10	0.00E+00	2.60E-02	1.54E-08	2.20E-02
BATCH-1000	7/12/31	137	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	8.38E+01	2.55E-12	4.26E+00	4.22E+01	4.00E-02	3.23E-10	0.00E+00	3.00E-02	1.75E-08	2.50E-02
BATCH-1001	7/15/31	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-02	7.37E+01	2.25E-12	3.75E+00	3.71E+01	3.50E-02	2.84E-10	0.00E+00	2.70E-02	1.54E-08	2.20E-02
BATCH-1002	7/26/31	60	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.87E+01	3.14E-13	1.18E+01	7.78E+00	2.60E-02	3.26E-13	0.00E+00	1.00E-03	1.00E-09	2.00E-03
BATCH-1003	7/27/31	60	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.84E+01	7.62E-13	1.64E+01	7.61E+00	1.40E-02	2.92E-13	0.00E+00	9.72E-04	2.38E-09	1.00E-03
BATCH-1004	8/2/31	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	5.68E+01	9.52E-13	2.73E+00	3.38E+01	1.60E-02	1.21E-10	0.00E+00	1.20E-02	6.58E-09	1.10E-02
BATCH-1005	8/3/31	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.29E+01	1.57E-15	2.35E+00	3.74E+01	2.00E-03	1.98E-13	0.00E+00	2.00E-03	8.61E-11	4.00E-03
BATCH-1006	8/13/31	135	14.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	6.05E+01	1.56E-15	2.69E+00	4.27E+01	2.00E-03	1.98E-13	0.00E+00	2.00E-03	9.69E-11	4.00E-03
BATCH-1007	8/15/31	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.33E+01	1.56E-15	2.37E+00	3.76E+01	2.00E-03	1.97E-13	0.00E+00	2.00E-03	8.66E-11	4.00E-03
BATCH-1008	8/27/31	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.24E+00	8.82E-14	3.31E+00	2.18E+00	7.00E-03	9.15E-14	0.00E+00	2.88E-04	2.81E-10	4.48E-04
BATCH-1009	8/28/31	20	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.97E-04	4.84E+00	2.01E-13	4.33E+00	2.00E+00	4.00E-03	7.69E-14	0.00E+00	2.56E-04	6.27E-10	2.85E-04
BATCH-1010	8/30/31	122	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	4.36E+01	1.55E-12	4.41E+01	1.74E+01	1.20E-02	3.39E-11	0.00E+00	7.00E-03	5.82E-09	4.00E-03
BATCH-1011	8/30/31	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	4.46E+01	1.18E-12	4.57E+01	1.68E+01	1.00E-02	3.16E-11	0.00E+00	7.00E-03	4.63E-09	4.00E-03
BATCH-1012	9/12/31	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	4.48E+01	1.21E-12	4.58E+01	1.65E+01	1.00E-02	3.55E-11	0.00E+00	7.00E-03	4.82E-09	4.00E-03
BATCH-1013	9/12/31	117	12.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	5.24E+01	4.06E-18	2.33E+00	3.70E+01	2.00E-03	2.70E-16	0.00E+00	2.00E-03	7.47E-11	4.00E-03
BATCH-1014	9/24/31	186	19.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	8.36E+01	2.12E-17	3.72E+00	5.90E+01	2.00E-03	2.25E-16	0.00E+00	3.00E-03	1.19E-10	6.00E-03
BATCH-1015	9/24/31	186	19.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	8.35E+01	3.88E-17	3.71E+00	5.89E+01	2.00E-03	2.21E-16	0.00E+00	3.00E-03	1.19E-10	6.00E-03
BATCH-1016	10/14/31	59	6.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.94E+01	6.86E-13	1.96E+01	7.74E+00	5.00E-03	1.51E-11	0.00E+00	3.00E-03	2.58E-09	2.00E-03
BATCH-1017	10/14/31	60	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.06E+01	5.46E-13	2.11E+01	7.76E+00	5.00E-03	1.46E-11	0.00E+00	3.00E-03	2.13E-09	2.00E-03
BATCH-1018	10/20/31	118	12.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	4.73E+01	3.15E-13	4.51E+01	1.66E+01	1.00E-02	3.99E-11	0.00E+00	7.00E-03	2.19E-09	5.00E-03
BATCH-1019	10/20/31	60	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.09E+01	5.65E-13	2.14E+01	7.72E+00	5.00E-03	1.66E-11	0.00E+00	3.00E-03	2.25E-09	2.00E-03
BATCH-1020	10/27/31	151	15.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.44E+02	1.25E-17	5.20E+00	3.93E+01	2.00E-03	3.21E-16	0.00E+00	1.30E-02	1.84E-10	3.90E-02
BATCH-1021	11/2/31	150	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	8.43E+01	5.73E-18	3.48E+00	4.57E+01	2.00E-03	2.02E-16	0.00E+00	5.00E-03	1.16E-10	1.20E-02
BATCH-1022	11/12/31	21	2.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.19E+00	1.84E-13	5.25E+00	2.07E+00	1.00E-03	4.03E-12	0.00E+00	8.58E-04	6.92E-10	5.11E-04
BATCH-1023	11/14/31	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.55E+00	1.47E-13	5.69E+00	2.09E+00	1.00E-03	3.93E-12	0.00E+00	8.13E-04	5.76E-10	4.97E-04
BATCH-1024	11/17/31	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	5.64E+00	1.52E-13	5.77E+00	2.08E+00	1.00E-03	4.47E-12	0.00E+00	8.22E-04	6.07E-10	5.15E-04
BATCH-1025	11/18/31	61	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.23E+01	1.49E-13	2.13E+01	7.85E+00	5.00E-03	1.88E-11	0.00E+00	4.00E-03	1.03E-09	2.00E-03
BATCH-1026	11/19/31	122	12.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	1.17E+02	1.02E-17	4.23E+00	3.20E+01	2.00E-03	2.61E-16	0.00E+00	1.00E-02	1.50E-10	3.20E-02
BATCH-1027	11/24/31	173	18.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.66E+02	4.47E-17	5.98E+00	4.52E+01	3.00E-03	1.03E-15	0.00E+00	1.50E-02	2.12E-10	4.50E-02
BATCH-1028	12/2/31	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	1.16E+02	1.01E-17	4.20E+00	3.18E+01	2.00E-03	2.59E-16	0.00E+00	1.00E-02	1.49E-10	3.10E-02

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H		14-C		59-Ni		60-Co		63-Ni		79-Se		90-Sr		93-Zr		93m-Nb		99-Tc		106-Ru		113m-Cd		125-Sb		126-Sn		129-I	
					Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci		Ci	
Fraction Remaining After Volatization Losses						0.00		0.00		1.00		1.00		1.00		0.90		1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00		0.25
BATCH-1029	12/12/31	173	18.0	0.24	0.00E+00		0.00E+00		7.40E-02		2.00E-03		5.31E+00		2.50E-01		2.79E+02		1.38E-01		1.60E-02		5.13E+00		8.98E-17		4.01E-01		1.34E-04		9.00E-03		8.25E-03
BATCH-1030	12/15/31	173	18.0	0.24	0.00E+00		0.00E+00		7.40E-02		2.00E-03		5.30E+00		2.49E-01		2.79E+02		1.38E-01		1.60E-02		5.12E+00		8.96E-17		4.01E-01		1.33E-04		9.00E-03		8.25E-03
BATCH-1031	12/31/31	21	2.2	0.24	0.00E+00		0.00E+00		5.00E-03		3.39E-04		3.61E-01		1.17E-02		1.06E+02		1.50E-02		2.00E-03		3.85E-01		6.43E-17		3.30E-02		1.34E-05		3.00E-03		5.00E-04
BATCH-1032	1/2/32	109	11.4	0.24	0.00E+00		0.00E+00		1.90E-02		4.82E-04		1.38E+00		6.84E-02		1.26E+02		4.30E-02		4.00E-03		1.49E+00		2.13E-17		1.19E-01		2.91E-05		3.00E-03		2.25E-03
BATCH-1033	1/2/32	62	6.5	0.24	0.00E+00		0.00E+00		2.70E-02		9.11E-04		1.92E+00		8.01E-02		3.54E+02		4.50E-02		5.00E-03		2.20E+00		5.36E-17		1.53E-01		3.09E-05		3.00E-03		2.75E-03
BATCH-1034	1/9/32	121	12.6	0.24	0.00E+00		0.00E+00		2.10E-02		6.02E-04		1.48E+00		7.65E-02		2.10E+02		5.50E-02		5.00E-03		1.81E+00		3.60E-17		1.54E-01		3.38E-05		3.00E-03		2.75E-03
BATCH-1035	1/13/32	50	5.2	0.24	0.00E+00		0.00E+00		2.10E-02		8.59E-04		1.54E+00		6.03E-02		3.83E+02		3.40E-02		3.00E-03		1.91E+00		5.75E-17		1.29E-01		2.23E-05		2.00E-03		2.25E-03
BATCH-1036	1/19/32	50	5.2	0.24	0.00E+00		0.00E+00		2.10E-02		8.59E-04		1.54E+00		6.03E-02		3.83E+02		3.40E-02		3.00E-03		1.91E+00		5.75E-17		1.29E-01		2.23E-05		2.00E-03		2.25E-03
BATCH-1037	1/22/32	61	6.4	0.24	0.00E+00		0.00E+00		2.60E-02		1.00E-03		1.89E+00		7.38E-02		4.70E+02		4.20E-02		4.00E-03		2.34E+00		7.05E-17		1.58E-01		2.73E-05		2.00E-03		2.75E-03
BATCH-1038	1/24/32	38	3.9	0.24	0.00E+00		0.00E+00		1.60E-02		6.47E-04		1.16E+00		4.50E-02		2.89E+02		2.60E-02		2.00E-03		1.44E+00		4.33E-17		9.70E-02		1.68E-05		1.00E-03		1.75E-03
BATCH-1039	1/28/32	60	6.3	0.24	0.00E+00		0.00E+00		1.00E-02		2.43E-04		6.95E-01		3.42E-02		6.34E+01		2.20E-02		2.00E-03		7.52E-01		1.08E-17		6.00E-02		1.47E-05		1.00E-03		1.25E-03
BATCH-1040	1/28/32	38	3.9	0.24	0.00E+00		0.00E+00		1.60E-02		6.49E-04		1.17E+00		4.50E-02		2.90E+02		2.60E-02		2.00E-03		1.44E+00		4.34E-17		9.80E-02		1.68E-05		1.00E-03		1.75E-03
BATCH-1041	2/1/32	56	5.8	0.24	0.00E+00		0.00E+00		9.00E-03		2.50E-04		6.13E-01		3.15E-02		8.70E+01		2.30E-02		2.00E-03		7.50E-01		1.49E-17		6.40E-02		1.40E-05		1.00E-03		1.00E-03
BATCH-1042	2/4/32	38	3.9	0.24	0.00E+00		0.00E+00		1.60E-02		6.48E-04		1.16E+00		4.50E-02		2.89E+02		2.60E-02		2.00E-03		1.44E+00		4.34E-17		9.70E-02		1.68E-05		1.00E-03		1.75E-03
BATCH-1043	2/7/32	159	16.5	0.24	0.00E+00		0.00E+00		2.10E-02		5.62E-04		1.48E+00		6.66E-02		1.64E+02		3.70E-02		4.00E-03		1.55E+00		2.54E-17		1.12E-01		2.68E-05		2.00E-03		2.25E-03
BATCH-1044	2/8/32	53	5.5	0.24	0.00E+00		0.00E+00		2.60E-02		1.00E-03		1.89E+00		5.22E-02		5.17E+02		2.50E-02		3.00E-03		1.62E+00		1.10E-16		1.21E-01		2.11E-05		3.00E-03		2.00E-03
BATCH-1045	2/14/32	157	16.4	0.24	0.00E+00		0.00E+00		1.80E-02		5.38E-04		1.31E+00		5.76E-02		1.76E+02		3.20E-02		3.00E-03		1.42E+00		2.71E-17		1.01E-01		2.29E-05		2.00E-03		2.00E-03
BATCH-1046	2/24/32	21	2.2	0.24	0.00E+00		0.00E+00		3.00E-03		6.42E-05		1.83E-01		9.00E-03		1.67E+01		6.00E-03		5.68E-04		1.99E-01		2.84E-18		1.60E-02		3.52E-06		3.11E-04		2.50E-04
BATCH-1047	2/27/32	18	1.9	0.24	0.00E+00		0.00E+00		2.00E-03		5.89E-05		1.45E-01		7.20E-03		2.05E+01		5.00E-03		4.90E-04		1.77E-01		3.52E-18		1.50E-02		3.31E-06		2.00E-03		2.50E-04
BATCH-1048	2/29/32	157	16.3	0.24	0.00E+00		0.00E+00		1.80E-02		5.37E-04		1.31E+00		5.76E-02		1.76E+02		3.20E-02		3.00E-03		1.42E+00		2.70E-17		1.01E-01		2.29E-05		2.00E-03		2.00E-03
BATCH-1049	3/1/32	141	14.7	0.24	0.00E+00		0.00E+00		1.20E-02		5.04E-04		8.81E-01		3.24E-02		2.23E+02		1.80E-02		2.00E-03		1.03E+00		3.61E-17		7.10E-02		1.22E-05		1.00E-03		1.25E-03
BATCH-1050	3/16/32	52	5.4	0.24	0.00E+00		0.00E+00		6.00E-03		1.65E-04		4.34E-01		1.98E-02		4.81E+01		1.10E-02		1.00E-03		4.57E-01		7.47E-18		3.30E-02		7.88E-06		6.85E-04		7.50E-04
BATCH-1051	3/16/32	96	10.0	0.24	0.00E+00		0.00E+00		5.00E-02		3.00E-03		3.71E+00		7.83E-02		1.07E+03		3.10E-02		5.00E-03		2.40E+00		2.61E-16		1.97E-01		3.45E-05		6.00E-03		3.00E-03
BATCH-1052	3/22/32	51	5.3	0.24	0.00E+00		0.00E+00		5.00E-03		1.55E-04		3.76E-01		1.62E-02		5.07E+01		9.00E-03		9.63E-04		4.08E-01		7.78E-18		2.90E-02		6.59E-06		5.69E-04		5.00E-04
BATCH-1053	3/26/32	96	10.0	0.24	0.00E+00		0.00E+00		5.00E-02		3.00E-03		3.71E+00		7.83E-02		1.07E+03		3.10E-02		5.00E-03		2.39E+00		2.61E-16		1.97E-01		3.44E-05		6.00E-03		3.00E-03
BATCH-1054	3/27/32	30	3.2	0.24	0.00E+00		0.00E+00		2.00E-03		9.58E-05		1.68E-01		6.30E-03		4.24E+01		3.00E-03		3.42E-04		1.96E-01		6.87E-18		1.30E-02		2.32E-06		2.12E-04		2.33E-04
BATCH-1055	3/31/32	50	5.3	0.24	0.00E+00		0.00E+00		5.00E-03		1.54E-04		3.75E-01		1.62E-02		5.06E+01		9.00E-03		9.61E-04		4.07E-01		7.76E-18		2.90E-02		6.57E-06		5.67E-04		5.00E-04
BATCH-1056	4/5/32	18	1.8	0.24	0.00E+00		0.00E+00		1.00E-03		4.01E-05		1.05E-01		4.50E-03		1.17E+01		3.00E-03		2.79E-04		1.11E-01		1.81E-18		8.00E-03		1.91E-06		1.66E-04		1.61E-04
BATCH-1057	4/5/32	75	7.8	0.24	0.00E+00		0.00E+00		4.00E-02		2.00E-03		2.91E+00		6.12E-02		8.41E+02		2.50E-02		4.00E-03		1.88E+00		2.05E-16		1.54E-01		2.70E-05		5.00E-03		2.25E-03
BATCH-1058	4/7/32	17	1.8	0.24	0.00E+00		0.00E+00		1.00E-03		3.69E-05		9.00E-02		3.60E-03		1.21E+01		2.00E-03		2.30E-04		9.70E-02		1.86E-18		7.00E-03		1.57E-06		1.36E-04		1.37E-04
BATCH-1059	4/9/32	11	1.1	0.24	0.00E+00		0.00E+00		5.53E-04		2.28E-05		4.00E-02		1.80E-03		1.01E+01		8.24E-04		8.14E-05		4.70E-02		1.64E-18		3.00E-03		5.53E-07		5.04E-05		5.54E-05
BATCH-1060	4/11/32	17	1.8	0.24	0.00E+00		0.00E+00		1.00E-03		3.68E-05		8.90E-02		3.60E-03		1.21E+01		2.00E-03		2.29E-04		9.70E-02		1.85E-18		7.00E-03		1.57E-06		1.35E-04		1.36E-04
BATCH-1061	4/13/32	75	7.8	0.24	0.00E+00		0.00E+00		3.90E-02		2.00E-03		2.91E+00		6.12E-02		8.40E+02		2.50E-02		4.00E-03		1.88E+00		2.05E-16		1.54E-01		2.70E-05		5.00E-03		2.25E-03
BATCH-1062	4/13/32	95	9.9	0.24	0.00E+00		0.00E+00		5.00E-02		3.00E-03		3.70E+00		7.74E-02		1.07E+03		3.10E-02		5.00E-03		2.39E+00		2.61E-16		1.96E-01		3.44E-05		6.00E-03		3.00E-03
BATCH-1063	4/20/32	91	9.5	0.24	0.00E+00		0.00E+00		7.70E-02		4.00E-03		5.69E+00		1.04E-01		1.63E+03		3.30E-02		7.00E-03		3.14E+00		4.21E-16		2.78E-01		5.17E-05		9.00E-03		3.75E-03
BATCH-1064	4/23/32	112	11.7	0.24	0.00E+00		0.00E+00		1.65E-01		9.00E-03		1.22E+01		2.01E-01		2.24E+03		4.90E-02		1.50E-02		5.94E+00		9.30E-16		5.60E-01		1.09E-04		1.70E-02		7.25E-03
BATCH-1065	4/30/32	69	7.2	0.24	0.00E+00		0.00E+00		1.01E-01		5.00E-03		7.47E+00		1.23E-01		1.37E+03		3.00E-02		9.00E-03		3.65E+00		5.71E-16		3.44E-01		6.68E-05		1.00E-02		4.50E-03
BATCH-1066	5/5/32	112	11.7	0.24	0.00E+00		0.00E+00		1.65E-01		9.00E-03		1.21E+01		2.00E-01		2.23E+03		4.90E-02		1.50E-02		5.93E+00		9.29E-16		5.59E-01		1.09E-04		1.70E-02		7.25E-03
BATCH-1067	5/8/32	69	7.2	0.24	0.00E+00		0.00E+00		1.01E-01		5.00E-03		7.46E+00		1.23E-01		1.37E+03		3.00E-02		9.00E-03		3.64E+00		5.71E-16		3.44E-01		6.68E-05		1.00E-02		4.50E-03
BATCH-1068	5/15/32	88	9.1	0.24	0.00E+00		0.00E+00		1.29E-01		7.00E-03		9.51E+00		1.57E-01		1.75E+03		3.90E-02		1.20E-02		4.65E+00		7.28E-16		4.38E-01		8.51E-05		1.30E-02		5.75E-03
BATCH-1069	5/17/32	81	8.5	0.24	0.00E+00		0.00E+00		1.20E-01		6.00E-03		8.84E+00		1.46E-01		1.63E+03		3.60E-02		1.10E-02		4.32E+00		6.76E-16		4.07E-01		7.91E-05		1.20E-02		5.25E-03
BATCH-1070	5/24/32	76	7.9	0.24	0.00E+00		0.00E+00		8.60E-02		4.00E-03		6.32E+00		1.60E-01		1.52E+03		1.75E-01		5.90E-02		7.05E+00		4.80E-16		3.55E-01		7.50E-04		1.00E-02		4.50E-03
BATCH-1071	5/26/32	115	12.0	0.24	0.00E+00		0.00E+00		2.40E-02		1.00E-03		1.75E+00		3.33E-02		5.04E+02		1.20E-02		2.00E-03		1.02E+00		1.28E-16		8.80E-02		1.60E-05		3.00E-03		1.25E-03
BATCH-1072	6/1/32	115	12.0	0.24	0.00E+00		0.00E+00		2.40E-02		1.00E-03		1.75E+00		3.33E-02		5.03E+02		1.20E-02		2.00E-03		1.02E+00		1.28E-16		8.80E-02		1.60E-05		3.00E-03		1.25E-03
BATCH-1073	6/7/32	52	5.4	0.24	0.00E+00		0.00E+00		3.00E-03		1.57E-04		2.01E-01		1.62E-01		1.04E+03		4.21E-01		1.44E-01		5.17E+00		6.50E-18		1.90E-01		2.00E-03		3.00E-03		1.75E-03
BATCH-1074	6/13/32	41	4.2	0.24	0.00E+00		0.00E+00		2.00E-03		1.24E-04		1.59E-01		1.27E-01		8.15E+02		3.30E-01		1.13E-01		4.06E+00		5.19E-18		1.49E-01		2.00E-03		2.00E-03		1.25E-03
BATCH-1075	6/14/32	38	4.0	0.24	0.00E+00		0.00E+00		2.00E-03		1.15E-04		1.48E-01		1.18E-01		7.58E+02		3.07E-01		1.05E-01		3.77E+00		4.85E-18		1.38E-01		1.00E-03		2.00E-03		1.25E-03
BATCH-1076	6/17/32	40	4.2	0.24	0.00E+00		0.00E+00		2.00E-03		1.21E-04		1.56E-01		1.26E-01		8.07E+02		3.28E-01		1.12E-01		4.02E+00		5.01E-18		1.47E-01		2.00E-03		2.00E-03		1.25E-03
BATCH-1077	6/18/32	52	5.4	0.24	0.00E+00		0.00E+00		1.00E-02		4.96E-04		7.09E-01		1.35E-02		2.04E+02		5.00E-03		9.18E-04		4.12E-01		5.17E-17		3.60E-02		6.48E-06		1.00E-03		5.00E-04

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1029	12/12/31	173	18.0	0.24	1.48E-08	5.19E+02	2.05E+00	2.00E-03	6.30E-02	4.00E-03	2.15E-06	6.89E-08	4.20E-04	1.14E-04	3.97E-05	1.94E-04	4.00E-03	1.90E-02	2.20E-02
BATCH-1030	12/15/31	173	18.0	0.24	1.47E-08	5.18E+02	2.05E+00	2.00E-03	6.30E-02	4.00E-03	2.14E-06	6.88E-08	4.19E-04	1.14E-04	3.96E-05	1.93E-04	4.00E-03	1.90E-02	2.20E-02
BATCH-1031	12/31/31	21	2.2	0.24	1.18E-09	6.40E+01	4.58E+00	3.21E-04	1.70E-02	7.11E-04	2.67E-07	1.42E-07	2.78E-05	7.26E-06	3.49E-06	1.46E-05	4.10E-04	2.00E-03	7.52E-04
BATCH-1032	1/2/32	109	11.4	0.24	3.93E-09	3.27E+02	9.68E-01	3.61E-04	1.50E-02	7.63E-04	7.41E-07	3.05E-08	9.13E-05	2.68E-05	1.06E-05	4.79E-05	8.55E-04	5.00E-03	5.00E-03
BATCH-1033	1/2/32	62	6.5	0.24	4.49E-09	1.87E+02	4.98E-01	3.61E-04	1.30E-02	8.25E-04	1.04E-06	1.60E-08	1.16E-04	2.97E-05	1.06E-05	5.39E-05	6.87E-04	4.00E-03	3.00E-03
BATCH-1034	1/9/32	121	12.6	0.24	5.82E-09	3.62E+02	1.64E+00	3.61E-04	1.50E-02	7.52E-04	1.04E-06	5.07E-08	8.73E-05	2.45E-05	1.17E-05	4.77E-05	8.29E-04	5.00E-03	3.00E-03
BATCH-1035	1/13/32	50	5.2	0.24	3.87E-09	1.50E+02	3.09E-01	2.27E-04	8.00E-03	5.48E-04	9.39E-07	9.69E-09	8.51E-05	1.94E-05	7.09E-06	3.71E-05	3.27E-04	2.00E-03	6.48E-04
BATCH-1036	1/19/32	50	5.2	0.24	3.87E-09	1.50E+02	3.09E-01	2.27E-04	8.00E-03	5.48E-04	9.39E-07	9.69E-09	8.51E-05	1.94E-05	7.09E-06	3.71E-05	3.27E-04	2.00E-03	6.47E-04
BATCH-1037	1/22/32	61	6.4	0.24	4.74E-09	1.83E+02	3.78E-01	2.77E-04	9.00E-03	6.71E-04	1.15E-06	1.19E-08	1.04E-04	2.38E-05	8.68E-06	4.54E-05	3.99E-04	2.00E-03	7.82E-04
BATCH-1038	1/24/32	38	3.9	0.24	2.91E-09	1.13E+02	2.32E-01	1.70E-04	6.00E-03	4.12E-04	7.08E-07	7.29E-09	6.41E-05	1.46E-05	5.34E-06	2.79E-05	2.46E-04	1.00E-03	4.82E-04
BATCH-1039	1/28/32	60	6.3	0.24	1.98E-09	1.80E+02	4.88E-01	1.82E-04	7.00E-03	3.85E-04	3.74E-07	1.54E-08	4.60E-05	1.35E-05	5.35E-06	2.41E-05	4.31E-04	2.00E-03	2.00E-03
BATCH-1040	1/28/32	38	3.9	0.24	2.92E-09	1.13E+02	2.33E-01	1.71E-04	6.00E-03	4.13E-04	7.09E-07	7.30E-09	6.42E-05	1.46E-05	5.35E-06	2.80E-05	2.46E-04	1.00E-03	4.81E-04
BATCH-1041	2/1/32	56	5.8	0.24	2.41E-09	1.66E+02	6.79E-01	1.50E-04	6.00E-03	3.12E-04	4.32E-07	2.10E-08	3.62E-05	1.02E-05	4.84E-06	1.98E-05	3.44E-04	2.00E-03	1.00E-03
BATCH-1042	2/4/32	38	3.9	0.24	2.92E-09	1.13E+02	2.32E-01	1.71E-04	6.00E-03	4.13E-04	7.08E-07	7.30E-09	6.41E-05	1.46E-05	5.34E-06	2.80E-05	2.46E-04	1.00E-03	4.81E-04
BATCH-1043	2/7/32	159	16.5	0.24	3.18E-09	4.75E+02	4.88E-01	3.49E-04	1.40E-02	7.65E-04	6.90E-07	1.59E-08	9.86E-05	2.79E-05	9.81E-06	6.13E-05	4.56E-04	3.00E-03	5.00E-03
BATCH-1044	2/8/32	53	5.5	0.24	2.63E-09	1.59E+02	2.58E+00	5.21E-04	1.40E-02	1.00E-03	1.28E-06	7.88E-08	1.49E-04	3.58E-05	6.41E-06	4.11E-05	3.00E-03	3.00E-03	1.80E-02
BATCH-1045	2/14/32	157	16.4	0.24	2.90E-09	4.71E+02	4.03E-01	2.90E-04	1.10E-02	6.42E-04	6.44E-07	1.31E-08	8.49E-05	2.33E-05	8.24E-06	4.11E-05	6.22E-04	3.00E-03	3.00E-03
BATCH-1046	2/24/32	21	2.2	0.24	2.90E-09	4.71E+02	4.03E-01	2.90E-04	1.10E-02	6.42E-04	6.44E-07	1.31E-08	8.49E-05	2.33E-05	8.24E-06	4.11E-05	6.22E-04	3.00E-03	3.00E-03
BATCH-1047	2/27/32	18	1.9	0.24	5.23E-10	6.18E+01	1.29E-01	4.80E-05	2.00E-03	1.02E-04	9.86E-08	4.06E-09	1.22E-05	3.56E-06	1.41E-06	6.37E-06	1.14E-04	6.29E-04	6.04E-04
BATCH-1048	2/29/32	157	16.3	0.24	5.69E-10	5.49E+01	1.60E-01	3.53E-05	1.00E-03	7.36E-05	1.02E-07	4.96E-09	8.54E-06	2.40E-06	1.14E-06	8.21E-06	4.66E-06	8.11E-05	4.48E-04
BATCH-1049	3/1/32	141	14.7	0.24	2.89E-09	4.70E+02	4.02E-01	2.89E-04	1.10E-02	6.40E-04	6.43E-07	1.30E-08	8.46E-05	2.33E-05	8.21E-06	4.09E-05	6.20E-04	3.00E-03	3.00E-03
BATCH-1050	3/16/32	52	5.4	0.24	2.04E-09	4.23E+02	3.59E-01	1.49E-04	5.00E-03	3.66E-04	5.47E-07	1.11E-08	5.22E-05	1.21E-05	3.86E-06	2.25E-05	2.30E-04	1.00E-03	1.00E-03
BATCH-1051	3/16/32	96	10.0	0.24	9.35E-10	1.56E+02	1.44E-01	1.03E-04	4.00E-03	2.25E-04	2.03E-07	4.66E-09	2.90E-05	8.22E-06	2.89E-06	1.43E-05	1.39E-04	9.65E-04	5.50E-02
BATCH-1052	3/22/32	51	5.3	0.24	8.33E-10	1.52E+02	1.16E-01	8.32E-05	3.00E-03	1.84E-04	1.85E-07	3.75E-09	2.44E-05	6.70E-06	2.37E-06	1.18E-05	1.79E-04	9.64E-04	5.50E-02
BATCH-1053	3/26/32	96	10.0	0.24	2.81E-09	2.87E+02	7.61E+00	1.00E-03	3.40E-02	3.00E-03	2.68E-06	2.31E-07	3.44E-04	8.42E-05	1.01E-05	1.39E-04	9.64E-04	5.00E-03	3.38E-04
BATCH-1054	3/27/32	30	3.2	0.24	3.87E-10	9.12E+01	6.80E-02	2.84E-05	9.12E-04	6.96E-05	1.04E-07	2.10E-09	9.94E-06	2.30E-06	7.34E-07	4.28E-06	3.63E-05	2.00E-04	3.38E-04
BATCH-1055	3/31/32	50	5.3	0.24	8.31E-10	1.51E+02	1.15E-01	8.30E-05	3.00E-03	1.84E-04	1.85E-07	3.74E-09	2.43E-05	6.69E-06	2.36E-06	1.18E-05	1.78E-04	9.85E-04	9.78E-04
BATCH-1056	4/5/32	18	1.8	0.24	2.27E-10	5.30E+01	3.50E-02	2.49E-05	9.72E-04	5.46E-05	4.93E-08	1.13E-09	7.04E-06	1.99E-06	7.00E-07	3.47E-06	5.59E-05	3.09E-04	3.23E-04
BATCH-1057	4/5/32	75	7.8	0.24	2.20E-09	2.25E+02	5.96E+00	1.00E-03	2.60E-02	3.00E-03	2.10E-06	1.81E-07	2.69E-04	6.60E-05	7.90E-06	1.09E-04	7.56E-04	4.00E-03	4.30E-02
BATCH-1058	4/7/32	17	1.8	0.24	1.99E-10	5.16E+01	2.80E-02	1.99E-05	7.63E-04	4.40E-05	4.42E-08	8.95E-10	5.82E-06	1.60E-06	5.65E-07	4.27E-05	2.36E-04	2.34E-04	2.34E-04
BATCH-1059	4/9/32	11	1.1	0.24	9.22E-11	3.30E+01	1.60E-02	6.76E-06	2.17E-04	1.66E-05	2.48E-08	5.01E-10	2.37E-06	5.47E-07	1.75E-07	1.02E-06	8.64E-06	4.77E-05	8.06E-05
BATCH-1060	4/11/32	17	1.8	0.24	1.98E-10	5.15E+01	2.80E-02	1.98E-05	7.60E-04	4.38E-05	4.40E-08	8.91E-10	5.80E-06	1.59E-06	5.63E-07	2.81E-06	4.25E-05	2.35E-04	2.33E-04
BATCH-1061	4/13/32	75	7.8	0.24	2.20E-09	2.25E+02	5.96E+00	1.00E-03	2.60E-02	3.00E-03	2.10E-06	1.81E-07	2.69E-04	6.59E-05	7.89E-06	1.09E-04	7.55E-04	4.00E-03	4.30E-02
BATCH-1062	4/13/32	95	9.9	0.24	2.80E-09	2.86E+02	7.59E+00	1.00E-03	3.40E-02	3.00E-03	2.67E-06	2.31E-07	3.43E-04	8.40E-05	1.01E-05	1.39E-04	9.62E-04	5.00E-03	5.50E-02
BATCH-1063	4/20/32	91	9.5	0.24	4.16E-09	2.72E+02	1.06E+01	1.00E-03	4.20E-02	3.00E-03	3.24E-06	3.21E-07	4.94E-04	1.13E-04	1.01E-05	1.86E-04	1.00E-03	6.00E-03	4.20E-02
BATCH-1064	4/23/32	112	11.7	0.24	8.67E-09	3.36E+02	2.10E+01	2.00E-03	7.50E-02	5.00E-03	5.64E-06	6.38E-07	1.00E-03	2.16E-04	1.37E-05	3.57E-04	2.00E-03	1.00E-02	2.90E-02
BATCH-1065	4/30/32	69	7.2	0.24	5.32E-09	2.06E+02	1.29E+01	1.00E-03	4.60E-02	3.00E-03	3.46E-06	3.92E-07	6.19E-04	1.33E-04	8.43E-06	2.20E-04	1.00E-03	6.00E-03	1.80E-02
BATCH-1066	5/5/32	112	11.7	0.24	8.66E-09	3.35E+02	2.10E+01	2.00E-03	7.50E-02	5.00E-03	5.63E-06	6.37E-07	1.00E-03	2.16E-04	1.37E-05	3.57E-04	2.00E-03	1.00E-02	2.90E-02
BATCH-1067	5/8/32	69	7.2	0.24	5.32E-09	2.06E+02	1.29E+01	1.00E-03	4.60E-02	3.00E-03	3.46E-06	3.91E-07	6.18E-04	1.33E-04	8.42E-06	2.19E-04	1.00E-03	6.00E-03	1.80E-02
BATCH-1068	5/15/32	88	9.1	0.24	6.78E-09	2.63E+02	1.64E+01	2.00E-03	5.80E-02	4.00E-03	4.41E-06	4.99E-07	7.88E-04	1.69E-04	1.07E-05	2.80E-04	1.00E-03	8.00E-03	2.30E-02
BATCH-1069	5/17/32	81	8.5	0.24	6.30E-09	2.44E+02	1.53E+01	2.00E-03	5.40E-02	4.00E-03	4.10E-06	4.64E-07	7.32E-04	1.57E-04	9.97E-06	2.60E-04	1.00E-03	7.00E-03	2.10E-02
BATCH-1070	5/24/32	76	7.9	0.24	5.64E-09	2.28E+02	1.10E+01	3.00E-03	1.69E-01	1.50E-02	5.24E-06	3.43E-07	5.20E-04	1.12E-04	1.16E-05	1.85E-04	9.54E-04	5.00E-03	1.80E-02
BATCH-1071	5/26/32	115	12.0	0.24	1.30E-09	3.46E+02	3.36E+00	4.90E-04	1.40E-02	1.00E-03	1.08E-06	1.02E-07	1.55E-04	3.63E-05	3.63E-06	5.98E-05	3.74E-04	2.00E-03	1.70E-02
BATCH-1072	6/1/32	115	12.0	0.24	1.29E-09	3.45E+02	3.36E+00	4.89E-04	1.40E-02	1.00E-03	1.08E-06	1.02E-07	1.55E-04	3.62E-05	3.62E-06	5.98E-05	3.73E-04	2.00E-03	1.70E-02
BATCH-1073	6/7/32	52	5.4	0.24	3.33E-09	1.56E+02	6.83E-01	5.00E-03	3.68E-01	3.90E-02	6.57E-06	4.25E-08	5.31E-06	2.43E-06	1.29E-05	4.09E-06	1.40E-04	7.71E-04	1.00E-02
BATCH-1074	6/13/32	41	4.2	0.24	2.61E-09	1.22E+02	5.38E-01	4.00E-03	2.89E-01	3.10E-02	5.16E-06	3.34E-08	4.26E-06	1.92E-06	1.01E-05	3.24E-06	1.10E-04	6.06E-04	7.00E-03
BATCH-1075	6/14/32	38	4.0	0.24	2.43E-09	1.14E+02	5.01E-01	3.00E-03	2.69E-01	2.90E-02	4.80E-06	3.11E-08	3.99E-06	1.80E-06	9.38E-06	3.02E-06	1.02E-04	5.64E-04	7.00E-03
BATCH-1076	6/17/32	40	4.2	0.24	2.59E-09	1.21E+02	5.30E-01	4.00E-03	2.86E-01	3.10E-02	5.11E-06	3.30E-08	4.08E-06	1.88E-06	1.00E-05	3.16E-06	1.09E-04	5.99E-04	7.00E-03
BATCH-1077	6/18/32	52	5.4	0.24	5.24E-10	1.55E+02	1.36E+00	1.98E-04	6.00E-03	4.93E-04	4.37E-07	4.14E-08	6.28E-05	1.47E-05	1.47E-06	2.42E-05	1.51E-04	8.34E-04	7.00E-03

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1029	12/12/31	173	18.0	0.24	7.93E-04	2.16E-04	4.00E-03	2.30E-02	2.30E-02	5.91E-01	6.80E-02	1.38E-01	8.20E-02	1.26E-28	2.35E-06	3.99E-06	2.74E-05	1.76E-04	6.48E-12
BATCH-1030	12/15/31	173	18.0	0.24	7.92E-04	2.16E-04	4.00E-03	2.30E-02	2.30E-02	5.90E-01	6.80E-02	1.38E-01	8.10E-02	1.26E-28	2.34E-06	3.98E-06	2.73E-05	1.76E-04	6.47E-12
BATCH-1031	12/31/31	21	2.2	0.24	2.99E-05	1.84E-05	8.64E-04	8.02E-04	8.02E-04	3.50E-02	6.00E-03	3.10E-02	1.00E-02	1.83E-29	3.25E-07	1.16E-06	5.03E-06	2.91E-05	1.97E-12
BATCH-1032	1/2/32	109	11.4	0.24	1.63E-04	4.76E-05	2.00E-03	5.00E-03	5.00E-03	1.38E-01	1.60E-02	3.50E-02	2.00E-02	9.84E-30	6.15E-07	1.08E-06	1.13E-05	6.83E-05	1.20E-12
BATCH-1033	1/2/32	62	6.5	0.24	1.15E-04	3.82E-05	2.00E-03	1.00E-02	3.00E-03	3.13E-01	4.60E-02	3.20E-02	6.70E-02	9.87E-30	1.39E-06	1.09E-06	1.12E-05	6.57E-05	2.77E-12
BATCH-1034	1/9/32	121	12.6	0.24	1.15E-04	3.88E-05	2.00E-03	5.00E-03	3.00E-03	1.25E-01	1.60E-02	3.60E-02	2.10E-02	1.45E-29	6.63E-07	1.20E-06	1.80E-05	1.06E-04	6.18E-13
BATCH-1035	1/13/32	50	5.2	0.24	2.68E-05	1.52E-05	2.00E-03	8.00E-03	6.05E-04	2.89E-01	4.60E-02	1.90E-02	6.90E-02	8.00E-30	1.33E-06	7.36E-07	9.56E-06	5.45E-05	2.39E-12
BATCH-1036	1/19/32	50	5.2	0.24	2.68E-05	1.52E-05	2.00E-03	8.00E-03	6.05E-04	2.89E-01	4.60E-02	1.90E-02	6.90E-02	8.00E-30	1.33E-06	7.36E-07	9.56E-06	5.45E-05	2.39E-12
BATCH-1037	1/22/32	61	6.4	0.24	3.24E-05	1.86E-05	2.00E-03	1.00E-02	7.28E-04	3.55E-01	5.60E-02	2.30E-02	8.40E-02	9.80E-30	1.62E-06	9.01E-07	1.17E-05	6.68E-05	2.93E-12
BATCH-1038	1/24/32	38	3.9	0.24	2.00E-05	1.14E-05	1.00E-03	6.00E-03	4.49E-04	2.18E-01	3.40E-02	1.40E-02	5.20E-02	6.03E-30	9.98E-07	5.54E-07	7.20E-06	4.10E-05	1.80E-12
BATCH-1039	1/28/32	60	6.3	0.24	8.24E-05	2.40E-05	8.30E-04	3.00E-03	2.00E-03	6.90E-02	8.00E-03	1.80E-02	1.00E-02	4.96E-30	3.10E-07	5.42E-07	5.69E-06	3.44E-05	6.07E-13
BATCH-1040	1/28/32	38	3.9	0.24	2.00E-05	1.14E-05	1.00E-03	6.00E-03	4.49E-04	2.19E-01	3.50E-02	1.40E-02	5.20E-02	6.04E-30	1.00E-06	5.55E-07	7.22E-06	4.11E-05	1.80E-12
BATCH-1041	2/1/32	56	5.8	0.24	4.76E-05	1.61E-05	1.00E-03	2.00E-03	1.00E-03	5.20E-02	6.00E-03	1.50E-02	9.00E-03	5.99E-30	2.75E-07	4.97E-07	7.46E-06	4.41E-05	2.56E-13
BATCH-1042	2/4/32	38	3.9	0.24	2.00E-05	1.14E-05	1.00E-03	6.00E-03	4.48E-04	2.18E-01	3.50E-02	1.40E-02	5.20E-02	6.03E-30	1.00E-06	5.55E-07	7.21E-06	4.11E-05	1.80E-12
BATCH-1043	2/7/32	159	16.5	0.24	1.63E-04	4.68E-05	1.00E-03	7.00E-03	5.00E-03	1.99E-01	2.60E-02	3.20E-02	3.50E-02	7.55E-30	8.40E-07	9.93E-07	7.98E-06	4.88E-05	1.96E-12
BATCH-1044	2/8/32	53	5.5	0.24	7.71E-04	1.39E-04	2.00E-03	5.00E-03	1.80E-02	2.49E-01	3.40E-02	4.90E-02	4.60E-02	7.41E-30	9.78E-07	1.30E-06	6.84E-06	3.55E-05	1.12E-12
BATCH-1045	2/14/32	157	16.4	0.24	1.23E-04	3.65E-05	1.00E-03	6.00E-03	4.00E-03	1.89E-01	2.60E-02	2.70E-02	3.60E-02	6.72E-30	8.11E-07	8.36E-07	7.26E-06	4.38E-05	1.79E-12
BATCH-1046	2/24/32	21	2.2	0.24	2.17E-05	6.34E-06	2.19E-04	7.10E-04	6.32E-04	1.80E-02	2.00E-03	5.00E-03	3.00E-03	1.31E-30	8.19E-08	1.43E-07	1.50E-06	9.09E-06	1.60E-13
BATCH-1047	2/27/32	18	1.9	0.24	1.12E-05	3.79E-06	2.38E-04	4.73E-04	3.18E-04	1.20E-02	2.00E-03	3.00E-03	2.00E-03	1.41E-30	6.49E-08	1.17E-07	1.76E-06	1.04E-05	6.05E-14
BATCH-1048	2/29/32	157	16.3	0.24	1.23E-04	3.64E-05	1.00E-03	6.00E-03	4.00E-03	1.88E-01	2.60E-02	2.60E-02	3.60E-02	6.70E-30	8.09E-07	8.34E-07	7.24E-06	4.37E-05	1.78E-12
BATCH-1049	3/1/32	141	14.7	0.24	7.61E-05	1.86E-05	1.00E-03	4.00E-03	2.00E-03	1.57E-01	2.40E-02	1.30E-02	3.60E-02	4.37E-30	7.04E-07	4.53E-07	5.06E-06	2.85E-05	1.21E-12
BATCH-1050	3/16/32	52	5.4	0.24	4.79E-05	1.38E-05	4.23E-04	2.00E-03	1.00E-03	5.90E-02	8.00E-03	1.00E-02	1.00E-02	2.22E-30	2.47E-07	2.92E-07	2.35E-06	1.44E-05	5.76E-13
BATCH-1051	3/16/32	96	10.0	0.24	2.00E-03	4.10E-04	4.00E-03	5.00E-03	5.60E-02	3.73E-01	4.30E-02	1.26E-01	4.60E-02	1.19E-29	1.20E-06	3.01E-06	7.96E-06	3.45E-05	1.48E-13
BATCH-1052	3/22/32	51	5.3	0.24	3.55E-05	1.05E-05	3.87E-04	2.00E-03	1.00E-03	5.40E-02	8.00E-03	1.00E-02	1.93E-30	2.33E-07	2.40E-07	2.09E-06	1.26E-05	5.13E-13
BATCH-1053	3/26/32	96	10.0	0.24	2.00E-03	4.10E-04	4.00E-03	5.00E-03	5.60E-02	3.73E-01	4.30E-02	1.26E-01	4.60E-02	1.19E-29	1.20E-06	3.01E-06	7.95E-06	3.45E-05	1.48E-13
BATCH-1054	3/27/32	30	3.2	0.24	1.45E-05	3.53E-06	2.09E-04	8.13E-04	3.41E-04	3.00E-02	5.00E-03	2.00E-03	7.00E-03	8.32E-31	1.34E-07	8.61E-08	9.62E-07	5.43E-06	2.31E-13
BATCH-1055	3/31/32	50	5.3	0.24	3.53E-05	1.05E-05	3.86E-04	2.00E-03	1.00E-03	5.40E-02	7.00E-03	8.00E-03	1.00E-02	1.92E-30	2.33E-07	2.40E-07	2.08E-06	1.26E-05	5.12E-13
BATCH-1056	4/5/32	18	1.8	0.24	1.16E-05	3.34E-06	1.03E-04	4.88E-04	3.38E-04	1.40E-02	2.00E-03	2.00E-03	2.00E-03	5.39E-31	6.00E-08	7.08E-08	5.69E-07	3.48E-06	1.40E-13
BATCH-1057	4/5/32	75	7.8	0.24	2.00E-03	3.21E-04	3.00E-03	4.00E-03	4.40E-02	2.92E-01	3.30E-02	9.90E-02	3.60E-02	9.33E-30	9.38E-07	2.36E-06	6.24E-06	2.70E-05	1.16E-13
BATCH-1058	4/7/32	17	1.8	0.24	8.48E-06	2.50E-06	9.23E-05	4.26E-04	2.44E-04	1.30E-02	2.00E-03	2.00E-03	2.00E-03	4.61E-31	5.56E-08	5.74E-08	4.98E-07	3.00E-06	1.22E-13
BATCH-1059	4/9/32	11	1.1	0.24	3.45E-06	8.41E-07	4.98E-05	1.94E-04	8.11E-05	7.00E-03	1.00E-03	5.82E-04	2.00E-03	1.98E-31	3.19E-08	2.05E-08	2.29E-07	1.29E-06	5.50E-14
BATCH-1060	4/11/32	17	1.8	0.24	8.43E-06	2.49E-06	9.20E-05	4.25E-04	2.43E-04	1.30E-02	2.00E-03	2.00E-03	2.00E-03	4.59E-31	5.54E-08	5.71E-08	4.96E-07	2.99E-06	1.22E-13
BATCH-1061	4/13/32	75	7.8	0.24	2.00E-03	3.21E-04	3.00E-03	4.00E-03	4.40E-02	2.92E-01	3.30E-02	9.90E-02	3.60E-02	9.33E-30	9.37E-07	2.36E-06	6.23E-06	2.70E-05	1.16E-13
BATCH-1062	4/13/32	95	9.9	0.24	2.00E-03	4.09E-04	4.00E-03	5.00E-03	5.60E-02	3.72E-01	4.30E-02	1.26E-01	4.60E-02	1.19E-29	1.19E-06	3.00E-06	7.94E-06	3.44E-05	1.48E-13
BATCH-1063	4/20/32	91	9.5	0.24	2.00E-03	3.27E-04	5.00E-03	5.00E-03	4.30E-02	3.58E-01	4.30E-02	1.36E-01	5.10E-02	1.31E-29	1.44E-06	3.75E-06	9.66E-06	4.51E-05	1.07E-13
BATCH-1064	4/23/32	112	11.7	0.24	1.00E-03	2.58E-04	1.00E-02	6.00E-03	2.90E-02	4.52E-01	5.90E-02	2.07E-01	8.10E-02	2.05E-29	2.48E-06	6.75E-06	1.69E-05	8.50E-05	5.08E-14
BATCH-1065	4/30/32	69	7.2	0.24	7.75E-04	1.58E-04	6.00E-03	4.00E-03	1.80E-02	2.78E-01	3.60E-02	1.27E-01	5.00E-02	1.26E-29	1.52E-06	4.15E-06	1.04E-05	5.22E-05	3.13E-14
BATCH-1066	5/5/32	112	11.7	0.24	1.00E-03	2.57E-04	1.00E-02	6.00E-03	2.90E-02	4.52E-01	5.90E-02	2.07E-01	8.10E-02	2.05E-29	2.48E-06	6.74E-06	1.69E-05	8.49E-05	5.07E-14
BATCH-1067	5/8/32	69	7.2	0.24	7.74E-04	1.58E-04	6.00E-03	4.00E-03	1.80E-02	2.78E-01	3.60E-02	1.27E-01	5.00E-02	1.26E-29	1.52E-06	4.14E-06	1.04E-05	5.22E-05	3.12E-14
BATCH-1068	5/15/32	88	9.1	0.24	9.87E-04	2.02E-04	8.00E-03	5.00E-03	2.30E-02	3.54E-01	4.60E-02	1.62E-01	6.40E-02	1.60E-29	1.94E-06	5.28E-06	1.33E-05	6.65E-05	3.98E-14
BATCH-1069	5/17/32	81	8.5	0.24	9.16E-04	1.87E-04	8.00E-03	5.00E-03	2.10E-02	3.29E-01	4.30E-02	1.51E-01	5.90E-02	1.49E-29	1.80E-06	4.91E-06	1.23E-05	6.18E-05	3.70E-14
BATCH-1070	5/24/32	76	7.9	0.24	7.97E-04	1.56E-04	5.00E-03	7.00E-03	1.90E-02	7.08E-01	7.90E-02	2.15E-01	8.30E-02	9.68E-29	2.54E-06	9.02E-06	1.60E-04	4.00E-03	3.27E-14
BATCH-1071	5/26/32	115	12.0	0.24	7.36E-04	1.30E-04	2.00E-03	2.00E-03	1.70E-02	1.31E-01	1.50E-02	4.70E-02	1.80E-02	4.54E-30	4.81E-07	1.24E-06	3.22E-06	1.47E-05	4.45E-14
BATCH-1072	6/1/32	115	12.0	0.24	7.35E-04	1.30E-04	2.00E-03	2.00E-03	1.70E-02	1.31E-01	1.50E-02	4.70E-02	1.80E-02	4.53E-30	4.80E-07	1.24E-06	3.22E-06	1.46E-05	4.45E-14
BATCH-1073	6/7/32	52	5.4	0.24	4.21E-04	6.62E-05	3.36E-04	1.10E-02	1.00E-02	1.34E+00	1.38E-01	3.05E-01	1.17E-01	2.42E-28	3.55E-06	4.24E-04	1.00E-02	1.86E-14
BATCH-1074	6/13/32	41	4.2	0.24	3.30E-04	5.20E-05	2.65E-04	8.00E-03	8.00E-03	1.05E+00	1.08E-01	2.40E-01	9.20E-02	1.90E-28	2.79E-06	3.32E-04	8.00E-03	1.46E-14
BATCH-1075	6/14/32	38	4.0	0.24	3.07E-04	4.83E-05	2.47E-04	8.00E-03	7.00E-03	9.75E-01	1.00E-01	2.23E-01	8.50E-02	1.77E-28	2.59E-06	1.14E-05	3.09E-04	7.00E-03	1.36E-14
BATCH-1076	6/17/32	40	4.2	0.24	3.27E-04	5.15E-05	2.61E-04	8.00E-03	8.00E-03	1.04E+00	1.07E-01	2.38E-01	9.10E-02	1.89E-28	2.76E-06	1.21E-05	3.30E-04	8.00E-03	1.45E-14
BATCH-1077	6/18/32	52	5.4	0.24	2.97E-04	5.26E-05	6.51E-04	6.66E-04	7.00E-03	5.30E-02	6.00E-03	1.90E-02	7.00E-03	1.84E-30	1.95E-07	5.01E-07	1.30E-06	5.93E-06	1.80E-14

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses																			
BATCH-1029	12/12/31	173	18.0	0.24	7.00E-03	1.95E+02	1.95E+02	2.86E-10	4.11E-14	4.38E-59	9.50E-02	1.25E+00	7.69E-13	3.70E-02	1.85E+01	0.00E+00	3.33E-04	3.50E+00	3.87E-07
BATCH-1030	12/15/31	173	18.0	0.24	7.00E-03	1.95E+02	1.95E+02	2.86E-10	4.10E-14	7.20E-54	9.50E-02	1.25E+00	7.67E-13	3.70E-02	1.85E+01	0.00E+00	3.37E-04	3.50E+00	3.86E-07
BATCH-1031	12/31/31	21	2.2	0.24	4.17E+01	0.00E+00	2.48E-13	5.42E-10	2.30E-13	1.41E-55	3.00E-03	2.01E-01	2.49E-12	8.02E-04	1.01E+00	0.00E+00	2.05E+00	0.00E+00	8.47E-07
BATCH-1032	1/2/32	109	11.4	0.24	2.70E+02	0.00E+00	3.38E-15	6.51E-10	7.55E-15	2.75E-54	5.90E-02	9.47E-01	3.41E-13	9.00E-03	5.95E+00	0.00E+00	1.12E+01	0.00E+00	1.80E-07
BATCH-1033	1/2/32	62	6.5	0.24	2.34E-06	5.00E+01	3.08E-12	5.19E-10	1.79E-12	4.84E-67	1.60E-02	4.23E-01	2.74E-12	1.30E-02	7.68E+00	0.00E+00	1.20E-07	7.96E-01	1.34E-07
BATCH-1034	1/9/32	121	12.6	0.24	2.94E+02	0.00E+00	1.76E-15	1.49E-09	3.96E-15	1.40E-53	4.60E-02	8.27E-01	5.58E-13	9.00E-03	7.91E+00	0.00E+00	1.02E+01	0.00E+00	3.01E-07
BATCH-1035	1/13/32	50	5.2	0.24	3.18E-06	3.23E+01	3.67E-12	5.78E-10	2.12E-12	2.10E-62	6.00E-03	3.28E-01	3.16E-12	1.00E-02	6.56E+00	0.00E+00	1.60E-07	4.58E-01	1.05E-07
BATCH-1036	1/19/32	50	5.2	0.24	3.20E-06	3.23E+01	3.67E-12	5.78E-10	2.12E-12	3.45E-57	6.00E-03	3.28E-01	3.15E-12	1.00E-02	6.56E+00	0.00E+00	1.62E-07	4.58E-01	1.05E-07
BATCH-1037	1/22/32	61	6.4	0.24	7.00E-03	3.95E+01	4.50E-12	7.09E-10	2.61E-12	2.28E-59	7.00E-03	4.02E-01	3.87E-12	1.20E-02	8.03E+00	0.00E+00	3.32E-04	5.60E-01	1.29E-07
BATCH-1038	1/24/32	38	3.9	0.24	1.49E-09	2.43E+01	2.76E-12	4.36E-10	1.60E-12	3.07E-70	4.00E-03	2.47E-01	2.38E-12	8.00E-03	4.94E+00	0.00E+00	7.64E-11	3.44E-01	7.91E-08
BATCH-1039	1/28/32	60	6.3	0.24	1.36E-02	0.00E+00	1.70E-15	3.28E-10	3.81E-15	1.39E-54	3.00E-02	4.77E-01	1.72E-13	5.00E-03	3.00E+00	0.00E+00	5.64E+00	0.00E+00	9.06E-08
BATCH-1040	1/28/32	38	3.9	0.24	2.01E-09	2.43E+01	2.77E-12	4.37E-10	1.61E-12	1.33E-65	4.00E-03	2.47E-01	2.38E-12	8.00E-03	4.95E+00	0.00E+00	1.01E-10	3.45E-01	7.93E-08
BATCH-1041	2/1/32	56	5.8	0.24	7.31E-16	0.00E+00	4.50E-16	8.67E-11	1.64E-15	5.79E-54	1.90E-02	3.43E-01	2.32E-13	4.00E-03	3.28E+00	0.00E+00	4.25E+00	0.00E+00	1.25E-07
BATCH-1042	2/4/32	38	3.9	0.24	6.18E-10	2.43E+01	2.77E-12	4.36E-10	1.60E-12	2.18E-60	4.00E-03	2.47E-01	2.38E-12	8.00E-03	4.95E+00	0.00E+00	1.02E-10	3.45E-01	7.92E-08
BATCH-1043	2/7/32	159	16.5	0.24	6.26E-02	0.00E+00	1.06E-12	2.22E-10	6.19E-13	1.83E-64	5.10E-02	1.11E+00	1.06E-12	1.00E-02	5.51E+00	0.00E+00	8.66E+00	0.00E+00	1.06E-07
BATCH-1044	2/8/32	53	5.5	0.24	2.71E-06	3.07E+01	1.79E-12	2.84E-10	1.08E-12	9.15E-63	2.90E-02	1.71E+00	2.45E-12	8.00E-03	5.57E+00	0.00E+00	1.33E-07	7.98E-01	5.75E-07
BATCH-1045	2/14/32	157	16.4	0.24	6.65E+02	0.00E+00	1.32E-12	2.48E-10	7.67E-13	6.29E-60	4.30E-02	1.05E+00	1.24E-12	9.00E-03	5.00E+00	0.00E+00	7.71E+00	0.00E+00	9.32E-08
BATCH-1046	2/24/32	21	2.2	0.24	3.60E+01	0.00E+00	4.50E-16	8.67E-11	1.01E-15	3.66E-55	8.00E-03	1.26E-01	4.54E-14	1.00E-03	7.91E-01	0.00E+00	1.49E+00	0.00E+00	2.39E-08
BATCH-1047	2/27/32	18	1.9	0.24	2.88E+01	0.00E+00	1.73E-16	1.46E-10	3.88E-16	1.37E-54	4.00E-03	8.10E-02	5.46E-14	9.16E-04	7.74E-01	0.00E+00	1.00E+00	0.00E+00	2.95E-08
BATCH-1048	2/29/32	157	16.3	0.24	6.65E+02	0.00E+00	1.31E-12	2.47E-10	7.65E-13	1.03E-54	4.30E-02	1.04E+00	1.24E-12	9.00E-03	4.99E+00	0.00E+00	7.70E+00	0.00E+00	9.29E-08
BATCH-1049	3/1/32	141	14.7	0.24	6.62E+02	0.00E+00	1.87E-12	2.95E-10	1.09E-12	5.14E-60	1.70E-02	7.65E-01	1.69E-12	5.00E-03	3.54E+00	0.00E+00	2.65E+00	0.00E+00	9.69E-08
BATCH-1050	3/15/32	52	5.4	0.24	1.84E+02	0.00E+00	3.11E-13	6.54E-11	1.82E-13	5.38E-65	1.50E-02	3.26E-01	3.11E-13	3.00E-03	1.62E+00	0.00E+00	2.55E+00	0.00E+00	3.12E-08
BATCH-1051	3/16/32	96	10.0	0.24	6.00E-03	5.07E+01	4.72E-13	7.87E-11	3.88E-13	5.70E-59	8.30E-02	4.88E+00	3.22E-12	1.00E-02	8.20E+00	0.00E+00	2.32E-04	1.84E+00	1.64E-06
BATCH-1052	3/22/32	51	5.3	0.24	1.91E+02	0.00E+00	3.78E-13	7.12E-11	2.20E-13	1.81E-60	1.20E-02	3.00E-01	3.56E-13	3.00E-03	1.44E+00	0.00E+00	2.22E+00	0.00E+00	2.68E-08
BATCH-1053	3/26/32	96	10.0	0.24	4.00E-03	5.06E+01	4.72E-13	7.87E-11	3.88E-13	1.78E-58	8.30E-02	4.87E+00	3.22E-12	1.00E-02	8.19E+00	0.00E+00	1.31E-04	1.84E+00	1.64E-06
BATCH-1054	3/27/32	30	3.2	0.24	1.26E+02	0.00E+00	3.56E-13	5.62E-11	2.07E-13	9.77E-61	3.00E-03	1.45E-01	3.21E-13	1.00E-03	6.74E-01	0.00E+00	5.03E-01	0.00E+00	1.84E-08
BATCH-1055	3/31/32	50	5.3	0.24	1.91E+02	0.00E+00	3.77E-13	7.11E-11	2.20E-13	2.97E-55	1.20E-02	3.00E-01	3.56E-13	3.00E-03	1.43E+00	0.00E+00	2.21E+00	0.00E+00	2.67E-08
BATCH-1056	4/5/32	18	1.8	0.24	4.47E+01	0.00E+00	7.55E-14	1.59E-11	4.42E-14	1.31E-65	4.00E-03	7.90E-02	7.55E-14	7.25E-04	3.93E-01	0.00E+00	6.18E-01	0.00E+00	7.56E-09
BATCH-1057	4/5/32	75	7.8	0.24	2.88E-06	3.97E+01	3.70E-13	6.17E-11	3.04E-13	2.93E-62	6.50E-02	3.82E+00	2.52E-12	8.00E-03	6.42E+00	0.00E+00	1.19E-07	1.45E+00	1.29E-06
BATCH-1058	4/7/32	17	1.8	0.24	4.57E+01	0.00E+00	9.02E-14	1.70E-11	5.26E-14	4.31E-61	3.00E-03	7.20E-02	8.50E-14	6.11E-04	3.43E-01	0.00E+00	5.29E-01	0.00E+00	6.39E-09
BATCH-1059	4/9/32	11	1.1	0.24	3.00E+01	0.00E+00	8.48E-14	1.34E-11	4.93E-14	2.33E-61	7.76E-04	3.50E-02	7.64E-14	2.41E-04	1.60E-01	0.00E+00	1.20E-01	0.00E+00	4.39E-09
BATCH-1060	4/11/32	17	1.8	0.24	4.56E+01	0.00E+00	8.99E-14	1.70E-11	5.24E-14	7.07E-56	3.00E-03	7.10E-02	8.48E-14	6.09E-04	3.42E-01	0.00E+00	5.27E-01	0.00E+00	6.36E-09
BATCH-1061	4/13/32	75	7.8	0.24	1.93E-06	3.97E+01	3.70E-13	6.16E-11	3.04E-13	9.16E-62	6.50E-02	3.82E+00	2.52E-12	8.00E-03	6.42E+00	0.00E+00	6.73E-08	1.44E+00	1.29E-06
BATCH-1062	4/13/32	95	9.9	0.24	6.00E-03	5.05E+01	4.71E-13	7.85E-11	3.87E-13	1.79E-69	8.30E-02	4.86E+00	3.21E-12	1.00E-02	8.17E+00	0.00E+00	8.47E-05	1.84E+00	1.64E-06
BATCH-1063	4/20/32	91	9.5	0.24	5.00E-03	5.60E+01	3.00E-13	5.10E-11	2.70E-13	4.85E-65	7.10E-02	4.68E+00	2.21E-12	9.00E-03	7.60E+00	0.00E+00	5.94E-05	1.83E+00	2.33E-06
BATCH-1064	4/23/32	112	11.7	0.24	6.00E-03	8.81E+01	1.70E-14	6.77E-12	1.01E-13	4.28E-65	6.80E-02	5.92E+00	7.26E-13	9.00E-03	8.95E+00	0.00E+00	2.20E-05	2.45E+00	4.70E-06
BATCH-1065	4/30/32	69	7.2	0.24	2.04E-09	5.41E+01	1.07E-14	4.20E-12	6.23E-14	2.08E-65	4.20E-02	3.64E+00	4.48E-13	5.00E-03	5.50E+00	0.00E+00	8.46E-11	1.51E+00	2.89E-06
BATCH-1066	5/5/32	112	11.7	0.24	7.00E-03	8.80E+01	1.70E-14	6.76E-12	1.01E-13	1.02E-59	6.70E-02	5.91E+00	7.25E-13	9.00E-03	8.94E+00	0.00E+00	7.63E-05	2.45E+00	4.70E-06
BATCH-1067	5/8/32	69	7.2	0.24	1.37E-09	5.41E+01	1.07E-14	4.19E-12	6.22E-14	6.50E-65	4.10E-02	3.63E+00	4.47E-13	5.00E-03	5.50E+00	0.00E+00	4.77E-11	1.51E+00	2.89E-06
BATCH-1068	5/15/32	88	9.1	0.24	3.41E-06	6.89E+01	1.36E-14	5.33E-12	7.93E-14	9.95E-73	5.30E-02	4.63E+00	5.70E-13	7.00E-03	7.01E+00	0.00E+00	4.71E-08	1.92E+00	3.68E-06
BATCH-1069	5/17/32	81	8.5	0.24	3.07E-06	6.40E+01	1.25E-14	4.94E-12	7.36E-14	2.90E-68	4.90E-02	4.30E+00	5.29E-13	6.00E-03	6.51E+00	0.00E+00	3.55E-08	1.79E+00	3.42E-06
BATCH-1070	5/24/32	76	7.9	0.24	2.40E-06	4.75E+01	1.18E-14	2.51E-09	6.27E-14	1.86E-68	6.20E-02	3.73E+00	4.81E-13	7.00E-03	6.44E+00	0.00E+00	9.57E-09	1.67E+00	2.46E-06
BATCH-1071	5/26/32	115	12.0	0.24	3.30E+02	0.00E+00	1.33E-13	2.25E-11	1.15E-13	8.98E-60	9.60E-02	2.21E+00	9.45E-13	3.00E-03	2.82E+00	0.00E+00	8.91E+00	0.00E+00	7.36E-07
BATCH-1072	6/1/32	115	12.0	0.24	3.30E+02	0.00E+00	1.33E-13	2.24E-11	1.14E-13	2.80E-59	9.60E-02	2.21E+00	9.44E-13	3.00E-03	2.82E+00	0.00E+00	8.90E+00	0.00E+00	7.35E-07
BATCH-1073	6/7/32	52	5.4	0.24	2.91E-06	6.21E+00	8.72E-15	7.04E-09	3.04E-14	4.52E-63	7.60E-02	1.94E+00	3.02E-13	7.00E-03	5.18E+00	0.00E+00	3.37E-08	1.14E+00	1.10E-07
BATCH-1074	6/13/32	41	4.2	0.24	1.92E-09	4.88E+00	6.84E-15	5.53E-09	2.38E-14	5.60E-76	5.90E-02	1.52E+00	2.37E-13	6.00E-03	4.06E+00	0.00E+00	2.65E-11	8.92E-01	8.71E-08
BATCH-1075	6/14/32	38	4.0	0.24	1.86E-09	4.54E+00	6.37E-15	5.14E-09	2.22E-14	1.75E-71	5.50E-02	1.41E+00	2.21E-13	5.00E-03	3.78E+00	0.00E+00	2.15E-11	8.29E-01	8.11E-08
BATCH-1076	6/17/32	40	4.2	0.24	1.36E-09	4.83E+00	6.78E-15	5.48E-09	2.36E-14	1.05E-71	5.90E-02	1.51E+00	2.35E-13	6.00E-03	4.03E+00	0.00E+00	5.43E-12	8.84E-01	8.57E-08
BATCH-1077	6/18/32	52	5.4	0.24	1.34E+02	0.00E+00	5.39E-14	9.08E-12	4.63E-14	3.63E-60	3.90E-02	8.93E-01	3.82E-13	1.00E-03	1.14E+00	0.00E+00	3.60E+00	0.00E+00	2.98E-07

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1029	12/12/31	173	18.0	0.24	5.49E-16	1.28E+02	1.60E-01	0.00E+00	0.00E+00	1.20E-03	1.37E+01	2.08E-04	3.19E-13	2.36E-13	1.60E-02	3.96E-11	2.96E+03	0.00E+00	9.43E-01
BATCH-1030	12/15/31	173	18.0	0.24	5.49E-16	1.27E+02	1.60E-01	0.00E+00	0.00E+00	1.20E-03	1.37E+01	2.08E-04	3.19E-13	2.38E-13	1.60E-02	3.95E-11	2.95E+03	0.00E+00	9.41E-01
BATCH-1031	12/31/31	21	2.2	0.24	4.67E-14	3.00E+00	1.54E-01	0.00E+00	0.00E+00	1.36E-05	4.62E-01	1.57E-06	7.83E-12	1.21E-10	2.00E-03	4.24E-11	3.65E+02	0.00E+00	8.90E-02
BATCH-1032	1/2/32	109	11.4	0.24	1.36E-16	3.00E+01	5.28E-01	0.00E+00	0.00E+00	2.00E-04	3.62E+00	4.05E-05	6.04E-14	5.98E-13	5.00E-03	7.35E-12	1.87E+03	0.00E+00	2.18E-01
BATCH-1033	1/2/32	62	6.5	0.24	2.12E-14	2.91E+01	3.01E-01	0.00E+00	0.00E+00	2.80E-03	4.06E+00	2.60E-05	1.02E-12	7.58E-11	8.00E-03	8.84E-12	1.06E+03	0.00E+00	4.37E-01
BATCH-1034	1/9/32	121	12.6	0.24	1.39E-16	2.74E+01	5.01E-01	0.00E+00	0.00E+00	1.47E-04	3.92E+00	2.45E-05	3.35E-14	1.40E-12	6.00E-03	3.77E-12	2.06E+03	0.00E+00	1.93E-01
BATCH-1035	1/13/32	50	5.2	0.24	2.51E-14	1.68E+01	3.36E-01	0.00E+00	0.00E+00	3.00E-03	2.91E+00	2.00E-06	1.17E-12	9.01E-11	7.00E-03	5.00E-12	8.52E+02	0.00E+00	3.89E-01
BATCH-1036	1/19/32	50	5.2	0.24	2.51E-14	1.68E+01	3.36E-01	0.00E+00	0.00E+00	3.00E-03	2.91E+00	2.00E-06	1.17E-12	9.01E-11	7.00E-03	5.00E-12	8.52E+02	0.00E+00	3.89E-01
BATCH-1037	1/22/32	61	6.4	0.24	3.08E-14	2.06E+01	4.12E-01	0.00E+00	0.00E+00	3.80E-03	3.57E+00	2.33E-06	1.44E-12	1.11E-10	8.00E-03	6.12E-12	1.04E+03	0.00E+00	4.76E-01
BATCH-1038	1/24/32	38	3.9	0.24	1.89E-14	1.26E+01	2.53E-01	0.00E+00	0.00E+00	2.40E-03	2.19E+00	1.45E-06	8.85E-13	6.79E-11	5.00E-03	3.76E-12	6.42E+02	0.00E+00	2.93E-01
BATCH-1039	1/28/32	60	6.3	0.24	6.84E-17	1.51E+01	2.66E-01	0.00E+00	0.00E+00	1.16E-04	1.82E+00	2.04E-05	3.04E-14	3.02E-13	2.00E-03	3.71E-12	1.03E+03	0.00E+00	1.10E-01
BATCH-1040	1/28/32	38	3.9	0.24	1.90E-14	1.27E+01	2.54E-01	0.00E+00	0.00E+00	2.40E-03	2.20E+00	1.43E-06	8.87E-13	6.81E-11	5.00E-03	3.77E-12	6.43E+02	0.00E+00	2.94E-01
BATCH-1041	2/1/32	56	5.8	0.24	5.75E-17	1.14E+01	2.08E-01	0.00E+00	0.00E+00	6.10E-05	1.63E+00	1.02E-05	1.39E-14	5.80E-13	2.00E-03	1.56E-12	9.48E+02	0.00E+00	8.00E-02
BATCH-1042	2/4/32	38	3.9	0.24	1.90E-14	1.26E+01	2.53E-01	0.00E+00	0.00E+00	2.40E-03	2.20E+00	1.43E-06	8.86E-13	6.80E-11	5.00E-03	3.77E-12	6.43E+02	0.00E+00	2.93E-01
BATCH-1043	2/7/32	159	16.5	0.24	7.33E-15	2.98E+01	5.78E-01	0.00E+00	0.00E+00	1.20E-03	3.52E+00	4.13E-05	4.00E-13	2.60E-11	5.00E-03	9.19E-12	2.71E+03	0.00E+00	2.96E-01
BATCH-1044	2/8/32	53	5.5	0.24	2.52E-14	3.89E+01	7.86E-01	0.00E+00	0.00E+00	3.40E-03	2.34E+00	3.31E-05	1.62E-12	4.48E-11	8.00E-03	2.24E-12	9.07E+02	0.00E+00	6.82E-01
BATCH-1045	2/14/32	157	16.4	0.24	9.07E-15	2.43E+01	5.67E-01	0.00E+00	0.00E+00	1.20E-03	3.01E+00	3.06E-05	4.66E-13	3.23E-11	5.00E-03	7.47E-12	2.68E+03	0.00E+00	2.75E-01
BATCH-1046	2/24/32	21	2.2	0.24	1.81E-17	3.99E+00	7.00E-02	0.00E+00	0.00E+00	3.06E-05	4.81E-01	5.40E-06	8.04E-15	7.96E-14	6.26E-04	9.78E-13	3.52E+02	0.00E+00	2.90E-02
BATCH-1047	2/27/32	18	1.9	0.24	1.36E-17	2.69E+00	4.90E-02	0.00E+00	0.00E+00	1.44E-05	3.83E-01	2.40E-06	3.27E-15	1.37E-13	5.63E-04	3.69E-13	3.13E+02	0.00E+00	1.90E-02
BATCH-1048	2/29/32	157	16.3	0.24	9.06E-15	2.43E+01	5.66E-01	0.00E+00	0.00E+00	1.20E-03	3.00E+00	3.04E-05	4.65E-13	3.22E-11	5.00E-03	7.45E-12	2.68E+03	0.00E+00	2.74E-01
BATCH-1049	3/1/32	141	14.7	0.24	1.39E-14	1.11E+01	5.20E-01	0.00E+00	0.00E+00	1.80E-03	1.56E+00	3.63E-06	6.87E-13	4.61E-11	4.00E-03	2.53E-12	2.41E+03	0.00E+00	2.39E-01
BATCH-1050	3/16/32	52	5.4	0.24	2.16E-15	8.78E+00	1.70E-01	0.00E+00	0.00E+00	4.00E-04	1.04E+00	1.21E-05	1.18E-13	7.64E-12	1.00E-03	2.70E-12	8.89E+02	0.00E+00	8.70E-02
BATCH-1051	3/16/32	96	10.0	0.24	4.35E-14	9.76E+01	1.98E+00	0.00E+00	0.00E+00	6.00E-03	3.23E+00	1.00E-04	3.40E-12	1.39E-11	1.60E-02	5.11E-15	1.63E+03	0.00E+00	1.58E+00
BATCH-1052	3/22/32	51	5.3	0.24	2.61E-15	6.99E+00	1.63E-01	0.00E+00	0.00E+00	4.00E-04	8.65E-01	8.78E-06	1.34E-13	9.28E-12	1.00E-03	2.15E-12	8.63E+02	0.00E+00	1.58E+00
BATCH-1053	3/26/32	96	10.0	0.24	4.35E-14	9.76E+01	1.98E+00	0.00E+00	0.00E+00	6.00E-03	3.23E+00	1.00E-04	3.40E-12	1.38E-11	1.60E-02	5.01E-15	1.63E+03	0.00E+00	4.50E-02
BATCH-1054	3/27/32	30	3.2	0.24	2.65E-15	2.11E+00	9.90E-02	0.00E+00	0.00E+00	4.00E-04	2.97E-01	6.90E-07	1.31E-13	8.77E-12	7.27E-04	4.82E-13	5.20E+02	0.00E+00	7.90E-02
BATCH-1055	3/31/32	50	5.3	0.24	2.60E-15	6.97E+00	1.63E-01	0.00E+00	0.00E+00	4.00E-04	8.63E-01	8.75E-06	1.34E-13	9.26E-12	1.00E-03	2.14E-12	8.63E+02	0.00E+00	2.10E-02
BATCH-1056	4/5/32	18	1.8	0.24	5.23E-16	2.13E+00	4.10E-02	0.00E+00	0.00E+00	7.93E-05	2.51E-01	2.94E-06	2.86E-14	1.85E-12	3.62E-04	6.55E-13	3.02E+02	0.00E+00	1.24E+00
BATCH-1057	4/5/32	75	7.8	0.24	3.41E-14	7.65E+01	1.55E+00	0.00E+00	0.00E+00	4.60E-03	2.53E+00	7.87E-05	2.67E-12	1.09E-11	1.20E-02	3.89E-15	1.28E+03	0.00E+00	1.90E-02
BATCH-1058	4/7/32	17	1.8	0.24	6.22E-16	1.67E+00	3.90E-02	0.00E+00	0.00E+00	8.69E-05	2.07E-01	2.10E-06	3.20E-14	2.21E-12	3.23E-04	5.12E-13	2.94E+02	0.00E+00	1.10E-02
BATCH-1059	4/9/32	11	1.1	0.24	6.30E-16	5.03E-01	2.40E-02	0.00E+00	0.00E+00	7.79E-05	7.10E-02	1.64E-07	3.11E-14	2.09E-12	1.73E-04	1.15E-13	1.88E+02	0.00E+00	1.10E-02
BATCH-1060	4/11/32	17	1.8	0.24	6.20E-16	1.66E+00	3.90E-02	0.00E+00	0.00E+00	8.66E-05	2.06E-01	2.09E-06	3.19E-14	2.21E-12	3.21E-04	5.10E-13	2.93E+02	0.00E+00	1.90E-02
BATCH-1061	4/13/32	75	7.8	0.24	3.41E-14	7.64E+01	1.55E+00	0.00E+00	0.00E+00	4.60E-03	2.53E+00	7.86E-05	2.66E-12	1.08E-11	1.20E-02	3.89E-15	1.28E+03	0.00E+00	1.24E+00
BATCH-1062	4/13/32	95	9.9	0.24	4.34E-14	9.73E+01	1.97E+00	0.00E+00	0.00E+00	6.00E-03	3.22E+00	1.00E-04	3.39E-12	1.38E-11	1.60E-02	5.04E-15	1.63E+03	0.00E+00	1.58E+00
BATCH-1063	4/20/32	91	9.5	0.24	4.21E-14	8.54E+01	2.83E+00	0.00E+00	0.00E+00	6.00E-03	3.54E+00	2.43E-04	2.40E-12	8.76E-12	1.80E-02	1.31E-13	1.55E+03	0.00E+00	2.55E+00
BATCH-1064	4/20/32	112	11.7	0.24	5.40E-14	8.82E+01	5.73E+00	0.00E+00	0.00E+00	3.40E-03	5.51E+00	6.51E-04	9.92E-13	4.38E-13	3.10E-02	4.61E-13	1.91E+03	0.00E+00	5.65E+00
BATCH-1065	4/30/32	69	7.2	0.24	3.32E-14	5.42E+01	3.52E+00	0.00E+00	0.00E+00	2.20E-03	3.38E+00	4.00E-04	6.11E-13	2.77E-13	1.90E-02	2.83E-13	1.18E+03	0.00E+00	3.47E+00
BATCH-1066	5/5/32	112	11.7	0.24	5.40E-14	8.81E+01	5.73E+00	0.00E+00	0.00E+00	3.40E-03	5.50E+00	6.50E-04	9.91E-13	4.38E-13	3.10E-02	4.60E-13	1.91E+03	0.00E+00	5.65E+00
BATCH-1067	5/8/32	69	7.2	0.24	3.32E-14	5.42E+01	3.52E+00	0.00E+00	0.00E+00	2.20E-03	3.38E+00	3.99E-04	6.10E-13	2.76E-13	1.90E-02	2.83E-13	1.17E+03	0.00E+00	3.47E+00
BATCH-1068	5/15/32	88	9.1	0.24	4.23E-14	6.91E+01	4.49E+00	0.00E+00	0.00E+00	2.60E-03	4.31E+00	5.09E-04	7.78E-13	3.50E-13	2.50E-02	3.60E-13	1.50E+03	0.00E+00	4.42E+00
BATCH-1069	5/17/32	81	8.5	0.24	3.93E-14	6.42E+01	4.17E+00	0.00E+00	0.00E+00	2.60E-03	4.00E+00	4.73E-04	7.22E-13	3.23E-13	2.30E-02	3.35E-13	1.39E+03	0.00E+00	4.11E+00
BATCH-1070	5/24/32	76	7.9	0.24	3.39E-14	6.10E+01	3.11E+00	0.00E+00	0.00E+00	2.20E-03	3.51E+00	1.00E-03	6.35E-13	3.84E-13	3.70E-02	2.86E-13	1.30E+03	0.00E+00	2.94E+00
BATCH-1071	5/26/32	115	12.0	0.24	1.54E-14	3.25E+01	1.78E+00	0.00E+00	0.00E+00	1.80E-03	1.23E+00	6.63E-05	1.01E-12	3.91E-12	6.00E-03	2.84E-14	1.97E+03	0.00E+00	7.74E-01
BATCH-1072	6/1/32	115	12.0	0.24	1.53E-14	3.25E+01	1.78E+00	0.00E+00	0.00E+00	1.80E-03	1.23E+00	6.62E-05	1.01E-12	3.90E-12	6.00E-03	2.83E-14	1.97E+03	0.00E+00	7.73E-01
BATCH-1073	6/7/32	52	5.4	0.24	1.72E-14	4.39E+01	4.52E-01	0.00E+00	0.00E+00	1.40E-03	1.90E+00	2.00E-03	3.51E-13	4.47E-13	5.80E-02	1.39E-13	8.87E+02	0.00E+00	8.70E-02
BATCH-1074	6/13/32	41	4.2	0.24	1.35E-14	3.45E+01	3.55E-01	0.00E+00	0.00E+00	1.00E-03	1.49E+00	2.00E-03	2.75E-13	3.50E-13	4.50E-02	1.09E-13	6.96E+02	0.00E+00	6.90E-02
BATCH-1075	6/14/32	38	4.0	0.24	1.25E-14	3.21E+01	3.30E-01	0.00E+00	0.00E+00	1.00E-03	1.39E+00	2.00E-03	2.56E-13	3.26E-13	4.20E-02	1.02E-13	6.48E+02	0.00E+00	6.40E-02
BATCH-1076	6/17/32	40	4.2	0.24	1.33E-14	3.42E+01	3.51E-01	0.00E+00	0.00E+00	1.00E-03	1.48E+00	2.00E-03	2.73E-13	3.47E-13	4.50E-02	1.08E-13	6.90E+02	0.00E+00	6.70E-02
BATCH-1077	6/18/32	52	5.4	0.24	6.21E-15	1.32E+01	7.20E-01	0.00E+00	0.00E+00	8.00E-04	4.97E-01	2.68E-05	4.09E-13	1.58E-12	3.00E-03	1.15E-14	8.86E+02	0.00E+00	3.13E-01

Appendix A Nominal ILAW Inventory

TWRSO&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	SI+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1029	12/12/31	173	18.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.65E+02	3.89E-17	5.97E+00	4.52E+01	3.00E-03	1.02E-15	0.00E+00	1.50E-02	2.12E-10	4.50E-02
BATCH-1030	12/15/31	173	18.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.65E+02	3.97E-17	5.97E+00	4.51E+01	3.00E-03	1.11E-15	0.00E+00	1.50E-02	2.12E-10	4.50E-02
BATCH-1031	12/31/31	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	6.18E+00	4.11E-14	5.89E+00	2.17E+00	1.00E-03	5.20E-12	0.00E+00	9.79E-04	2.86E-10	6.13E-04
BATCH-1032	1/2/32	109	11.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	6.82E+01	5.71E-18	3.34E+01	1.41E+01	6.67E-04	8.58E-17	0.00E+00	3.00E-03	4.87E-11	9.00E-03
BATCH-1033	1/2/32	62	6.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	3.39E+01	1.73E-13	1.48E+00	1.80E+01	2.00E-03	4.95E-17	0.00E+00	2.00E-03	1.93E-10	6.00E-03
BATCH-1034	1/9/32	121	12.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.94E+01	3.69E-18	3.75E+01	1.68E+01	7.20E-04	7.65E-17	0.00E+00	2.00E-03	4.30E-11	5.00E-03
BATCH-1035	1/13/32	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.72E+01	2.06E-13	9.27E+01	1.51E+01	2.00E-03	7.45E-18	0.00E+00	1.16E-04	2.00E-10	7.13E-04
BATCH-1036	1/19/32	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.72E+01	2.06E-13	9.27E+01	1.51E+01	2.00E-03	7.49E-18	0.00E+00	1.16E-04	2.00E-10	7.13E-04
BATCH-1037	1/22/32	61	6.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	2.11E+01	2.53E-13	1.14E+00	1.85E+01	3.00E-03	8.52E-16	0.00E+00	1.34E-04	2.45E-10	8.49E-04
BATCH-1038	1/24/32	38	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.30E+01	1.55E-13	6.98E-01	1.14E+01	2.00E-03	5.27E-18	0.00E+00	2.00E-03	1.51E-10	5.25E-04
BATCH-1039	1/28/32	60	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	3.44E+01	2.88E-18	1.68E-01	7.12E+00	3.36E-04	4.33E-17	0.00E+00	2.45E-11	4.00E-03	4.00E-03
BATCH-1040	1/28/32	38	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.30E+01	1.56E-13	6.99E-01	1.14E+01	2.00E-03	5.26E-18	0.00E+00	2.00E-03	1.51E-10	5.23E-04
BATCH-1041	2/1/32	56	5.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.46E+01	1.53E-18	1.55E+01	6.97E+00	2.99E-04	3.17E-17	0.00E+00	9.00E-04	1.78E-11	2.00E-03
BATCH-1042	2/4/32	38	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.30E+01	1.56E-13	6.98E-01	1.14E+01	2.00E-03	5.25E-18	0.00E+00	8.24E-05	1.51E-10	5.23E-04
BATCH-1043	2/7/32	159	16.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	6.16E+01	5.92E-14	2.87E+01	1.40E+01	1.00E-03	1.69E-16	0.00E+00	3.00E-03	9.90E-11	9.00E-03
BATCH-1044	2/8/32	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	7.36E+01	1.09E-13	3.22E+00	1.44E+01	5.00E-03	3.91E-18	0.00E+00	3.00E-03	2.89E-10	1.50E-02
BATCH-1045	2/14/32	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	5.18E+01	7.37E-14	2.77E+01	1.27E+01	1.00E-03	1.50E-16	0.00E+00	2.00E-03	1.02E-10	7.00E-03
BATCH-1046	2/24/32	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E-04	9.08E+00	7.60E-19	4.44E+00	1.88E+00	8.87E-05	1.14E-17	0.00E+00	4.37E-04	6.48E-12	1.00E-03
BATCH-1047	2/27/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.72E-04	5.81E+00	3.61E-19	3.67E+00	1.64E+00	7.04E-05	7.48E-18	0.00E+00	2.12E-04	4.21E-12	5.25E-04
BATCH-1048	2/29/32	157	16.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	5.16E+01	7.36E-14	2.77E+01	1.26E+01	1.00E-03	1.62E-16	0.00E+00	2.00E-03	1.02E-10	7.00E-03
BATCH-1049	3/1/32	141	14.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.82E+01	1.06E-13	1.92E+01	8.93E+00	2.00E-03	1.94E-16	0.00E+00	3.28E-04	1.18E-10	2.00E-03
BATCH-1050	3/16/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.81E+01	1.74E-14	8.43E+00	4.12E+00	3.42E-04	4.98E-17	0.00E+00	9.41E-04	2.91E-11	3.00E-03
BATCH-1051	3/16/32	96	10.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.05E+02	5.25E-14	8.72E+00	2.38E+01	1.40E-02	1.43E-18	0.00E+00	8.00E-03	6.19E-10	4.70E-02
BATCH-1052	3/22/32	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.49E+01	2.12E-14	7.96E+00	3.64E+00	3.43E-04	4.30E-17	0.00E+00	2.93E-11	2.00E-03	2.00E-03
BATCH-1053	3/26/32	96	10.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.05E+02	5.25E-14	8.72E+00	2.38E+01	1.40E-02	1.43E-18	0.00E+00	8.00E-03	6.19E-10	4.70E-02
BATCH-1054	3/27/32	30	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.96E-04	5.36E+00	2.02E-14	3.66E+00	1.70E+00	2.92E-04	3.68E-17	0.00E+00	6.23E-05	2.24E-11	3.03E-04
BATCH-1055	3/31/32	50	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.48E+01	2.12E-14	7.95E+00	3.63E+00	3.42E-04	4.66E-17	0.00E+00	6.88E-04	2.93E-11	2.00E-03
BATCH-1056	4/5/32	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-04	4.40E+00	4.23E-15	2.05E+00	9.99E-01	8.30E-05	1.21E-17	0.00E+00	2.28E-04	7.07E-12	6.38E-04
BATCH-1057	4/5/32	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	1.61E+02	4.11E-14	6.83E+00	1.86E+01	1.10E-02	1.12E-18	0.00E+00	6.00E-03	4.85E-10	3.70E-02
BATCH-1058	4/7/32	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.27E-04	3.55E+00	5.06E-15	1.90E+00	8.68E-01	8.18E-05	1.03E-17	0.00E+00	1.65E-04	7.00E-12	4.57E-04
BATCH-1059	4/9/32	11	1.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	1.28E+00	4.80E-15	8.71E-01	4.04E-01	6.95E-05	8.77E-18	0.00E+00	1.48E-05	5.34E-12	7.23E-05
BATCH-1060	4/11/32	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-04	3.54E+00	5.04E-15	1.90E+00	8.64E-01	8.15E-05	1.11E-17	0.00E+00	1.64E-04	6.97E-12	4.55E-04
BATCH-1061	4/13/32	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	1.60E+02	4.11E-14	6.83E+00	1.86E+01	1.10E-02	1.12E-18	0.00E+00	6.00E-03	4.85E-10	3.70E-02
BATCH-1062	4/13/32	95	9.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.04E+02	5.23E-14	8.70E+00	2.37E+01	1.40E-02	1.42E-18	0.00E+00	8.00E-03	6.17E-10	4.70E-02
BATCH-1063	4/20/32	91	9.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	1.72E+02	3.31E-14	6.95E+00	2.36E+01	1.70E-02	1.34E-14	0.00E+00	6.00E-03	3.91E-10	3.70E-02
BATCH-1064	4/23/32	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	1.59E+02	1.10E-15	5.43E+00	3.14E+01	3.20E-02	4.85E-14	0.00E+00	5.00E-03	1.84E-11	2.80E-02
BATCH-1065	4/30/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	9.80E+01	7.04E-16	3.34E+00	1.93E+01	2.00E-02	2.98E-14	0.00E+00	3.00E-03	1.16E-11	1.70E-02
BATCH-1066	5/5/32	112	11.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	1.59E+02	1.10E-15	5.42E+00	3.13E+01	3.20E-02	4.84E-14	0.00E+00	5.00E-03	1.83E-11	2.80E-02
BATCH-1067	5/8/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-02	9.79E+01	7.03E-16	3.34E+00	1.93E+01	2.00E-02	2.97E-14	0.00E+00	3.00E-03	1.16E-11	1.70E-02
BATCH-1068	5/15/32	88	9.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.25E+02	8.89E-16	4.25E+00	2.46E+01	2.50E-02	3.79E-14	0.00E+00	4.00E-03	1.47E-11	2.20E-02
BATCH-1069	5/17/32	81	8.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.16E+02	8.18E-16	3.95E+00	2.28E+01	2.40E-02	3.52E-14	0.00E+00	3.00E-03	1.36E-11	2.00E-02
BATCH-1070	5/24/32	76	7.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.26E+02	7.56E-16	5.06E+00	2.11E+01	3.90E-02	2.99E-14	0.00E+00	3.00E-03	1.75E-10	1.50E-02
BATCH-1071	5/26/32	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.30E+02	1.48E-14	3.43E+01	1.10E+01	6.00E-03	2.84E-15	0.00E+00	3.00E-03	1.74E-10	1.50E-02
BATCH-1072	6/1/32	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.30E+02	1.48E-14	3.43E+01	1.10E+01	6.00E-03	2.84E-15	0.00E+00	3.00E-03	1.74E-10	1.50E-02
BATCH-1073	6/7/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.24E+02	5.38E-16	6.37E+00	1.39E+01	6.40E-02	1.42E-14	0.00E+00	7.21E-04	1.03E-10	1.70E-02
BATCH-1074	6/13/32	41	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	9.76E+01	4.22E-16	4.99E+00	1.09E+01	5.00E-02	1.11E-14	0.00E+00	5.66E-04	8.11E-11	1.30E-02
BATCH-1075	6/14/32	38	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	9.08E+01	3.93E-16	4.64E+00	1.01E+01	4.60E-02	1.03E-14	0.00E+00	5.26E-04	7.54E-11	1.30E-02
BATCH-1076	6/17/32	40	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	9.68E+01	4.19E-16	4.95E+00	1.08E+01	4.90E-02	1.10E-14	0.00E+00	5.60E-04	8.04E-11	1.30E-02
BATCH-1077	6/18/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.27E+01	5.97E-15	1.39E+01	4.44E+00	2.00E-03	1.15E-15	0.00E+00	1.00E-03	7.06E-11	6.00E-03

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1078	6/21/32	38	4.0	0.24	0.00E+00	0.00E+00	2.00E-03	1.12E-04	1.44E-01	1.19E-01	7.60E+02	3.08E-01	1.05E-01	3.79E+00	4.46E-18	1.39E-01	1.00E-03	2.00E-03	1.25E-03
BATCH-1079	6/23/32	52	5.4	0.24	0.00E+00	0.00E+00	1.00E-02	4.95E-04	7.08E-01	1.35E-02	2.04E+02	5.00E-03	9.17E-04	4.12E-01	5.16E-17	3.60E-02	6.47E-06	1.00E-03	5.00E-04
BATCH-1080	6/25/32	108	11.3	0.24	0.00E+00	0.00E+00	2.00E-02	1.00E-03	1.44E+00	5.04E-02	2.17E+03	7.40E-02	2.40E-02	2.52E+00	1.05E-16	9.80E-02	3.16E-04	3.00E-03	1.25E-03
BATCH-1081	6/29/32	120	12.5	0.24	0.00E+00	0.00E+00	2.30E-02	1.00E-03	1.71E+00	5.58E-02	2.40E+03	7.50E-02	2.40E-02	2.68E+00	1.25E-16	1.12E-01	3.18E-04	3.00E-03	1.50E-03
BATCH-1082	7/7/32	104	10.8	0.24	0.00E+00	0.00E+00	3.30E-02	2.00E-03	2.45E+00	6.75E-02	2.08E+03	8.20E-02	2.80E-02	3.11E+00	1.86E-16	1.44E-01	3.57E-04	4.00E-03	1.75E-03
BATCH-1083	7/12/32	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.24E-04	1.77E-01	3.60E-03	5.09E+01	1.00E-03	2.29E-04	1.03E-01	1.29E-17	9.00E-03	1.08E-01	2.00E-03	1.25E-03
BATCH-1084	7/14/32	99	10.3	0.24	0.00E+00	0.00E+00	1.50E-02	7.75E-04	1.09E+00	6.84E-02	1.97E+03	1.39E-01	4.70E-02	4.10E+00	8.03E-17	1.08E-01	6.33E-04	2.00E-03	1.25E-04
BATCH-1085	7/18/32	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.24E-04	1.77E-01	3.60E-03	5.08E+01	1.00E-03	2.29E-04	1.03E-01	1.29E-17	9.00E-03	1.62E-06	2.81E-04	1.25E-04
BATCH-1086	7/20/32	53	5.5	0.24	0.00E+00	0.00E+00	9.00E-03	4.51E-04	6.40E-01	2.25E-02	1.06E+03	3.30E-02	1.10E-02	1.12E+00	4.69E-17	4.40E-02	1.41E-04	1.00E-03	5.00E-04
BATCH-1087	7/24/32	50	5.2	0.24	0.00E+00	0.00E+00	9.00E-03	4.54E-04	6.45E-01	2.07E-02	1.00E+03	2.80E-02	9.00E-03	1.01E+00	4.71E-17	4.20E-02	1.20E-04	1.00E-03	5.00E-04
BATCH-1088	7/26/32	60	6.3	0.24	0.00E+00	0.00E+00	3.00E-03	1.78E-04	2.28E-01	1.88E-01	1.21E+03	4.90E-01	1.67E-01	6.01E+00	7.09E-18	2.20E-01	2.00E-03	4.00E-03	2.00E-03
BATCH-1089	7/30/32	52	5.4	0.24	0.00E+00	0.00E+00	1.50E-02	7.82E-04	1.10E+00	3.06E-02	1.03E+03	3.70E-02	1.20E-02	1.40E+00	8.35E-17	6.50E-02	1.61E-04	2.00E-03	7.50E-04
BATCH-1090	8/1/32	53	5.5	0.24	0.00E+00	0.00E+00	3.00E-03	2.53E-04	1.89E-01	1.44E-01	1.05E+03	3.62E-01	1.20E-01	5.23E+00	6.21E-18	1.64E-01	2.00E-03	3.00E-03	1.70E-02
BATCH-1091	8/4/32	53	5.6	0.24	0.00E+00	0.00E+00	7.00E-03	3.86E-04	5.42E-01	3.42E-02	1.07E+03	6.90E-02	2.40E-02	2.04E+00	4.00E-17	5.40E-02	3.16E-04	1.00E-03	5.00E-04
BATCH-1092	8/7/32	20	2.0	0.24	0.00E+00	0.00E+00	2.00E-03	1.28E-04	1.81E-01	6.30E-03	3.90E+02	9.00E-03	3.00E-03	3.17E-01	1.33E-17	1.20E-02	3.98E-05	3.32E-04	1.53E-04
BATCH-1093	8/9/32	18	1.9	0.24	0.00E+00	0.00E+00	2.00E-03	1.19E-04	1.70E-01	5.40E-03	3.60E+02	7.00E-03	2.00E-03	2.65E-01	1.24E-17	1.10E-02	3.15E-05	3.05E-04	1.40E-04
BATCH-1094	8/10/32	51	5.3	0.24	0.00E+00	0.00E+00	2.00E-03	7.00E-04	1.42E-01	4.86E-02	1.55E+02	5.30E-02	6.03E-04	4.10E+00	6.22E-18	3.20E-02	4.35E-06	4.00E-03	8.68E-02
BATCH-1095	8/11/32	19	2.0	0.24	0.00E+00	0.00E+00	4.00E-03	2.18E-04	3.07E-01	8.10E-03	3.79E+02	1.00E-02	3.00E-03	3.90E-01	2.33E-17	1.80E-02	4.48E-05	4.89E-04	2.19E-04
BATCH-1096	8/11/32	43	4.5	0.24	0.00E+00	0.00E+00	2.00E-03	5.92E-04	1.20E-01	4.14E-02	1.32E+02	4.40E-02	5.10E-04	3.46E+00	5.25E-18	2.70E-02	3.68E-06	3.00E-03	7.33E-02
BATCH-1097	8/16/32	21	2.2	0.24	0.00E+00	0.00E+00	2.00E-03	1.23E-04	1.73E-01	1.08E-02	4.21E+02	2.20E-02	8.00E-03	6.51E-01	1.28E-17	1.70E-02	1.01E-04	3.86E-04	1.86E-04
BATCH-1098	8/18/32	69	7.2	0.24	0.00E+00	0.00E+00	3.00E-03	9.53E-04	1.93E-01	6.66E-02	1.36E+02	7.10E-02	7.09E-04	5.57E+00	8.46E-18	4.30E-02	4.41E-06	5.00E-03	1.18E-01
BATCH-1099	8/18/32	69	7.2	0.24	0.00E+00	0.00E+00	3.00E-03	9.52E-04	1.92E-01	6.66E-02	1.36E+02	7.10E-02	7.09E-04	5.56E+00	8.45E-18	4.30E-02	4.41E-06	5.00E-03	1.18E-01
BATCH-1100	8/25/32	69	7.2	0.24	0.00E+00	0.00E+00	3.00E-03	9.52E-04	1.92E-01	6.66E-02	1.36E+02	7.10E-02	7.09E-04	5.56E+00	8.45E-18	4.30E-02	4.41E-06	5.00E-03	1.18E-01
BATCH-1101	8/26/32	98	10.2	0.24	0.00E+00	0.00E+00	1.00E-03	2.04E-04	7.90E-02	4.86E-02	1.95E+03	1.09E-01	3.30E-02	3.55E+00	2.89E-18	5.10E-02	4.46E-04	2.00E-03	2.13E-02
BATCH-1102	9/2/32	120	12.5	0.24	0.00E+00	0.00E+00	1.00E-03	2.20E-04	1.06E-01	7.11E-02	2.39E+03	1.69E-01	5.40E-02	5.13E+00	3.71E-18	7.80E-02	7.26E-04	2.00E-03	2.08E-02
BATCH-1103	9/5/32	69	7.2	0.24	0.00E+00	0.00E+00	3.00E-03	9.50E-04	1.92E-01	6.66E-02	1.36E+02	7.10E-02	7.09E-04	5.55E+00	8.44E-18	4.30E-02	4.41E-06	5.00E-03	1.18E-01
BATCH-1104	9/12/32	50	5.3	0.24	0.00E+00	0.00E+00	3.00E-03	8.01E-04	2.51E-01	6.65E-01	1.01E+03	5.46E-01	5.60E-02	5.02E+00	1.63E-17	1.24E+00	4.50E-04	1.70E-02	9.13E-02
BATCH-1105	9/15/32	52	5.4	0.24	0.00E+00	0.00E+00	4.00E-03	8.28E-04	2.64E-01	7.18E-01	1.03E+03	5.89E-01	6.00E-02	5.15E+00	1.73E-17	1.34E+00	4.88E-04	1.90E-02	9.38E-02
BATCH-1106	9/18/32	52	5.4	0.24	0.00E+00	0.00E+00	4.00E-03	8.28E-04	2.64E-01	7.18E-01	1.03E+03	5.89E-01	6.00E-02	5.15E+00	1.73E-17	1.34E+00	4.88E-04	1.90E-02	9.38E-02
BATCH-1107	9/20/32	49	5.1	0.24	0.00E+00	0.00E+00	5.07E-04	9.30E-05	3.60E-02	2.25E-02	9.87E+02	5.00E-02	1.50E-02	1.62E+00	1.32E-18	2.30E-02	2.03E-04	7.20E-04	9.75E-03
BATCH-1108	9/24/32	52	5.4	0.24	0.00E+00	0.00E+00	4.00E-03	8.28E-04	2.64E-01	7.19E-01	1.03E+03	5.90E-01	6.00E-02	5.15E+00	1.73E-17	1.35E+00	4.88E-04	1.90E-02	9.38E-02
BATCH-1109	9/25/32	46	4.8	0.24	0.00E+00	0.00E+00	5.13E-04	7.54E-05	3.60E-02	2.43E-02	9.23E+02	5.80E-02	1.80E-02	1.76E+00	1.27E-18	2.70E-02	2.49E-04	6.85E-04	7.25E-03
BATCH-1110	9/29/32	122	12.7	0.24	0.00E+00	0.00E+00	2.00E-03	4.63E-04	1.15E-01	1.77E-01	2.43E+03	1.50E-01	1.30E-02	3.10E+00	6.30E-18	3.07E-01	1.08E-04	6.00E-03	5.55E-02
BATCH-1111	10/1/32	119	12.4	0.24	0.00E+00	0.00E+00	2.00E-03	4.57E-04	1.17E-01	2.02E-01	2.37E+03	1.70E-01	1.60E-02	3.13E+00	6.62E-18	3.56E-01	1.26E-04	6.00E-03	5.45E-02
BATCH-1112	10/12/32	119	12.4	0.24	0.00E+00	0.00E+00	2.00E-03	4.57E-04	1.17E-01	2.02E-01	2.37E+03	1.69E-01	1.60E-02	3.13E+00	6.61E-18	3.56E-01	1.26E-04	6.00E-03	5.43E-02
BATCH-1113	10/13/32	18	1.9	0.24	0.00E+00	0.00E+00	1.38E-04	2.54E-05	1.00E-02	6.30E-03	3.62E+02	1.40E-02	4.00E-03	4.41E-01	3.59E-19	6.00E-03	5.54E-05	1.96E-04	2.75E-03
BATCH-1114	10/15/32	119	12.4	0.24	0.00E+00	0.00E+00	2.00E-03	4.55E-04	1.17E-01	2.01E-01	2.37E+03	1.69E-01	1.60E-02	3.12E+00	6.60E-18	3.56E-01	1.26E-04	6.00E-03	5.43E-02
BATCH-1115	10/24/32	17	1.7	0.24	0.00E+00	0.00E+00	1.31E-04	1.92E-05	9.00E-03	6.30E-03	3.34E+02	1.50E-02	5.00E-03	4.49E-01	3.25E-19	7.00E-03	6.34E-05	1.75E-04	1.75E-03
BATCH-1116	10/26/32	50	5.2	0.24	0.00E+00	0.00E+00	5.88E-04	1.73E-04	4.30E-02	6.57E-02	1.00E+03	5.60E-02	5.00E-03	1.16E+00	2.35E-18	1.15E-01	4.04E-05	2.00E-03	2.08E-02
BATCH-1117	10/28/32	51	5.3	0.24	0.00E+00	0.00E+00	6.16E-04	1.75E-04	4.50E-02	7.74E-02	1.01E+03	6.50E-02	6.00E-03	1.20E+00	2.54E-18	1.37E-01	4.84E-05	2.00E-03	2.08E-02
BATCH-1118	11/1/32	75	7.8	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	3.81E-01	1.04E+00	1.49E+03	8.51E-01	8.70E-02	7.43E+00	2.50E-17	1.94E+00	7.04E-04	2.70E-02	1.35E-01
BATCH-1119	11/2/32	51	5.3	0.24	0.00E+00	0.00E+00	6.16E-04	1.75E-04	4.50E-02	7.74E-02	1.01E+03	6.50E-02	6.00E-03	1.20E+00	2.54E-18	1.37E-01	4.84E-05	2.00E-03	2.08E-02
BATCH-1120	11/8/32	50	5.3	0.24	0.00E+00	0.00E+00	6.15E-04	1.75E-04	4.50E-02	7.74E-02	1.01E+03	6.50E-02	6.00E-03	1.20E+00	2.53E-18	1.36E-01	4.84E-05	2.00E-03	2.08E-02
BATCH-1121	11/9/32	75	7.8	0.24	0.00E+00	0.00E+00	5.00E-03	1.00E-03	3.81E-01	1.04E+00	1.49E+03	8.50E-01	8.70E-02	7.42E+00	2.50E-17	1.94E+00	7.04E-04	2.70E-02	1.35E-01
BATCH-1122	11/13/32	18	1.9	0.24	0.00E+00	0.00E+00	1.56E-04	4.59E-05	1.10E-02	1.80E-02	3.62E+02	1.50E-02	1.00E-03	3.07E-01	6.24E-19	3.00E-02	1.07E-05	5.49E-04	5.50E-03
BATCH-1123	11/15/32	18	1.9	0.24	0.00E+00	0.00E+00	1.64E-04	4.67E-05	1.20E-02	2.07E-02	3.64E+02	1.70E-02	2.00E-03	3.20E-01	6.76E-19	3.60E-02	1.29E-05	6.18E-04	5.50E-03
BATCH-1124	11/17/32	18	1.9	0.24	0.00E+00	0.00E+00	1.64E-04	4.66E-05	1.20E-02	2.07E-02	3.64E+02	1.70E-02	2.00E-03	3.19E-01	6.75E-19	3.60E-02	1.29E-05	6.17E-04	5.50E-03
BATCH-1125	11/17/32	52	5.4	0.24	0.00E+00	0.00E+00	4.00E-03	8.27E-04	2.64E-01	7.18E-01	1.03E+03	5.89E-01	6.00E-02	5.14E+00	1.73E-17	1.34E+00	4.88E-04	1.90E-02	9.38E-02
BATCH-1126	11/19/32	18	1.9	0.24	0.00E+00	0.00E+00	1.63E-04	4.65E-05	1.20E-02	2.07E-02	3.63E+02	1.70E-02	2.00E-03	3.18E-01	6.73E-19	3.60E-02	1.29E-05	6.16E-04	5.50E-03

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-moi for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1078	6/21/32	38	4.0	0.24	2.44E-09	1.14E+02	4.94E-01	3.00E-03	2.70E-01	2.90E-02	4.81E-06	3.09E-08	3.56E-06	1.71E-06	9.41E-06	2.88E-06	1.02E-04	5.62E-04	7.00E-03
BATCH-1079	6/23/32	52	5.4	0.24	5.23E-10	1.55E+02	1.36E+00	1.98E-04	6.00E-03	4.92E-04	4.37E-07	4.13E-08	6.27E-05	1.47E-05	1.47E-06	2.42E-05	1.51E-04	8.32E-04	7.00E-03
BATCH-1080	6/25/32	108	11.3	0.24	1.54E-09	3.25E+02	2.71E+00	1.00E-03	6.70E-02	7.00E-03	1.81E-06	8.57E-08	1.23E-04	2.80E-05	4.45E-06	4.63E-05	2.88E-04	2.00E-03	1.20E-02
BATCH-1081	6/29/32	120	12.5	0.24	1.75E-09	3.60E+02	3.25E+00	1.00E-03	7.00E-02	7.00E-03	1.99E-06	1.02E-07	1.47E-04	3.39E-05	5.05E-06	5.60E-05	3.50E-04	2.00E-03	1.50E-02
BATCH-1082	7/7/32	104	10.8	0.24	2.29E-09	3.11E+02	4.28E+00	1.00E-03	7.80E-02	8.00E-03	2.25E-06	1.34E-07	2.01E-04	4.33E-05	4.93E-06	7.16E-05	3.73E-04	2.00E-03	7.00E-03
BATCH-1083	7/12/32	18	1.9	0.24	1.31E-10	5.38E+01	3.40E-01	4.95E-05	1.00E-03	1.23E-04	1.09E-07	1.03E-08	1.57E-05	3.66E-06	3.67E-07	6.05E-06	3.77E-05	2.08E-04	2.00E-03
BATCH-1084	7/14/32	99	10.3	0.24	1.79E-09	2.96E+02	1.99E+00	2.00E-03	1.24E-01	1.30E-02	2.58E-06	6.72E-08	8.64E-05	1.90E-05	5.27E-06	3.14E-05	1.93E-04	1.00E-03	5.00E-03
BATCH-1085	7/18/32	18	1.9	0.24	1.31E-10	5.37E+01	3.39E-01	4.94E-05	1.00E-03	1.23E-04	1.09E-07	1.03E-08	1.57E-05	3.66E-06	3.66E-07	6.03E-06	3.76E-05	2.08E-04	2.00E-03
BATCH-1086	7/18/32	53	5.5	0.24	6.88E-10	1.59E+02	1.21E+00	4.74E-04	3.00E-02	3.00E-03	8.09E-07	3.82E-08	5.46E-05	1.25E-05	1.99E-06	2.07E-05	1.29E-04	7.10E-04	5.00E-03
BATCH-1087	7/24/32	50	5.2	0.24	6.58E-10	1.51E+02	1.22E+00	4.30E-04	2.60E-02	3.00E-03	7.48E-07	3.84E-08	5.54E-05	1.28E-05	1.90E-06	2.11E-05	1.32E-04	7.26E-04	5.00E-03
BATCH-1088	7/26/32	60	6.3	0.24	3.87E-09	1.81E+02	7.84E-01	5.00E-03	4.28E-01	4.60E-02	7.65E-06	4.91E-08	5.66E-06	2.71E-06	1.50E-05	4.57E-06	1.62E-04	8.92E-04	1.10E-02
BATCH-1089	7/30/32	52	5.4	0.24	1.03E-09	1.55E+02	1.93E+00	5.48E-04	3.50E-02	3.00E-03	1.01E-06	6.02E-08	9.03E-05	1.95E-05	2.22E-06	3.22E-05	1.68E-04	9.27E-04	3.00E-03
BATCH-1090	8/1/32	53	5.5	0.24	4.45E-09	1.58E+02	5.83E-01	4.00E-03	3.08E-01	3.30E-02	5.53E-06	3.65E-08	5.41E-05	2.34E-06	1.40E-05	4.20E-06	1.27E-04	7.00E-04	8.00E-03
BATCH-1091	8/4/32	53	5.6	0.24	8.94E-10	1.60E+02	9.89E-01	8.29E-04	6.20E-02	6.00E-03	1.29E-06	3.35E-08	4.31E-05	9.45E-06	2.63E-06	1.56E-05	9.60E-05	5.30E-04	3.00E-03
BATCH-1092	8/7/32	20	2.0	0.24	1.94E-10	5.85E+01	3.42E-01	1.34E-04	9.00E-03	8.73E-04	2.29E-07	1.08E-08	1.55E-05	3.54E-06	5.61E-07	5.84E-06	3.63E-05	2.01E-04	1.00E-03
BATCH-1093	8/9/32	18	1.9	0.24	1.73E-10	5.41E+01	3.22E-01	1.13E-04	7.00E-03	7.05E-04	1.97E-07	1.01E-08	1.46E-05	3.36E-06	5.01E-07	5.54E-06	3.46E-05	1.91E-04	1.00E-03
BATCH-1094	8/10/32	51	5.3	0.24	9.32E-09	1.52E+02	1.05E-01	7.85E-05	7.49E-04	2.07E-04	1.72E-07	6.43E-09	7.47E-06	2.16E-06	1.80E-05	5.07E-06	5.81E-05	3.22E-04	3.00E-03
BATCH-1095	8/11/32	19	2.0	0.24	2.87E-10	5.68E+01	5.37E-01	1.53E-04	1.00E-02	9.66E-04	2.82E-07	1.68E-08	2.52E-05	5.43E-06	6.18E-07	8.98E-06	4.68E-05	2.58E-04	9.22E-04
BATCH-1096	8/13/32	43	4.5	0.24	7.87E-09	1.28E+02	8.80E-02	6.63E-05	6.34E-04	1.75E-04	1.45E-07	5.43E-09	6.31E-06	1.82E-06	1.52E-05	4.29E-06	4.91E-05	2.72E-04	2.00E-03
BATCH-1097	8/16/32	21	2.2	0.24	2.85E-10	6.31E+01	3.15E-01	2.64E-04	2.00E-02	2.00E-03	4.10E-07	1.07E-08	1.37E-05	3.02E-06	8.37E-07	4.98E-06	3.06E-05	1.69E-04	8.70E-04
BATCH-1098	8/18/32	69	7.2	0.24	1.27E-08	2.07E+02	1.42E-01	1.03E-04	7.35E-04	2.52E-04	2.29E-07	8.72E-09	1.02E-05	2.93E-06	2.45E-05	6.90E-06	7.90E-05	4.38E-04	4.00E-03
BATCH-1099	8/18/32	69	7.2	0.24	1.27E-08	2.07E+02	1.42E-01	1.03E-04	7.34E-04	2.52E-04	2.28E-07	8.71E-09	1.02E-05	2.93E-06	2.45E-05	6.90E-06	7.90E-05	4.37E-04	4.00E-03
BATCH-1100	8/25/32	69	7.2	0.24	1.27E-08	2.07E+02	1.42E-01	1.03E-04	7.34E-04	2.52E-04	2.28E-07	8.71E-09	1.02E-05	2.93E-06	2.45E-05	6.89E-06	7.89E-05	4.37E-04	4.00E-03
BATCH-1101	8/26/32	98	10.2	0.24	3.01E-09	2.93E+02	1.79E-01	1.00E-03	8.40E-02	9.00E-03	1.54E-06	1.12E-08	2.91E-06	1.05E-06	7.28E-06	2.12E-06	4.57E-05	2.53E-04	3.00E-03
BATCH-1102	9/2/32	120	12.5	0.24	3.41E-09	3.59E+02	2.75E-01	2.00E-03	1.37E-01	1.50E-02	2.48E-06	1.72E-08	3.55E-06	1.37E-06	8.97E-06	2.64E-06	6.52E-05	3.60E-04	4.00E-03
BATCH-1103	9/5/32	69	7.2	0.24	1.26E-08	2.06E+02	1.41E-01	1.03E-04	7.35E-04	2.52E-04	2.28E-07	8.70E-09	1.01E-05	2.93E-06	2.44E-05	6.89E-06	7.88E-05	4.36E-04	4.00E-03
BATCH-1104	9/12/32	50	5.3	0.24	1.17E-08	1.51E+02	2.80E+00	7.49E-04	6.20E-02	6.00E-03	1.22E-05	1.82E-07	1.46E-05	1.03E-05	4.84E-05	1.98E-05	3.61E-04	2.00E-03	4.00E-03
BATCH-1105	9/15/32	52	5.4	0.24	1.21E-08	1.55E+02	3.03E+00	8.08E-04	6.70E-02	6.00E-03	1.33E-05	1.97E-07	1.54E-05	1.10E-05	5.15E-05	2.12E-05	3.89E-04	2.00E-03	4.00E-03
BATCH-1106	9/18/32	52	5.4	0.24	1.21E-08	1.55E+02	3.03E+00	8.08E-04	6.70E-02	6.00E-03	1.33E-05	1.97E-07	1.55E-05	1.10E-05	5.15E-05	2.12E-05	3.89E-04	2.00E-03	4.00E-03
BATCH-1107	9/20/32	49	5.1	0.24	1.37E-09	1.48E+02	8.20E-02	4.91E-04	3.80E-02	4.00E-03	7.02E-07	5.10E-09	1.33E-06	4.80E-07	3.32E-06	9.67E-07	2.09E-05	1.15E-04	1.00E-03
BATCH-1108	9/24/32	52	5.4	0.24	1.21E-08	1.55E+02	3.03E+00	8.08E-04	6.70E-02	6.00E-03	1.33E-05	1.97E-07	1.55E-05	1.10E-05	5.15E-05	2.12E-05	3.89E-04	2.00E-03	4.00E-03
BATCH-1109	9/25/32	46	4.8	0.24	1.17E-09	1.38E+02	9.40E-02	5.98E-04	4.70E-02	5.00E-03	8.52E-07	5.89E-09	1.22E-06	4.70E-07	3.08E-06	9.06E-07	2.24E-05	1.24E-04	1.00E-03
BATCH-1110	9/29/32	122	12.7	0.24	6.41E-09	3.64E+02	7.06E-01	2.08E-04	1.50E-02	1.00E-03	2.98E-06	4.57E-08	6.39E-06	3.29E-06	1.85E-05	6.68E-06	1.09E-04	6.01E-04	2.00E-03
BATCH-1111	10/1/32	119	12.4	0.24	6.36E-09	3.56E+02	8.13E-01	2.34E-04	1.70E-02	2.00E-03	3.46E-06	5.27E-08	6.57E-06	3.59E-06	1.95E-05	7.20E-06	1.20E-04	6.64E-04	2.00E-03
BATCH-1112	10/12/32	119	12.4	0.24	6.36E-09	3.56E+02	8.13E-01	2.34E-04	1.70E-02	2.00E-03	3.46E-06	5.27E-08	6.57E-06	3.58E-06	1.95E-05	7.20E-06	1.20E-04	6.63E-04	2.00E-03
BATCH-1113	10/13/32	18	1.9	0.24	3.74E-10	5.43E+01	2.20E-02	1.34E-04	1.00E-02	1.00E-03	1.91E-07	1.39E-09	3.62E-07	1.31E-07	9.05E-07	2.64E-07	5.68E-06	3.14E-05	3.57E-04
BATCH-1114	10/15/32	119	12.4	0.24	6.34E-09	3.55E+02	8.12E-01	2.34E-04	1.70E-02	2.00E-03	3.46E-06	5.27E-08	6.55E-06	3.58E-06	1.94E-05	7.19E-06	1.20E-04	6.63E-04	2.00E-03
BATCH-1115	10/24/32	17	1.7	0.24	2.98E-10	5.01E+01	2.40E-02	1.52E-04	1.20E-02	1.00E-03	2.17E-07	1.50E-09	3.10E-07	1.20E-07	7.84E-07	2.31E-07	5.70E-06	3.15E-05	3.69E-04
BATCH-1116	10/26/32	50	5.2	0.24	2.39E-09	1.51E+02	2.63E-01	7.74E-05	6.00E-03	5.55E-04	1.11E-06	1.70E-08	2.38E-06	1.23E-06	6.91E-06	2.49E-06	4.05E-05	2.24E-04	7.41E-04
BATCH-1117	10/28/32	51	5.3	0.24	2.44E-09	1.52E+02	3.12E-01	8.97E-05	7.00E-03	6.60E-04	1.33E-06	2.02E-08	2.52E-06	1.38E-06	7.48E-06	2.76E-06	4.60E-05	2.55E-04	7.57E-04
BATCH-1118	11/1/32	75	7.8	0.24	1.75E-08	2.24E+02	4.37E+00	1.00E-03	9.70E-02	9.00E-03	1.92E-05	2.84E-07	2.23E-05	1.59E-05	7.43E-05	3.05E-05	5.61E-04	3.00E-03	5.00E-03
BATCH-1119	11/2/32	51	5.3	0.24	2.44E-09	1.51E+02	3.12E-01	8.97E-05	7.00E-03	6.59E-04	1.33E-06	2.02E-08	2.52E-06	1.38E-06	7.47E-06	2.76E-06	4.60E-05	2.54E-04	7.55E-04
BATCH-1120	11/8/32	50	5.3	0.24	2.43E-09	1.51E+02	3.12E-01	8.96E-05	7.00E-03	6.59E-04	1.33E-06	2.02E-08	2.52E-06	1.37E-06	7.46E-06	2.76E-06	4.60E-05	2.54E-04	7.55E-04
BATCH-1121	11/9/32	75	7.8	0.24	1.75E-08	2.24E+02	4.37E+00	1.00E-03	9.70E-02	9.00E-03	1.91E-05	2.84E-07	2.23E-05	1.59E-05	7.42E-05	3.05E-05	5.60E-04	3.00E-03	5.00E-03
BATCH-1122	11/13/32	18	1.9	0.24	6.35E-10	5.43E+01	7.00E-02	2.06E-05	1.00E-03	1.47E-04	2.95E-07	4.53E-09	6.33E-07	3.26E-07	1.84E-06	6.62E-07	1.08E-05	5.95E-05	1.97E-04
BATCH-1123	11/15/32	18	1.9	0.24	6.50E-10	5.46E+01	8.30E-02	2.39E-05	2.00E-03	1.76E-04	3.54E-07	5.38E-09	6.71E-07	3.66E-07	1.99E-06	7.36E-07	1.23E-05	6.78E-05	2.02E-04
BATCH-1124	11/17/32	18	1.9	0.24	6.49E-10	5.46E+01	8.30E-02	2.39E-05	2.00E-03	1.75E-04	3.53E-07	5.38E-09	6.70E-07	3.66E-07	1.99E-06	7.35E-07	1.22E-05	6.77E-05	2.01E-04
BATCH-1125	11/17/32	52	5.4	0.24	1.21E-08	1.55E+02	3.03E+00	8.08E-04	6.70E-02	6.00E-03	1.33E-05	1.97E-07	1.54E-05	1.10E-05	5.14E-05	2.11E-05	3.88E-04	2.00E-03	4.00E-03
BATCH-1126	11/19/32	18	1.9	0.24	6.47E-10	5.45E+01	8.30E-02	2.38E-05	2.00E-03	1.75E-04	3.53E-07	5.37E-09	6.69E-07	3.65E-07	1.98E-06	7.33E-07	1.22E-05	6.76E-05	2.01E-04

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days to fill cask	Days	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1078	6/21/32	38	4.0	0.24	3.08E-04	4.84E-05	2.43E-04	8.80E-03	7.00E-03	9.79E-01	1.01E-01	2.24E-01	8.60E-02	1.78E-28	2.60E-06	1.14E-05	3.10E-04	7.00E-03	1.36E-14
BATCH-1079	6/23/32	52	5.4	0.24	2.97E-04	5.25E-05	6.50E-04	6.65E-04	7.00E-03	5.30E-02	6.00E-03	1.90E-02	7.00E-03	1.83E-30	1.94E-07	5.01E-07	1.30E-06	5.92E-06	1.80E-14
BATCH-1080	6/25/32	108	11.3	0.24	5.04E-04	8.91E-05	1.00E-03	3.00E-03	1.20E-02	2.95E-01	3.20E-02	8.10E-02	3.10E-02	4.08E-29	9.03E-07	3.34E-06	6.82E-05	2.00E-03	2.84E-14
BATCH-1081	6/29/32	120	12.5	0.24	6.30E-04	1.11E-04	2.00E-03	3.00E-03	1.50E-02	3.16E-01	3.40E-02	8.80E-02	3.40E-02	4.15E-29	9.81E-07	3.54E-06	6.86E-05	2.00E-03	3.61E-14
BATCH-1082	7/7/32	104	10.8	0.24	3.22E-04	6.25E-05	2.00E-03	3.00E-03	8.00E-03	3.20E-01	3.50E-02	9.40E-02	3.80E-02	4.58E-29	1.10E-06	4.02E-06	7.63E-05	2.00E-03	1.33E-14
BATCH-1083	7/12/32	18	1.9	0.24	7.43E-05	1.31E-05	1.63E-04	1.66E-04	2.00E-03	1.30E-02	2.00E-03	5.00E-03	2.00E-03	4.58E-31	4.86E-08	1.25E-07	3.26E-07	1.48E-06	4.50E-15
BATCH-1084	7/14/32	99	10.3	0.24	2.41E-04	4.29E-05	9.81E-04	4.00E-03	6.00E-03	4.66E-01	4.90E-02	1.15E-01	4.40E-02	7.93E-29	1.35E-06	5.56E-06	1.37E-04	3.00E-03	1.02E-14
BATCH-1085	7/18/32	18	1.9	0.24	7.41E-05	1.31E-05	1.62E-04	1.66E-04	2.00E-03	1.30E-02	2.00E-03	5.00E-03	2.00E-03	4.57E-31	4.85E-08	1.25E-07	3.25E-07	1.48E-06	4.49E-15
BATCH-1086	7/20/32	53	5.5	0.24	3.98E-05	5.85E-04	1.00E-03	5.00E-03	1.31E-01	1.40E-02	3.60E-02	1.40E-02	1.82E-29	4.03E-07	1.49E-06	3.04E-05	6.99E-04	1.27E-14	
BATCH-1087	7/24/32	50	5.2	0.24	2.37E-04	4.19E-05	5.90E-04	1.00E-03	6.00E-03	1.19E-01	1.30E-02	3.30E-02	1.30E-02	1.56E-29	3.69E-07	1.33E-06	2.58E-05	5.89E-04	1.36E-14
BATCH-1088	7/26/32	60	6.3	0.24	4.89E-04	7.69E-05	3.86E-04	1.20E-02	1.10E-02	1.56E+00	1.60E-01	3.55E-01	1.36E-01	2.82E-28	4.13E-06	1.82E-05	4.93E-04	1.20E-02	2.16E-14
BATCH-1089	7/30/32	52	5.4	0.24	1.45E-04	2.81E-05	9.52E-04	1.00E-03	3.00E-03	1.44E-01	1.60E-02	4.20E-02	1.60E-02	2.06E-29	4.96E-07	1.81E-06	3.43E-05	7.83E-04	5.97E-15
BATCH-1090	8/1/32	53	5.5	0.24	3.75E-04	5.96E-05	3.32E-04	1.50E-02	9.00E-03	1.98E+00	2.02E-01	2.74E-01	1.69E-01	2.07E-28	5.17E-06	1.35E-05	3.56E-04	8.00E-03	4.15E-12
BATCH-1091	8/4/32	53	5.6	0.24	1.20E-04	2.14E-05	4.89E-04	2.00E-03	3.00E-03	2.32E-01	2.40E-02	5.70E-02	2.20E-02	3.95E-29	6.71E-07	2.77E-06	6.83E-05	2.00E-03	5.10E-15
BATCH-1092	8/7/32	20	2.0	0.24	6.35E-05	1.12E-05	1.65E-04	3.47E-04	1.00E-03	3.70E-02	4.00E-03	1.00E-02	4.00E-03	5.15E-30	1.14E-07	4.22E-07	8.60E-06	1.98E-04	3.58E-15
BATCH-1093	8/9/32	18	1.9	0.24	6.24E-05	1.10E-05	1.55E-04	3.00E-04	1.00E-03	3.10E-02	3.00E-03	9.00E-03	3.00E-03	4.12E-30	9.72E-08	3.51E-07	6.80E-06	1.55E-04	3.58E-15
BATCH-1094	8/10/32	51	5.3	0.24	1.29E-04	2.40E-05	3.05E-04	3.60E-02	3.00E-03	4.81E+00	4.87E-01	1.04E-01	3.98E-01	2.09E-29	1.22E-05	2.47E-06	8.32E-06	2.19E-05	2.31E-11
BATCH-1095	8/11/32	19	2.0	0.24	4.04E-05	7.84E-06	2.65E-04	3.84E-04	9.41E-04	4.00E-02	4.00E-03	1.20E-02	5.00E-03	5.74E-30	1.38E-07	5.04E-07	9.56E-06	2.18E-04	1.66E-15
BATCH-1096	8/13/32	43	4.5	0.24	1.09E-04	2.02E-05	2.58E-04	3.10E-02	2.00E-03	4.06E+00	4.11E-01	8.80E-02	3.36E-01	1.77E-29	1.03E-05	2.08E-06	7.03E-06	1.85E-05	1.95E-11
BATCH-1097	8/16/32	21	2.2	0.24	3.82E-05	6.81E-06	1.56E-04	6.20E-04	8.85E-04	7.40E-02	8.00E-03	1.80E-02	7.00E-03	1.26E-29	2.14E-07	8.84E-07	2.18E-05	5.10E-04	1.63E-15
BATCH-1098	8/18/32	69	7.2	0.24	1.75E-04	3.26E-05	4.15E-04	4.90E-02	4.00E-03	6.55E+00	6.62E-01	1.41E-01	5.41E-01	2.83E-29	1.66E-05	3.34E-06	1.10E-05	2.20E-05	3.14E-11
BATCH-1099	8/18/32	69	7.2	0.24	1.75E-04	3.25E-05	4.15E-04	4.90E-02	4.00E-03	6.54E+00	6.62E-01	1.41E-01	5.40E-01	2.83E-29	1.66E-05	3.34E-06	1.10E-05	2.20E-05	3.14E-11
BATCH-1100	8/25/32	69	7.2	0.24	1.75E-04	3.25E-05	4.14E-04	4.90E-02	4.00E-03	6.54E+00	6.62E-01	1.41E-01	5.40E-01	2.83E-29	1.66E-05	3.34E-06	1.10E-05	2.20E-05	3.14E-11
BATCH-1101	8/26/32	98	10.2	0.24	1.27E-04	2.09E-05	1.49E-04	1.10E-02	3.00E-03	1.47E+00	1.49E-01	9.50E-02	1.23E-01	6.04E-29	3.77E-06	4.16E-06	9.87E-05	2.00E-03	5.58E-12
BATCH-1102	9/2/32	120	12.5	0.24	1.86E-04	3.02E-05	1.94E-04	1.20E-02	4.00E-03	1.62E+00	1.65E-01	1.38E-01	1.36E-01	9.49E-29	4.17E-06	6.37E-06	1.59E-04	4.00E-03	5.38E-12
BATCH-1103	9/5/32	69	7.2	0.24	1.75E-04	3.25E-05	4.14E-04	4.90E-02	4.00E-03	6.53E+00	6.61E-01	1.41E-01	5.40E-01	2.82E-29	1.66E-05	3.34E-06	1.10E-05	2.20E-05	3.13E-11
BATCH-1104	9/12/32	50	5.3	0.24	1.60E-04	3.20E-05	6.17E-04	8.00E-03	4.00E-03	1.17E+00	1.11E-01	7.10E-02	8.60E-02	8.32E-29	2.66E-06	3.26E-06	1.17E-04	2.00E-03	1.30E-12
BATCH-1105	9/15/32	52	5.4	0.24	1.66E-04	3.33E-05	6.51E-04	7.00E-03	4.00E-03	9.86E-01	9.10E-02	7.10E-02	7.00E-02	8.90E-29	2.15E-06	3.39E-06	1.27E-04	3.00E-03	3.28E-14
BATCH-1106	9/18/32	52	5.4	0.24	1.66E-04	3.33E-05	6.51E-04	7.00E-03	4.00E-03	9.86E-01	9.10E-02	7.10E-02	7.00E-02	8.90E-29	2.15E-06	3.39E-06	1.27E-04	3.00E-03	3.28E-14
BATCH-1107	9/20/32	49	5.1	0.24	5.79E-05	9.51E-06	6.81E-05	5.00E-03	1.00E-03	6.69E-01	6.80E-02	4.30E-02	5.60E-02	2.75E-29	1.72E-06	1.89E-06	4.50E-05	1.00E-03	2.54E-12
BATCH-1108	9/24/32	52	5.4	0.24	1.66E-04	3.34E-05	6.52E-04	7.00E-03	4.00E-03	9.86E-01	9.10E-02	7.10E-02	7.00E-02	8.91E-29	2.15E-06	3.39E-06	1.27E-04	3.00E-03	3.27E-14
BATCH-1109	9/25/32	46	4.8	0.24	6.39E-05	1.03E-05	6.67E-05	4.00E-03	1.00E-03	5.55E-01	5.60E-02	4.70E-02	4.70E-02	3.26E-29	1.43E-06	2.19E-06	5.47E-05	1.00E-03	1.85E-12
BATCH-1110	9/29/32	122	12.7	0.24	8.82E-05	1.69E-05	2.66E-04	1.60E-02	2.00E-03	2.15E+00	2.16E-01	5.70E-02	1.75E-01	2.79E-29	5.40E-06	1.73E-06	3.11E-05	5.88E-04	9.30E-12
BATCH-1111	10/1/32	119	12.4	0.24	8.76E-05	1.69E-05	2.74E-04	1.40E-02	2.00E-03	1.93E+00	1.94E-01	5.40E-02	1.57E-01	3.01E-29	4.83E-06	1.73E-06	3.54E-05	6.86E-04	8.07E-12
BATCH-1112	10/12/32	119	12.4	0.24	8.74E-05	1.69E-05	2.73E-04	1.40E-02	2.00E-03	1.93E+00	1.93E-01	5.40E-02	1.57E-01	3.01E-29	4.82E-06	1.73E-06	3.54E-05	6.85E-04	8.06E-12
BATCH-1113	10/13/32	18	1.9	0.24	1.58E-05	2.59E-06	1.86E-05	1.00E-03	3.61E-04	1.82E-01	1.90E-02	1.20E-02	1.50E-02	7.50E-30	4.68E-07	5.16E-07	1.23E-05	2.84E-04	6.93E-13
BATCH-1114	10/15/32	119	12.4	0.24	8.72E-05	1.69E-05	2.73E-04	1.40E-02	2.00E-03	1.92E+00	1.93E-01	5.40E-02	1.56E-01	3.00E-29	4.80E-06	1.72E-06	3.53E-05	6.85E-04	8.02E-12
BATCH-1115	10/24/32	17	1.7	0.24	1.63E-05	2.64E-06	1.70E-05	1.00E-03	3.73E-04	1.41E-01	1.40E-02	1.20E-02	1.20E-02	8.30E-30	3.65E-07	5.57E-07	1.39E-05	3.26E-04	4.71E-13
BATCH-1116	10/26/32	50	5.2	0.24	3.29E-05	6.32E-06	9.90E-05	6.00E-03	7.51E-04	8.02E-01	8.10E-02	2.10E-02	6.50E-02	1.04E-29	2.01E-06	6.46E-07	1.16E-05	2.19E-04	3.47E-12
BATCH-1117	10/28/32	51	5.3	0.24	3.36E-05	6.49E-06	1.05E-04	6.00E-03	7.68E-04	7.42E-01	7.40E-02	2.10E-02	6.00E-02	1.16E-29	1.85E-06	6.63E-07	1.36E-05	2.63E-04	3.10E-12
BATCH-1118	11/1/32	75	7.8	0.24	2.39E-04	4.81E-05	9.40E-04	9.00E-03	6.00E-03	1.42E+00	1.31E-01	1.02E-01	1.00E-01	1.29E-28	3.09E-06	4.89E-06	1.83E-04	4.00E-03	2.39E-14
BATCH-1119	11/2/32	51	5.3	0.24	3.35E-05	6.48E-06	1.05E-04	6.00E-03	7.67E-04	7.41E-01	7.40E-02	2.10E-02	6.00E-02	1.15E-29	1.85E-06	6.62E-07	1.36E-05	2.63E-04	3.09E-12
BATCH-1120	11/8/32	50	5.3	0.24	3.35E-05	6.47E-06	1.05E-04	5.00E-03	7.66E-04	7.38E-01	7.40E-02	2.10E-02	6.00E-02	1.15E-29	1.84E-06	6.61E-07	1.36E-05	2.63E-04	3.08E-12
BATCH-1121	11/9/32	75	7.8	0.24	2.39E-04	4.81E-05	9.39E-04	9.00E-03	5.00E-03	1.42E+00	1.31E-01	1.02E-01	1.00E-01	1.28E-28	3.09E-06	4.88E-06	1.83E-04	4.00E-03	2.38E-14
BATCH-1122	11/13/32	18	1.9	0.24	8.73E-06	1.68E-06	2.63E-05	2.00E-03	2.00E-04	2.13E-01	2.10E-02	6.00E-03	1.70E-02	2.76E-30	5.35E-07	1.72E-07	3.08E-06	5.82E-05	9.21E-13
BATCH-1123	11/15/32	18	1.9	0.24	8.94E-06	1.73E-06	2.80E-05	1.00E-03	2.04E-04	1.98E-01	2.00E-02	6.00E-03	1.60E-02	3.08E-30	4.93E-07	1.77E-07	3.61E-06	7.01E-05	8.25E-13
BATCH-1124	11/17/32	18	1.9	0.24	8.93E-06	1.72E-06	2.79E-05	1.00E-03	2.04E-04	1.97E-01	2.00E-02	6.00E-03	1.60E-02	3.07E-30	4.92E-07	1.76E-07	3.61E-06	7.00E-05	8.22E-13
BATCH-1125	11/17/32	52	5.4	0.24	1.66E-04	3.33E-05	6.51E-04	7.00E-03	4.00E-03	9.82E-01	9.10E-02	7.10E-02	6.90E-02	8.90E-29	2.14E-06	3.38E-06	1.27E-04	3.00E-03	1.65E-14
BATCH-1126	11/19/32	18	1.9	0.24	8.90E-06	1.72E-06	2.78E-05	1.00E-03	2.04E-04	1.96E-01	2.00E-02	6.00E-03	1.60E-02	3.07E-30	4.90E-07	1.76E-07	3.61E-06	6.99E-05	8.19E-13

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1078	6/21/32	38	4.0	0.24	1.76E-09	4.52E+00	6.38E-15	5.16E-09	2.22E-14	2.72E-66	5.50E-02	1.42E+00	2.21E-13	5.00E-03	3.79E+00	0.00E+00	2.03E-11	8.32E-01	7.94E-08
BATCH-1079	6/23/32	52	5.4	0.24	1.33E+02	0.00E+00	5.39E-14	9.07E-12	4.63E-14	1.13E-59	3.90E-02	8.92E-01	3.82E-13	1.00E-03	1.14E+00	0.00E+00	3.60E+00	0.00E+00	2.97E-07
BATCH-1080	6/25/32	108	11.3	0.24	2.76E+02	0.00E+00	7.25E-14	1.11E-09	6.92E-14	2.66E-70	1.03E-01	2.00E+00	5.75E-13	3.00E-03	2.65E+00	0.00E+00	1.09E+01	0.00E+00	5.91E-07
BATCH-1081	6/29/32	120	12.5	0.24	2.72E+02	0.00E+00	9.60E-14	1.11E-09	8.92E-14	1.53E-65	1.08E-01	2.30E+00	7.40E-13	4.00E-03	3.12E+00	0.00E+00	1.12E+01	0.00E+00	7.09E-07
BATCH-1082	7/7/32	104	10.8	0.24	2.25E+02	0.00E+00	4.87E-15	1.21E-09	2.53E-14	3.85E-66	9.90E-02	2.10E+00	1.96E-13	3.00E-03	2.67E+00	0.00E+00	1.19E+01	0.00E+00	9.52E-07
BATCH-1083	7/12/32	18	1.9	0.24	3.34E+01	0.00E+00	1.35E-14	2.27E-12	1.16E-14	9.06E-61	1.00E-02	2.23E-01	9.55E-14	3.34E-04	2.85E-01	0.00E+00	9.00E-01	0.00E+00	7.44E-08
BATCH-1084	7/14/32	99	10.3	0.24	2.12E+02	0.00E+00	4.22E-15	2.26E-09	1.82E-14	8.63E-61	1.09E-01	1.75E+00	1.58E-13	3.00E-03	2.41E+00	0.00E+00	1.28E+01	0.00E+00	4.31E-07
BATCH-1085	7/18/32	18	1.9	0.24	3.33E+01	0.00E+00	1.34E-14	2.26E-12	1.16E-14	2.83E-60	1.00E-02	2.22E-01	9.53E-14	3.34E-04	2.84E-01	0.00E+00	8.98E-01	0.00E+00	7.42E-08
BATCH-1086	7/20/32	53	5.5	0.24	1.23E+02	0.00E+00	3.24E-14	4.94E-10	3.09E-14	1.19E-70	4.60E-02	8.93E-01	2.57E-13	1.00E-03	1.18E+00	0.00E+00	4.86E+00	0.00E+00	2.64E-07
BATCH-1087	7/24/32	50	5.2	0.24	1.02E+02	0.00E+00	3.61E-14	4.17E-10	3.36E-14	5.77E-66	4.10E-02	8.65E-01	2.78E-13	1.00E-03	1.17E+00	0.00E+00	4.21E+00	0.00E+00	2.67E-07
BATCH-1088	7/26/32	60	6.3	0.24	4.00E-03	7.18E+00	1.01E-14	8.20E-09	3.53E-14	1.21E-64	8.80E-02	2.25E+00	3.51E-13	9.00E-03	6.02E+00	0.00E+00	1.20E-04	1.32E+00	1.26E-07
BATCH-1089	7/30/32	52	5.4	0.24	1.01E+02	0.00E+00	2.19E-15	5.46E-10	1.14E-14	1.73E-66	4.50E-02	9.45E-01	8.82E-14	1.00E-03	1.20E+00	0.00E+00	5.33E+00	0.00E+00	4.28E-07
BATCH-1090	8/1/32	53	5.5	0.24	4.00E-03	7.23E+00	8.72E-12	7.11E-09	4.14E-12	3.01E-64	6.60E-02	1.75E+00	2.75E-12	7.00E-03	5.73E+00	0.00E+00	9.55E-05	1.24E+00	9.46E-08
BATCH-1091	8/4/32	53	5.6	0.24	1.06E+02	0.00E+00	2.10E-15	1.12E-09	9.08E-15	4.30E-61	5.40E-02	8.70E-01	7.86E-14	2.00E-03	1.20E+00	0.00E+00	6.39E+00	0.00E+00	2.15E-07
BATCH-1092	8/7/32	20	2.0	0.24	3.49E+01	0.00E+00	9.15E-15	1.40E-10	8.73E-15	3.35E-71	1.30E-02	2.53E-01	7.25E-14	4.10E-04	3.34E-01	0.00E+00	1.37E+00	0.00E+00	7.45E-08
BATCH-1093	8/9/32	18	1.9	0.24	2.69E+01	0.00E+00	9.51E-15	1.10E-10	8.84E-15	1.52E-66	1.10E-02	2.28E-01	7.33E-14	3.78E-04	3.09E-01	0.00E+00	1.11E+00	0.00E+00	7.02E-08
BATCH-1094	8/10/32	51	5.3	0.24	2.17E-06	1.15E+01	4.86E-11	6.76E-09	2.30E-11	5.89E-68	1.70E-02	7.39E-01	1.39E-11	6.00E-03	7.84E+00	0.00E+00	5.85E-08	1.61E+00	2.15E-08
BATCH-1095	8/11/32	19	2.0	0.24	2.83E+01	0.00E+00	6.11E-16	1.52E-10	3.17E-15	4.83E-67	1.20E-02	2.63E-01	2.46E-14	3.76E-04	3.34E-01	0.00E+00	1.49E+00	0.00E+00	1.19E-07
BATCH-1096	8/13/32	43	4.5	0.24	2.05E-06	9.73E+00	4.11E-11	5.71E-09	1.94E-11	1.74E-67	1.40E-02	6.24E-01	1.18E-11	5.00E-03	6.62E+00	0.00E+00	5.53E-08	1.36E+00	1.82E-08
BATCH-1097	8/16/32	21	2.2	0.24	3.37E+01	0.00E+00	6.71E-16	3.58E-10	2.89E-15	1.37E-61	1.70E-02	2.78E-01	2.51E-14	4.97E-04	3.83E-01	0.00E+00	2.04E+00	0.00E+00	6.85E-08
BATCH-1098	8/18/32	69	7.2	0.24	5.00E-03	1.57E+01	6.62E-11	9.19E-09	3.13E-11	5.03E-75	2.30E-02	1.00E+00	1.89E-11	8.00E-03	1.07E+01	0.00E+00	2.06E-04	2.19E+00	2.92E-08
BATCH-1099	8/18/32	69	7.2	0.24	4.00E-03	1.57E+01	6.61E-11	9.19E-09	3.12E-11	2.06E-70	2.30E-02	1.00E+00	1.89E-11	8.00E-03	1.07E+01	0.00E+00	1.50E-04	2.19E+00	2.92E-08
BATCH-1100	8/25/32	69	7.2	0.24	4.00E-03	1.56E+01	6.61E-11	9.18E-09	3.12E-11	7.10E-71	2.30E-02	1.00E+00	1.89E-11	8.00E-03	1.06E+01	0.00E+00	2.18E-04	2.19E+00	2.92E-08
BATCH-1101	8/26/32	98	10.2	0.24	2.44E+02	0.00E+00	1.18E-11	3.24E-09	5.56E-12	2.37E-65	9.60E-02	1.27E+00	3.43E-12	3.00E-03	3.07E+00	0.00E+00	9.00E+00	0.00E+00	2.99E-08
BATCH-1102	9/2/32	120	12.5	0.24	2.58E+02	0.00E+00	1.13E-11	4.19E-09	5.36E-12	1.34E-64	1.10E-01	1.57E+00	3.35E-12	4.00E-03	3.75E+00	0.00E+00	9.32E+00	0.00E+00	4.53E-08
BATCH-1103	9/5/32	69	7.2	0.24	6.00E-03	1.56E+01	6.60E-11	9.17E-09	3.12E-11	2.46E-65	2.30E-02	1.00E+00	1.89E-11	8.00E-03	1.06E+01	0.00E+00	3.65E-04	2.18E+00	2.91E-08
BATCH-1104	9/12/32	50	5.3	0.24	1.62E-06	1.55E+01	2.78E-12	5.22E-10	1.31E-12	1.56E-78	4.40E-02	1.11E+00	8.77E-13	1.30E-02	5.25E+00	0.00E+00	6.38E-08	7.46E-01	4.36E-07
BATCH-1105	9/15/32	52	5.4	0.24	1.89E-06	1.62E+01	1.14E-13	1.64E-10	4.84E-14	1.07E-73	4.60E-02	1.16E+00	1.22E-13	1.40E-02	5.23E+00	0.00E+00	7.78E-08	7.14E-01	4.72E-07
BATCH-1106	9/18/32	52	5.4	0.24	2.16E-06	1.62E+01	1.14E-13	1.64E-10	4.84E-14	3.69E-74	4.60E-02	1.16E+00	1.22E-13	1.40E-02	5.23E+00	0.00E+00	1.14E-07	7.14E-01	4.72E-07
BATCH-1107	9/20/32	49	5.1	0.24	1.11E-02	0.00E+00	5.36E-12	1.48E-09	2.53E-12	1.08E-65	4.40E-02	5.76E-01	1.56E-12	1.00E-03	1.40E+00	0.00E+00	4.10E+00	0.00E+00	1.36E-08
BATCH-1108	9/24/32	52	5.4	0.24	3.14E-06	1.62E+01	1.14E-13	1.64E-10	4.84E-14	1.28E-68	4.60E-02	1.16E+00	1.22E-13	1.40E-02	5.23E+00	0.00E+00	1.90E-07	7.14E-01	4.72E-07
BATCH-1109	9/25/32	46	4.8	0.24	8.84E+01	0.00E+00	3.89E-12	1.44E-09	1.84E-12	4.58E-65	3.80E-02	5.37E-01	1.15E-12	1.00E-03	1.29E+00	0.00E+00	3.20E+00	0.00E+00	1.55E-08
BATCH-1110	9/29/32	122	12.7	0.24	3.57E+02	0.00E+00	1.96E-11	2.76E-09	9.26E-12	1.31E-75	9.30E-02	1.19E+00	5.63E-12	5.00E-03	4.30E+00	0.00E+00	4.10E+00	0.00E+00	1.12E-07
BATCH-1111	10/1/32	119	12.4	0.24	3.53E+02	0.00E+00	1.70E-11	2.40E-09	8.04E-12	5.29E-71	9.30E-02	1.17E+00	4.89E-12	6.00E-03	4.08E+00	0.00E+00	3.91E+00	0.00E+00	1.29E-07
BATCH-1112	10/12/32	119	12.4	0.24	3.52E+02	0.00E+00	1.70E-11	2.40E-09	8.02E-12	1.82E-71	9.30E-02	1.17E+00	4.88E-12	6.00E-03	4.07E+00	0.00E+00	3.91E+00	0.00E+00	1.28E-07
BATCH-1113	10/13/32	18	1.9	0.24	3.03E+01	0.00E+00	1.46E-12	4.03E-10	6.90E-13	2.94E-66	1.20E-02	1.57E-01	4.26E-13	3.90E-04	3.82E-01	0.00E+00	1.12E+00	0.00E+00	3.72E-09
BATCH-1114	10/15/32	119	12.4	0.24	3.52E+02	0.00E+00	1.69E-11	2.39E-09	7.99E-12	6.29E-66	9.30E-02	1.16E+00	4.86E-12	6.00E-03	4.06E+00	0.00E+00	3.90E+00	0.00E+00	1.28E-07
BATCH-1115	10/24/32	17	1.7	0.24	2.25E+01	0.00E+00	9.90E-13	3.67E-10	4.69E-13	1.17E-65	1.00E-02	1.37E-01	2.93E-13	3.64E-04	3.28E-01	0.00E+00	8.15E-01	0.00E+00	3.96E-09
BATCH-1116	10/26/32	50	5.2	0.24	1.33E+02	0.00E+00	7.31E-12	1.03E-09	3.45E-12	4.88E-76	3.50E-02	4.42E-01	2.10E-12	2.00E-03	1.60E+00	0.00E+00	1.53E+00	0.00E+00	4.18E-08
BATCH-1117	10/28/32	51	5.3	0.24	1.35E+02	0.00E+00	6.53E-12	9.22E-10	3.08E-12	2.03E-71	3.60E-02	4.48E-01	1.88E-12	2.00E-03	1.57E+00	0.00E+00	1.50E+00	0.00E+00	4.93E-08
BATCH-1118	11/1/32	75	7.8	0.24	4.00E-03	2.34E+01	1.16E-13	2.30E-10	4.66E-14	4.17E-70	6.70E-02	1.68E+00	1.62E-13	2.00E-02	7.54E+00	0.00E+00	1.59E-04	1.03E+00	6.81E-07
BATCH-1119	11/2/32	51	5.3	0.24	1.35E+02	0.00E+00	6.52E-12	9.20E-10	3.08E-12	6.99E-72	3.60E-02	4.47E-01	1.87E-12	2.00E-03	1.56E+00	0.00E+00	1.50E+00	0.00E+00	4.93E-08
BATCH-1120	11/8/32	50	5.3	0.24	1.35E+02	0.00E+00	6.50E-12	9.17E-10	3.07E-12	2.42E-66	3.60E-02	4.47E-01	1.87E-12	2.00E-03	1.56E+00	0.00E+00	1.50E+00	0.00E+00	4.93E-08
BATCH-1121	11/9/32	75	7.8	0.24	3.00E-03	2.33E+01	1.15E-13	2.30E-10	4.65E-14	6.70E-02	1.68E+00	1.62E-13	1.50E-02	2.00E-02	7.54E+00	0.00E+00	1.05E-04	1.03E+00	6.80E-07
BATCH-1122	11/13/32	18	1.9	0.24	3.54E+01	0.00E+00	1.94E-12	2.73E-10	9.17E-13	1.30E-76	9.00E-03	1.17E-01	5.57E-13	5.38E-04	4.26E-01	0.00E+00	4.06E-01	0.00E+00	1.11E-08
BATCH-1123	11/15/32	18	1.9	0.24	3.60E+01	0.00E+00	1.74E-12	2.45E-10	8.21E-13	5.40E-72	9.00E-03	1.19E-01	5.00E-13	5.76E-04	4.17E-01	0.00E+00	4.00E-01	0.00E+00	1.31E-08
BATCH-1124	11/17/32	18	1.9	0.24	3.60E+01	0.00E+00	1.73E-12	2.45E-10	8.19E-13	1.86E-72	9.00E-03	1.19E-01	4.98E-13	5.75E-04	4.16E-01	0.00E+00	3.99E-01	0.00E+00	1.31E-08
BATCH-1125	11/17/32	52	5.4	0.24	2.23E-06	1.62E+01	7.99E-14	1.59E-10	3.22E-14	2.17E-73	4.60E-02	1.16E+00	1.12E-13	1.40E-02	5.22E+00	0.00E+00	8.24E-08	7.13E-01	4.71E-07
BATCH-1126	11/19/32	18	1.9	0.24	3.59E+01	0.00E+00	1.73E-12	2.44E-10	8.15E-13	6.42E-67	9.00E-03	1.19E-01	4.96E-13	5.74E-04	4.14E-01	0.00E+00	3.98E-01	0.00E+00	1.31E-08

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization			Losses		1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1078	6/21/32	38	4.0	0.24	1.26E-14	3.21E+01	3.29E-01	0.00E+00	0.00E+00	1.00E-03	1.39E+00	2.00E-03	2.57E-13	3.27E-13	4.20E-02	1.02E-13	6.50E+02	0.00E+00	6.20E-02
BATCH-1079	6/23/32	52	5.4	0.24	6.20E-15	1.31E+01	7.19E-01	0.00E+00	0.00E+00	8.00E-04	4.96E-01	2.68E-05	4.09E-13	1.58E-12	3.00E-03	1.15E-14	8.85E+02	0.00E+00	3.13E-01
BATCH-1080	6/25/32	108	11.3	0.24	1.29E-14	2.75E+01	1.79E+00	0.00E+00	0.00E+00	1.40E-03	1.16E+00	4.10E-04	6.28E-13	2.15E-12	1.30E-02	5.47E-14	1.85E+03	0.00E+00	6.44E-01
BATCH-1081	6/29/32	120	12.5	0.24	1.55E-14	3.30E+01	1.93E+00	0.00E+00	0.00E+00	1.60E-03	1.36E+00	4.20E-04	8.04E-13	2.84E-12	1.40E-02	5.85E-14	2.05E+03	0.00E+00	7.66E-01
BATCH-1082	7/7/32	104	10.8	0.24	1.37E-14	2.51E+01	2.25E+00	0.00E+00	0.00E+00	1.00E-03	1.42E+00	5.16E-04	2.57E-13	1.64E-13	1.60E-02	1.15E-13	1.78E+03	0.00E+00	1.14E+00
BATCH-1083	7/12/32	18	1.9	0.24	1.55E-15	3.29E+00	1.80E-01	0.00E+00	0.00E+00	1.90E-04	1.24E-01	6.70E-06	1.02E-13	3.95E-13	6.28E-04	2.87E-15	3.06E+02	0.00E+00	7.80E-02
BATCH-1084	7/14/32	99	10.3	0.24	1.00E-14	2.15E+01	1.78E+00	0.00E+00	0.00E+00	8.00E-04	1.07E+00	7.75E-04	1.96E-13	1.80E-13	2.10E-02	8.33E-14	1.68E+03	0.00E+00	5.03E-01
BATCH-1085	7/18/32	18	1.9	0.24	1.55E-15	3.28E+00	1.79E-01	0.00E+00	0.00E+00	1.89E-04	1.24E-01	6.68E-06	1.02E-13	3.94E-13	6.26E-04	2.86E-15	3.06E+02	0.00E+00	7.80E-02
BATCH-1086	7/20/32	53	5.5	0.24	5.76E-15	1.23E+01	7.99E-01	0.00E+00	0.00E+00	6.00E-04	5.18E-01	1.83E-04	2.80E-13	9.60E-13	6.00E-03	2.44E-14	9.07E+02	0.00E+00	2.87E-01
BATCH-1087	7/24/32	50	5.2	0.24	5.82E-15	1.24E+01	7.28E-01	0.00E+00	0.00E+00	6.00E-04	5.13E-01	1.58E-04	3.03E-13	1.07E-12	5.00E-03	2.20E-14	8.59E+02	0.00E+00	2.88E-01
BATCH-1088	7/26/32	60	6.3	0.24	1.99E-14	5.11E+01	5.23E-01	0.00E+00	0.00E+00	1.60E-03	2.21E+00	3.00E-03	4.08E-13	5.19E-13	6.70E-02	1.62E-13	1.03E+03	0.00E+00	9.80E-02
BATCH-1089	7/30/32	52	5.4	0.24	6.15E-15	1.13E+01	1.01E+00	0.00E+00	0.00E+00	4.00E-04	6.39E-01	2.32E-04	1.16E-13	7.36E-14	7.00E-03	5.19E-14	8.81E+02	0.00E+00	5.11E-01
BATCH-1090	8/1/32	53	5.5	0.24	4.97E-14	4.40E+01	4.44E-01	0.00E+00	0.00E+00	1.20E-03	1.86E+00	2.00E-03	3.13E-12	2.34E-10	5.40E-02	8.71E-13	8.98E+02	0.00E+00	8.50E-02
BATCH-1091	8/4/32	53	5.6	0.24	5.00E-15	1.07E+01	8.85E-01	0.00E+00	0.00E+00	4.00E-04	5.34E-01	3.86E-04	9.75E-14	8.96E-14	1.10E-02	4.15E-14	9.12E+02	0.00E+00	2.51E-01
BATCH-1092	8/7/32	20	2.0	0.24	1.63E-15	3.47E+00	2.26E-01	0.00E+00	0.00E+00	1.69E-04	1.46E-01	5.17E-05	7.92E-14	2.71E-13	2.00E-03	6.90E-15	3.34E+02	0.00E+00	8.10E-02
BATCH-1093	8/9/32	18	1.9	0.24	1.53E-15	3.27E+00	1.92E-01	0.00E+00	0.00E+00	1.65E-04	1.35E-01	4.16E-05	7.97E-14	2.81E-13	1.00E-03	5.80E-15	3.08E+02	0.00E+00	7.60E-02
BATCH-1094	8/10/32	51	5.3	0.24	1.97E-13	4.06E+01	3.80E-01	0.00E+00	0.00E+00	1.48E-04	1.53E+00	1.03E-04	1.58E-11	1.30E-09	3.00E-02	4.21E-12	8.66E+02	0.00E+00	7.80E-02
BATCH-1095	8/11/32	19	2.0	0.24	1.71E-15	3.14E+00	2.82E-01	0.00E+00	0.00E+00	1.15E-04	1.78E-01	6.48E-05	3.22E-14	2.05E-14	2.00E-03	1.45E-14	3.24E+02	0.00E+00	1.42E-01
BATCH-1096	8/13/32	43	4.5	0.24	1.67E-13	3.43E+01	3.21E-01	0.00E+00	0.00E+00	1.25E-04	1.29E+00	8.66E-05	1.34E-11	1.10E-09	2.50E-02	3.56E-12	7.32E+02	0.00E+00	6.50E-02
BATCH-1097	8/16/32	21	2.2	0.24	1.60E-15	3.41E+00	2.82E-01	0.00E+00	0.00E+00	1.16E-04	1.70E-01	1.23E-04	3.11E-14	2.86E-14	3.00E-03	1.32E-14	3.60E+02	0.00E+00	8.00E-02
BATCH-1098	8/18/32	69	7.2	0.24	2.68E-13	5.52E+01	5.16E-01	0.00E+00	0.00E+00	2.00E-04	2.08E+00	1.38E-04	2.15E-11	1.77E-09	4.10E-02	5.73E-12	1.18E+03	0.00E+00	1.05E-01
BATCH-1099	8/18/32	69	7.2	0.24	2.68E-13	5.51E+01	5.16E-01	0.00E+00	0.00E+00	2.00E-04	2.08E+00	1.38E-04	2.15E-11	1.77E-09	4.10E-02	5.72E-12	1.18E+03	0.00E+00	1.05E-01
BATCH-1100	8/25/32	69	7.2	0.24	2.68E-13	5.51E+01	5.16E-01	0.00E+00	0.00E+00	2.00E-04	2.08E+00	1.38E-04	2.15E-11	1.77E-09	4.10E-02	5.72E-12	1.18E+03	0.00E+00	1.05E-01
BATCH-1101	8/26/32	98	10.2	0.24	5.15E-14	1.98E+01	1.21E+00	0.00E+00	0.00E+00	4.00E-04	8.03E-01	5.38E-04	3.90E-12	3.15E-10	2.00E-02	1.05E-12	1.67E+03	0.00E+00	3.80E-02
BATCH-1102	9/2/32	120	12.5	0.24	5.23E-14	2.58E+01	1.31E+00	0.00E+00	0.00E+00	6.00E-04	1.06E+00	8.60E-04	3.81E-12	3.04E-10	2.80E-02	1.03E-12	2.04E+03	0.00E+00	5.00E-02
BATCH-1103	9/5/32	69	7.2	0.24	2.68E-13	5.50E+01	5.15E-01	0.00E+00	0.00E+00	2.00E-04	2.08E+00	1.37E-04	2.15E-11	1.77E-09	4.10E-02	5.71E-12	1.18E+03	0.00E+00	1.05E-01
BATCH-1104	9/12/32	50	5.3	0.24	1.11E-14	3.91E+01	7.75E-01	0.00E+00	0.00E+00	2.00E-04	1.48E+00	2.41E-05	1.27E-12	7.67E-11	1.20E-02	2.34E-13	8.62E+02	0.00E+00	5.50E-02
BATCH-1105	9/15/32	52	5.4	0.24	2.71E-16	4.01E+01	8.19E-01	0.00E+00	0.00E+00	2.00E-04	1.52E+00	2.01E-05	4.39E-13	5.43E-12	1.10E-02	2.98E-15	8.83E+02	0.00E+00	5.50E-02
BATCH-1106	9/18/32	52	5.4	0.24	2.71E-16	4.01E+01	8.19E-01	0.00E+00	0.00E+00	2.00E-04	1.52E+00	2.01E-05	4.39E-13	5.43E-12	1.10E-02	2.97E-15	8.84E+02	0.00E+00	5.50E-02
BATCH-1107	9/20/32	49	5.1	0.24	2.35E-14	9.03E+00	5.52E-01	0.00E+00	0.00E+00	1.58E-04	3.66E-01	2.45E-04	1.78E-12	1.44E-10	9.00E-03	4.78E-13	8.43E+02	0.00E+00	1.70E-02
BATCH-1108	9/24/32	52	5.4	0.24	2.71E-16	4.01E+01	8.19E-01	0.00E+00	0.00E+00	2.00E-04	1.52E+00	2.01E-05	4.40E-13	5.43E-12	1.10E-02	2.97E-15	8.84E+02	0.00E+00	5.50E-02
BATCH-1109	9/25/32	46	4.8	0.24	1.79E-14	8.84E+00	4.49E-01	0.00E+00	0.00E+00	1.86E-04	3.64E-01	2.95E-04	1.31E-12	1.04E-10	1.00E-02	3.54E-13	7.89E+02	0.00E+00	1.70E-02
BATCH-1110	9/29/32	122	12.7	0.24	7.94E-14	2.51E+01	1.39E+00	0.00E+00	0.00E+00	1.15E-04	9.49E-01	4.52E-05	6.46E-12	5.26E-10	1.50E-02	1.70E-12	2.08E+03	0.00E+00	4.30E-02
BATCH-1111	10/1/32	119	12.4	0.24	6.90E-14	2.45E+01	1.40E+00	0.00E+00	0.00E+00	1.17E-04	9.24E-01	4.06E-05	5.64E-12	4.57E-10	1.30E-02	1.47E-12	2.03E+03	0.00E+00	4.10E-02
BATCH-1112	10/12/32	119	12.4	0.24	6.88E-14	2.44E+01	1.40E+00	0.00E+00	0.00E+00	1.17E-04	9.23E-01	4.05E-05	5.63E-12	4.56E-10	1.30E-02	1.47E-12	2.03E+03	0.00E+00	4.10E-02
BATCH-1113	10/13/32	18	1.9	0.24	6.40E-15	2.46E+00	1.50E-01	0.00E+00	0.00E+00	4.32E-05	1.00E-01	6.69E-05	4.84E-13	3.91E-11	3.00E-03	1.30E-13	3.10E+02	0.00E+00	5.00E-03
BATCH-1114	10/15/32	119	12.4	0.24	6.86E-14	2.44E+01	1.40E+00	0.00E+00	0.00E+00	1.17E-04	9.20E-01	4.03E-05	5.60E-12	4.54E-10	1.30E-02	1.46E-12	2.02E+03	0.00E+00	4.10E-02
BATCH-1115	10/24/32	17	1.7	0.24	4.57E-15	2.25E+00	1.14E-01	0.00E+00	0.00E+00	4.74E-05	9.30E-02	7.52E-05	3.33E-13	2.66E-11	2.00E-03	9.02E-14	2.85E+02	0.00E+00	4.00E-03
BATCH-1116	10/26/32	50	5.2	0.24	2.96E-14	9.36E+00	5.18E-01	0.00E+00	0.00E+00	4.30E-05	3.54E-01	1.68E-05	2.41E-12	1.96E-10	5.00E-03	6.32E-13	8.59E+02	0.00E+00	1.60E-02
BATCH-1117	10/28/32	51	5.3	0.24	2.65E-14	9.38E+00	5.37E-01	0.00E+00	0.00E+00	4.49E-05	3.54E-01	1.56E-05	2.16E-12	1.75E-10	5.00E-03	5.65E-13	8.64E+02	0.00E+00	1.60E-02
BATCH-1118	11/1/32	75	7.8	0.24	1.92E-16	5.78E+01	1.18E+00	0.00E+00	0.00E+00	4.00E-04	2.19E+00	2.89E-05	6.18E-13	6.52E-12	1.60E-02	1.85E-17	1.28E+03	0.00E+00	7.90E-02
BATCH-1119	11/2/32	51	5.3	0.24	2.64E-14	9.37E+00	5.37E-01	0.00E+00	0.00E+00	4.48E-05	3.54E-01	1.55E-05	2.16E-12	1.75E-10	5.00E-03	5.64E-13	8.63E+02	0.00E+00	1.60E-02
BATCH-1120	11/8/32	50	5.3	0.24	2.63E-14	9.35E+00	5.36E-01	0.00E+00	0.00E+00	4.47E-05	3.53E-01	1.55E-05	2.15E-12	1.74E-10	5.00E-03	5.62E-13	8.63E+02	0.00E+00	1.60E-02
BATCH-1121	11/9/32	75	7.8	0.24	1.91E-16	5.77E+01	1.18E+00	0.00E+00	0.00E+00	4.00E-04	2.19E+00	2.89E-05	6.18E-13	6.51E-12	1.60E-02	1.16E-17	1.27E+03	0.00E+00	7.90E-02
BATCH-1122	11/13/32	18	1.9	0.24	7.87E-15	2.49E+00	1.38E-01	0.00E+00	0.00E+00	1.14E-05	9.40E-02	4.47E-06	6.40E-13	5.21E-11	1.00E-03	1.68E-13	3.10E+02	0.00E+00	4.00E-03
BATCH-1123	11/15/32	18	1.9	0.24	7.04E-15	2.50E+00	1.43E-01	0.00E+00	0.00E+00	1.19E-05	9.40E-02	4.14E-06	5.76E-13	4.67E-11	1.00E-03	1.50E-13	3.11E+02	0.00E+00	4.00E-03
BATCH-1124	11/17/32	18	1.9	0.24	7.03E-15	2.49E+00	1.43E-01	0.00E+00	0.00E+00	1.19E-05	9.40E-02	4.13E-06	5.74E-13	4.66E-11	1.00E-03	1.50E-13	3.11E+02	0.00E+00	4.00E-03
BATCH-1125	11/17/32	52	5.4	0.24	1.32E-16	4.00E+01	8.18E-01	0.00E+00	0.00E+00	2.00E-04	1.51E+00	2.00E-05	4.28E-13	4.51E-12	1.10E-02	9.62E-21	8.83E+02	0.00E+00	5.50E-02
BATCH-1126	11/19/32	18	1.9	0.24	6.99E-15	2.49E+00	1.43E-01	0.00E+00	0.00E+00	1.19E-05	9.40E-02	4.12E-06	5.72E-13	4.64E-11	1.00E-03	1.49E-13	3.11E+02	0.00E+00	4.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1078	6/21/32	38	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	9.11E+01	3.94E-16	4.66E+00	1.02E+01	4.70E-02	1.04E-14	0.00E+00	5.26E-04	7.57E-11	1.30E-02
BATCH-1079	6/23/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.26E+01	5.97E-15	1.39E+01	4.44E+00	2.00E-03	1.15E-15	0.00E+00	1.00E-03	7.05E-11	6.00E-03
BATCH-1080	6/25/32	108	11.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.28E+02	7.94E-15	4.68E+01	9.83E+00	1.40E-02	5.60E-15	0.00E+00	2.00E-03	1.09E-10	1.20E-02
BATCH-1081	6/29/32	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.38E+02	1.05E-14	4.78E+01	1.12E+01	1.50E-02	5.98E-15	0.00E+00	2.00E-03	1.40E-10	1.40E-02
BATCH-1082	7/7/32	104	10.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.16E+02	3.11E-16	5.11E+01	1.02E+01	1.70E-02	1.21E-14	0.00E+00	1.00E-03	2.14E-11	8.00E-03
BATCH-1083	7/12/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.34E-04	1.32E+01	1.49E-15	3.47E+00	1.11E+00	5.76E-04	2.87E-16	0.00E+00	2.84E-04	1.76E-11	1.00E-03
BATCH-1084	7/14/32	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.22E+02	2.65E-16	5.95E+01	8.41E+00	2.30E-02	8.61E-15	0.00E+00	7.14E-04	3.46E-11	8.00E-03
BATCH-1085	7/18/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.32E-04	1.31E+01	1.49E-15	3.46E+00	1.11E+00	5.75E-04	2.86E-16	0.00E+00	2.83E-04	1.76E-11	1.00E-03
BATCH-1086	7/20/32	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.69E+01	3.54E-15	2.09E+01	4.39E+00	6.00E-03	2.50E-15	0.00E+00	8.14E-04	4.86E-11	5.00E-03
BATCH-1087	7/24/32	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	5.20E+01	3.97E-15	1.80E+01	4.22E+00	6.00E-03	2.25E-15	0.00E+00	8.50E-04	5.26E-11	5.00E-03
BATCH-1088	7/26/32	60	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.45E+02	6.26E-16	7.40E+00	1.61E+01	7.40E-02	1.65E-14	0.00E+00	8.36E-04	1.20E-10	2.00E-02
BATCH-1089	7/30/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.22E+01	1.40E-16	2.30E+01	4.57E+00	8.00E-03	5.42E-15	0.00E+00	5.39E-04	9.64E-12	4.00E-03
BATCH-1090	8/1/32	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.13E+02	3.36E-14	7.14E+00	1.92E+01	5.40E-02	1.92E-14	0.00E+00	6.04E-04	1.89E-10	1.70E-02
BATCH-1091	8/4/32	53	5.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.07E+01	1.32E-16	2.97E+01	4.19E+00	1.10E-02	4.29E-15	0.00E+00	3.56E-04	1.73E-11	4.00E-03
BATCH-1092	8/7/32	20	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E-04	1.61E+01	1.00E-15	5.91E+00	1.24E+00	2.00E-03	7.07E-16	0.00E+00	2.30E-04	1.38E-11	1.00E-03
BATCH-1093	8/9/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.28E-04	1.37E+01	1.04E-15	4.74E+00	1.11E+00	1.00E-03	5.92E-16	0.00E+00	2.24E-04	1.38E-11	1.00E-03
BATCH-1094	8/10/32	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	4.73E+01	1.85E-13	1.01E+01	4.26E+01	4.00E-03	4.10E-14	0.00E+00	1.18E-05	5.74E-10	1.40E-02
BATCH-1095	8/11/32	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.89E-04	1.46E+01	3.89E-17	6.41E+00	1.27E+00	2.00E-03	1.51E-15	0.00E+00	1.50E-04	2.69E-12	1.00E-03
BATCH-1096	8/13/32	43	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	3.99E+01	1.56E-13	8.54E+00	3.60E+01	3.00E-03	3.47E-14	0.00E+00	9.96E-06	4.85E-10	1.10E-02
BATCH-1097	8/16/32	21	2.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.60E-04	1.94E+01	4.21E-17	9.46E+00	1.34E+00	4.00E-03	1.37E-15	0.00E+00	1.14E-04	5.50E-12	1.00E-03
BATCH-1098	8/18/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.42E+01	2.52E-13	1.38E+01	5.80E+01	5.00E-03	5.58E-14	0.00E+00	1.55E-05	7.81E-10	1.80E-02
BATCH-1099	8/18/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.42E+01	2.52E-13	1.38E+01	5.79E+01	5.00E-03	5.58E-14	0.00E+00	1.55E-05	7.80E-10	1.80E-02
BATCH-1100	8/25/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.41E+01	2.51E-13	1.37E+01	5.79E+01	5.00E-03	5.58E-14	0.00E+00	1.55E-05	7.80E-10	1.80E-02
BATCH-1101	8/26/32	98	10.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.12E+02	4.48E-14	6.66E+01	1.46E+01	1.50E-02	1.31E-14	0.00E+00	1.76E-04	1.62E-10	7.00E-03
BATCH-1102	9/2/32	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.33E+02	4.33E-14	7.02E+01	1.62E+01	2.40E-02	1.48E-14	0.00E+00	2.79E-04	1.72E-10	1.00E-02
BATCH-1103	9/5/32	69	7.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	6.41E+01	2.51E-13	1.37E+01	5.78E+01	5.00E-03	5.57E-14	0.00E+00	1.55E-05	7.79E-10	1.80E-02
BATCH-1104	9/12/32	50	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.59E+01	1.03E-14	1.00E+01	4.64E+01	6.20E-02	2.28E-15	0.00E+00	4.39E-04	3.46E-11	2.40E-02
BATCH-1105	9/15/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.70E+01	1.31E-16	1.03E+01	4.78E+01	6.70E-02	2.90E-17	0.00E+00	4.76E-04	3.31E-12	2.50E-02
BATCH-1106	9/18/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.70E+01	1.31E-16	1.03E+01	4.78E+01	6.70E-02	2.90E-17	0.00E+00	4.76E-04	3.31E-12	2.50E-02
BATCH-1107	9/20/32	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	5.12E+01	2.04E-14	3.03E+01	6.63E+00	7.00E-03	5.99E-15	0.00E+00	8.02E-05	7.40E-11	3.00E-03
BATCH-1108	9/24/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.70E+01	1.30E-16	1.03E+01	4.79E+01	6.70E-02	2.89E-17	0.00E+00	4.76E-04	3.31E-12	2.50E-02
BATCH-1109	9/25/32	46	4.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.57E+01	1.48E-14	2.41E+01	5.57E+00	8.00E-03	5.08E-15	0.00E+00	9.57E-05	5.90E-11	3.00E-03
BATCH-1110	9/29/32	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.15E+02	7.45E-14	7.01E+01	2.91E+01	1.60E-02	1.65E-14	0.00E+00	1.23E-04	2.32E-10	1.10E-02
BATCH-1111	10/1/32	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.13E+02	6.47E-14	6.83E+01	2.86E+01	1.80E-02	1.44E-14	0.00E+00	1.41E-04	2.02E-10	1.10E-02
BATCH-1112	10/12/32	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.13E+02	6.45E-14	6.82E+01	2.86E+01	1.80E-02	1.43E-14	0.00E+00	1.41E-04	2.01E-10	1.10E-02
BATCH-1113	10/13/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.76E-04	1.40E+01	5.57E-15	8.27E+00	1.81E+00	2.00E-03	1.63E-15	0.00E+00	2.19E-05	2.02E-11	8.92E-04
BATCH-1114	10/15/32	119	12.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.12E+02	6.43E-14	6.81E+01	2.85E+01	1.80E-02	1.43E-14	0.00E+00	1.41E-04	2.00E-10	1.10E-02
BATCH-1115	10/24/32	17	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.07E-04	1.16E+01	3.78E-15	6.14E+00	1.42E+00	2.00E-03	1.30E-15	0.00E+00	2.44E-05	1.51E-11	8.33E-04
BATCH-1116	10/26/32	50	5.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.27E+01	2.78E-14	2.61E+01	1.09E+01	6.00E-03	6.16E-15	0.00E+00	4.58E-05	8.64E-11	4.00E-03
BATCH-1117	10/28/32	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.32E+01	2.48E-14	2.62E+01	1.10E+01	7.00E-03	5.50E-15	0.00E+00	5.40E-05	7.73E-11	4.00E-03
BATCH-1118	11/1/32	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	6.78E+01	7.90E-19	1.48E+01	6.90E+01	9.60E-02	2.32E-19	0.00E+00	6.87E-04	4.20E-12	3.60E-02
BATCH-1119	11/2/32	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.32E+01	2.48E-14	2.62E+01	1.10E+01	7.00E-03	5.49E-15	0.00E+00	5.40E-05	7.69E-11	4.00E-03
BATCH-1120	11/8/32	50	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	4.32E+01	2.47E-14	2.62E+01	1.09E+01	7.00E-03	5.47E-15	0.00E+00	5.40E-05	6.86E-11	4.00E-03
BATCH-1121	11/9/32	75	7.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-02	6.78E+01	4.87E-19	1.48E+01	6.90E+01	9.60E-02	1.67E-19	0.00E+00	6.86E-04	4.20E-12	3.60E-02
BATCH-1122	11/13/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-04	1.14E+01	7.38E-15	6.95E+00	2.88E+00	2.00E-03	1.64E-15	0.00E+00	1.22E-05	2.30E-11	1.00E-03
BATCH-1123	11/15/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-04	1.15E+01	6.61E-15	6.98E+00	2.92E+00	2.00E-03	1.47E-15	0.00E+00	1.44E-05	2.06E-11	1.00E-03
BATCH-1124	11/17/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.79E-04	1.15E+01	6.59E-15	6.97E+00	2.92E+00	2.00E-03	1.46E-15	0.00E+00	1.44E-05	2.05E-11	1.00E-03
BATCH-1125	11/17/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	4.70E+01	4.10E-22	1.03E+01	4.78E+01	6.70E-02	1.21E-22	0.00E+00	4.76E-04	2.91E-12	2.50E-02
BATCH-1126	11/19/32	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.77E-04	1.15E+01	6.56E-15	6.95E+00	2.91E+00	2.00E-03	1.46E-15	0.00E+00	1.44E-05	2.04E-11	1.00E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H Ci	14-C Ci	59-Ni Ci	60-Co Ci	63-Ni Ci	79-Se Ci	90-Sr Ci	93-Zr Ci	93m-Nb Ci	99-Tc Ci	106-Ru Ci	113m-Cd Ci	125-Sb Ci	126-Sn Ci	129-I Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1127	11/21/32	29	3.0	0.24	0.00E+00	0.00E+00	2.50E-02	2.40E-04	1.89E+00	1.83E-01	5.83E+02	9.00E-02	6.60E-02	2.90E+00	7.47E-16	8.70E-02	7.91E-04	2.90E-02	1.25E-03
BATCH-1128	11/23/32	44	4.6	0.24	0.00E+00	0.00E+00	3.10E-02	4.38E-04	2.31E+00	3.50E-01	8.87E+02	2.15E-01	9.00E-02	4.42E+00	8.99E-16	3.49E-01	1.00E-03	3.80E-02	1.85E-02
BATCH-1129	11/24/32	42	4.4	0.24	0.00E+00	0.00E+00	3.70E-02	3.45E-04	2.72E+00	2.63E-01	8.39E+02	1.29E-01	9.40E-02	4.18E+00	1.08E-15	1.24E-01	1.00E-03	4.10E-02	1.75E-03
BATCH-1130	11/28/32	42	4.4	0.24	0.00E+00	0.00E+00	3.70E-02	3.44E-04	2.71E+00	2.63E-01	8.39E+02	1.29E-01	9.40E-02	4.18E+00	1.08E-15	1.24E-01	1.00E-03	4.10E-02	1.75E-03
BATCH-1131	11/28/32	42	4.4	0.24	0.00E+00	0.00E+00	3.70E-02	3.44E-04	2.71E+00	2.63E-01	8.38E+02	1.29E-01	9.40E-02	4.18E+00	1.08E-15	1.24E-01	1.00E-03	4.10E-02	1.75E-03
BATCH-1132	12/2/32	115	12.0	0.24	0.00E+00	0.00E+00	2.00E-03	5.04E-04	1.61E-01	4.37E-01	2.30E+03	3.59E-01	3.70E-02	4.03E+00	1.05E-17	8.18E-01	2.97E-04	1.10E-02	5.70E-02
BATCH-1133	12/3/32	124	12.9	0.24	0.00E+00	0.00E+00	8.00E-03	3.83E-04	6.14E-01	3.26E-01	2.48E+03	2.51E-01	4.10E-02	3.43E+00	2.10E-16	5.41E-01	4.03E-04	1.50E-02	3.65E-02
BATCH-1134	12/15/32	28	2.9	0.24	0.00E+00	0.00E+00	2.40E-02	2.28E-04	1.80E+00	1.74E-01	5.56E+02	8.50E-02	6.20E-02	2.77E+00	7.12E-16	8.20E-02	7.54E-04	2.70E-02	1.25E-03
BATCH-1135	12/16/32	29	3.0	0.24	0.00E+00	0.00E+00	2.50E-02	2.71E-04	1.82E+00	3.56E-01	5.82E+02	2.12E-01	3.60E-02	2.90E+00	5.32E-16	5.20E-02	3.67E-04	3.20E-02	1.00E-03
BATCH-1136	12/18/32	39	4.1	0.24	0.00E+00	0.00E+00	3.20E-02	3.99E-04	2.37E+00	6.72E-01	3.84E+02	4.23E-01	1.40E-02	3.89E+00	4.76E-16	3.30E-02	2.03E-05	4.60E-02	1.50E-03
BATCH-1137	12/19/32	39	4.1	0.24	0.00E+00	0.00E+00	3.20E-02	4.00E-04	2.37E+00	6.72E-01	3.84E+02	4.23E-01	1.40E-02	3.89E+00	4.76E-16	3.30E-02	2.03E-05	4.60E-02	1.50E-03
BATCH-1138	12/22/32	52	5.4	0.24	0.00E+00	0.00E+00	8.85E-04	2.05E-04	6.50E-02	1.77E-01	1.03E+03	1.46E-01	1.50E-02	1.64E+00	4.28E-18	3.33E-01	1.21E-04	5.00E-03	2.33E-02
BATCH-1139	12/24/32	48	5.0	0.24	0.00E+00	0.00E+00	3.00E-03	1.32E-04	2.11E-01	1.13E-01	9.56E+02	8.60E-02	1.40E-02	1.18E+00	7.22E-17	1.86E-01	1.39E-04	5.00E-03	1.25E-02
BATCH-1140	12/28/32	139	14.5	0.24	0.00E+00	0.00E+00	1.50E-02	2.81E-04	1.12E+00	2.30E-01	2.77E+03	1.54E-01	4.80E-02	3.01E+00	4.29E-16	2.85E-01	5.36E-04	2.00E-02	1.70E-02
BATCH-1141	12/29/32	150	15.6	0.24	0.00E+00	0.00E+00	2.10E-02	2.07E-04	1.60E+00	1.75E-01	2.99E+03	9.00E-02	5.20E-02	2.73E+00	6.11E-16	6.90E-02	6.24E-04	2.50E-02	1.00E-03
BATCH-1142	1/11/33	136	14.2	0.24	0.00E+00	0.00E+00	2.00E-02	1.85E-04	1.44E+00	2.61E-01	2.72E+03	1.53E-01	3.00E-02	2.45E+00	2.26E-16	4.40E-02	2.68E-04	2.50E-02	1.00E-03
BATCH-1143	1/14/33	136	14.2	0.24	0.00E+00	0.00E+00	2.00E-02	1.85E-04	1.44E+00	2.61E-01	2.72E+03	1.53E-01	3.00E-02	2.45E+00	2.25E-16	4.30E-02	2.67E-04	2.50E-02	1.00E-03
BATCH-1144	1/26/33	19	2.0	0.24	0.00E+00	0.00E+00	2.42E-04	4.90E-05	1.80E-02	4.86E-02	3.75E+02	4.00E-02	4.00E-03	4.47E-01	5.88E-19	8.70E-02	2.57E-05	1.00E-03	6.25E-03
BATCH-1145	1/28/33	17	1.8	0.24	0.00E+00	0.00E+00	7.08E-04	2.87E-05	5.20E-02	2.79E-02	3.38E+02	2.10E-02	3.00E-03	2.93E-01	9.01E-18	4.40E-02	2.68E-05	1.00E-03	3.00E-03
BATCH-1146	1/28/33	41	4.3	0.24	0.00E+00	0.00E+00	4.00E-03	6.46E-05	2.91E-01	6.03E-02	8.28E+02	4.00E-02	1.20E-02	7.88E-01	5.64E-17	7.10E-02	1.09E-04	5.00E-03	4.50E-03
BATCH-1147	1/30/33	39	4.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.14E-05	3.61E-01	3.96E-02	7.80E+02	2.00E-02	1.10E-02	6.23E-01	7.00E-17	1.50E-02	1.11E-04	6.00E-03	2.28E-04
BATCH-1148	2/2/33	39	4.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.67E-05	3.64E-01	6.57E-02	7.81E+02	3.90E-02	8.00E-03	6.18E-01	5.69E-17	1.10E-02	6.75E-05	6.00E-03	2.25E-04
BATCH-1149	2/3/33	39	4.1	0.24	0.00E+00	0.00E+00	5.00E-03	4.66E-05	3.63E-01	6.57E-02	7.80E+02	3.90E-02	8.00E-03	6.17E-01	5.68E-17	1.10E-02	6.73E-05	6.00E-03	2.25E-04
BATCH-1150	2/6/33	56	5.9	0.24	0.00E+00	0.00E+00	4.60E-02	5.06E-04	3.40E+00	9.72E-01	5.11E+02	6.11E-01	2.00E-02	5.62E+00	3.45E-16	4.50E-02	2.22E-05	6.70E-02	2.00E-03
BATCH-1151	2/8/33	56	5.9	0.24	0.00E+00	0.00E+00	4.60E-02	5.06E-04	3.40E+00	9.72E-01	5.10E+02	6.11E-01	2.00E-02	5.62E+00	3.45E-16	4.50E-02	2.22E-05	6.70E-02	2.00E-03
BATCH-1152	2/12/33	15	1.6	0.24	0.00E+00	0.00E+00	9.35E-04	1.53E-05	6.90E-02	1.44E-02	3.01E+02	1.00E-02	3.00E-03	1.86E-01	1.33E-17	1.70E-02	2.58E-05	1.00E-03	1.00E-03
BATCH-1153	2/14/33	14	1.5	0.24	0.00E+00	0.00E+00	1.00E-03	9.77E-06	8.50E-02	9.00E-03	2.86E+02	5.00E-03	3.00E-03	1.47E-01	1.65E-17	4.00E-03	2.62E-05	1.00E-03	5.38E-05
BATCH-1154	2/14/33	14	1.5	0.24	0.00E+00	0.00E+00	1.00E-03	1.11E-05	8.60E-02	1.53E-02	2.84E+02	9.00E-03	2.00E-03	1.46E-01	1.35E-17	3.00E-03	1.60E-05	1.00E-03	5.33E-05
BATCH-1155	2/15/33	14	1.5	0.24	0.00E+00	0.00E+00	1.00E-03	1.10E-05	8.60E-02	1.53E-02	2.84E+02	9.00E-03	2.00E-03	1.46E-01	1.34E-17	3.00E-03	1.59E-05	1.00E-03	5.32E-05
BATCH-1156	2/15/33	40	4.2	0.24	0.00E+00	0.00E+00	3.30E-02	3.59E-04	2.41E+00	6.89E-01	3.61E+02	4.33E-01	1.40E-02	3.98E+00	2.45E-16	3.20E-02	1.57E-05	4.70E-02	1.50E-03
BATCH-1157	2/17/33	40	4.2	0.24	0.00E+00	0.00E+00	3.30E-02	3.59E-04	2.41E+00	6.89E-01	3.61E+02	4.33E-01	1.40E-02	3.98E+00	2.44E-16	3.20E-02	1.57E-05	4.70E-02	1.50E-03
BATCH-1158	2/20/33	58	6.0	0.24	0.00E+00	0.00E+00	2.90E-02	3.73E-04	2.12E+00	9.23E-01	1.15E+03	5.08E-01	1.37E-01	4.28E+00	1.66E-16	5.10E-02	1.00E-03	9.50E-02	1.50E-03
BATCH-1159	2/21/33	71	7.4	0.24	0.00E+00	0.00E+00	2.10E-02	3.48E-04	1.57E+00	1.08E+00	1.42E+03	5.37E-01	2.59E-01	4.12E+00	6.16E-17	6.60E-02	2.00E-03	1.38E-01	1.50E-03
BATCH-1160	2/26/33	71	7.4	0.24	0.00E+00	0.00E+00	2.10E-02	3.48E-04	1.57E+00	1.08E+00	1.42E+03	5.37E-01	2.58E-01	4.12E+00	6.16E-17	6.60E-02	2.00E-03	1.37E-01	1.50E-03
BATCH-1161	3/1/33	71	7.4	0.24	0.00E+00	0.00E+00	2.10E-02	3.48E-04	1.57E+00	1.08E+00	1.42E+03	5.36E-01	2.58E-01	4.11E+00	6.15E-17	6.60E-02	2.00E-03	1.37E-01	1.50E-03
BATCH-1162	3/5/33	139	14.5	0.24	0.00E+00	0.00E+00	2.20E-02	2.39E-04	1.60E+00	4.58E-01	2.40E+02	2.88E-01	9.00E-03	2.67E+00	1.63E-16	2.10E-02	1.05E-05	3.10E-02	1.00E-03
BATCH-1163	3/8/33	139	14.5	0.24	0.00E+00	0.00E+00	2.20E-02	2.38E-04	1.60E+00	4.57E-01	2.40E+02	2.87E-01	9.00E-03	2.66E+00	1.62E-16	2.10E-02	1.04E-05	3.10E-02	1.00E-03
BATCH-1164	3/20/33	45	4.7	0.24	0.00E+00	0.00E+00	1.40E-02	2.22E-04	1.00E+00	6.91E-01	9.06E+02	3.43E-01	1.65E-01	2.63E+00	3.94E-17	4.20E-02	2.00E-03	8.80E-02	1.00E-03
BATCH-1165	3/23/33	51	5.3	0.24	0.00E+00	0.00E+00	1.50E-02	2.49E-04	1.12E+00	7.75E-01	1.02E+03	3.84E-01	1.85E-01	2.95E+00	4.41E-17	4.70E-02	2.00E-03	9.80E-02	1.25E-03
BATCH-1166	3/25/33	51	5.3	0.24	0.00E+00	0.00E+00	1.50E-02	2.49E-04	1.12E+00	7.74E-01	1.02E+03	3.84E-01	1.85E-01	2.94E+00	4.40E-17	4.70E-02	2.00E-03	9.80E-02	1.25E-03
BATCH-1167	3/29/33	31	3.3	0.24	0.00E+00	0.00E+00	1.30E-02	5.92E-05	9.78E-01	4.54E-01	6.24E+02	2.05E-01	4.40E-02	1.64E+00	2.57E-17	1.30E-02	3.54E-04	4.10E-02	5.00E-04
BATCH-1168	3/31/33	37	3.9	0.24	0.00E+00	0.00E+00	5.00E-03	5.66E-05	3.81E-01	1.09E-01	5.70E+01	6.80E-02	2.00E-03	6.33E-01	3.86E-17	5.00E-03	2.48E-06	7.00E-03	2.29E-04
BATCH-1169	4/1/33	37	3.9	0.24	0.00E+00	0.00E+00	5.00E-03	5.65E-05	3.80E-01	1.09E-01	5.69E+01	6.80E-02	2.00E-03	6.31E-01	3.85E-17	5.00E-03	2.48E-06	7.00E-03	2.29E-04
BATCH-1170	4/4/33	139	14.5	0.24	0.00E+00	0.00E+00	1.80E-02	2.22E-04	1.31E+00	5.21E-01	2.78E+03	2.95E-01	6.50E-02	2.53E+00	1.11E-16	2.80E-02	5.67E-04	5.00E-02	1.00E-03
BATCH-1171	4/5/33	120	12.5	0.24	0.00E+00	0.00E+00	9.00E-03	1.43E-04	6.45E-01	4.45E-01	2.40E+03	2.20E-01	1.06E-01	1.69E+00	2.53E-17	2.70E-02	9.99E-04	5.60E-02	7.50E-04
BATCH-1172	4/18/33	120	12.5	0.24	0.00E+00	0.00E+00	9.00E-03	1.43E-04	6.43E-01	4.43E-01	2.40E+03	2.20E-01	1.06E-01	1.69E+00	2.52E-17	2.70E-02	9.96E-04	5.60E-02	7.50E-04
BATCH-1173	4/18/33	124	12.9	0.24	0.00E+00	0.00E+00	9.00E-03	1.11E-04	6.66E-01	4.08E-01	2.48E+03	1.97E-01	8.20E-02	1.53E+00	2.31E-17	2.10E-02	7.61E-04	4.80E-02	5.00E-04
BATCH-1174	5/1/33	14	1.4	0.24	0.00E+00	0.00E+00	1.00E-03	1.34E-05	9.00E-02	2.61E-02	1.35E+01	1.60E-02	5.25E-04	1.50E-01	9.15E-18	1.00E-03	5.89E-07	2.00E-03	5.44E-05
BATCH-1175	5/2/33	14	1.4	0.24	0.00E+00	0.00E+00	1.00E-03	1.34E-05	9.00E-02	2.61E-02	1.35E+01	1.60E-02	5.24E-04	1.50E-01	9.13E-18	1.00E-03	5.88E-07	2.00E-03	5.43E-05

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction Remaining After Volatization Losses					0.24	8.75E-01	3.04E+00	1.00E-03	9.80E-02	3.00E-03	6.70E-06	1.33E-07	1.36E-05	4.00E-06	1.49E-05	8.70E-06	2.03E-04	1.00E-03	1.10E-02
BATCH-1127	11/21/32	29	3.0	4.6	0.24	1.33E+02	4.19E+00	2.00E-03	1.30E-01	5.00E-03	1.04E-05	1.95E-07	1.91E-05	6.81E-06	2.72E-05	1.43E-05	3.13E-04	2.00E-03	1.40E-02
BATCH-1128	11/23/32	44	4.6	4.4	0.24	1.26E+02	4.37E+00	2.00E-03	1.41E-01	4.00E-03	9.63E-06	1.91E-07	1.95E-05	5.76E-06	2.14E-05	1.25E-05	2.91E-04	2.00E-03	1.60E-02
BATCH-1129	11/24/32	42	4.4	4.4	0.24	1.26E+02	4.37E+00	2.00E-03	1.41E-01	4.00E-03	9.63E-06	1.91E-07	1.95E-05	5.75E-06	2.14E-05	1.25E-05	2.91E-04	2.00E-03	1.60E-02
BATCH-1130	11/28/32	42	4.4	4.4	0.24	1.26E+02	4.36E+00	2.00E-03	1.41E-01	4.00E-03	9.62E-06	1.91E-07	1.95E-05	5.75E-06	2.14E-05	1.25E-05	2.91E-04	2.00E-03	1.60E-02
BATCH-1131	11/28/32	42	4.4	12.0	0.24	3.45E+02	1.84E+00	4.92E-04	4.10E-02	4.00E-03	8.08E-06	1.20E-07	9.40E-06	6.72E-06	3.13E-05	1.29E-05	2.37E-04	1.00E-03	2.00E-03
BATCH-1132	12/2/32	115	12.0	12.9	0.24	3.71E+02	1.99E+00	6.61E-04	5.30E-02	3.00E-03	6.92E-06	1.12E-07	9.62E-06	5.33E-06	2.38E-05	1.05E-05	2.04E-04	1.00E-03	5.00E-03
BATCH-1133	12/3/32	124	12.9	2.9	0.24	8.34E+01	2.89E+00	1.00E-03	9.40E-02	3.00E-03	6.38E-06	1.26E-07	1.29E-05	3.81E-06	1.42E-05	8.28E-06	1.93E-04	1.00E-03	1.10E-02
BATCH-1134	12/15/32	28	2.9	3.0	0.24	8.73E+01	5.92E+00	9.51E-04	6.00E-02	2.00E-03	4.26E-06	2.02E-07	9.05E-06	4.84E-06	3.37E-05	9.73E-06	3.96E-04	2.00E-03	9.00E-03
BATCH-1135	12/16/32	29	3.0	4.1	0.24	1.17E+02	1.12E+01	9.02E-04	3.70E-02	2.00E-03	3.01E-06	3.49E-07	7.15E-06	7.44E-06	6.65E-05	1.43E-05	7.49E-04	4.00E-03	1.00E-02
BATCH-1136	12/18/32	39	4.1	4.4	0.24	1.17E+02	1.12E+01	9.02E-04	3.70E-02	2.00E-03	3.01E-06	3.50E-07	7.15E-06	7.44E-06	6.65E-05	1.43E-05	7.49E-04	4.00E-03	1.00E-02
BATCH-1137	12/19/32	39	4.1	5.4	0.24	1.55E+02	7.49E-01	2.00E-04	1.70E-02	2.00E-03	3.28E-06	4.87E-08	3.82E-06	2.73E-06	1.27E-05	5.23E-06	9.61E-05	5.32E-04	9.29E-04
BATCH-1138	12/22/32	52	5.4	5.0	0.24	1.43E+02	6.84E-01	2.27E-04	1.80E-02	1.00E-03	2.38E-06	3.84E-08	3.31E-06	1.83E-06	8.19E-06	3.61E-06	7.03E-05	3.89E-04	2.00E-03
BATCH-1139	12/24/32	48	5.0	14.5	0.24	4.16E+02	2.26E+00	8.75E-04	6.80E-02	3.00E-03	6.14E-06	1.10E-07	1.04E-05	4.21E-06	1.75E-05	8.65E-06	1.83E-04	1.00E-03	7.00E-03
BATCH-1140	12/28/32	139	14.5	15.6	0.24	4.48E+02	2.90E+00	1.00E-03	7.90E-02	2.00E-03	5.41E-06	1.20E-07	1.10E-05	3.49E-06	1.48E-05	7.50E-06	1.94E-04	1.00E-03	9.00E-03
BATCH-1141	12/29/32	150	15.6	14.2	0.24	4.31E+02	7.57E-04	4.80E-02	2.00E-03	3.68E-06	1.47E-07	6.98E-06	3.74E-06	2.45E-05	7.60E-06	2.88E-04	2.00E-03	8.00E-03
BATCH-1142	1/11/33	136	14.2	14.2	0.24	4.31E+00	7.56E-04	4.80E-02	2.00E-03	3.67E-06	1.47E-07	6.97E-06	3.73E-06	2.45E-05	7.59E-06	2.88E-04	2.00E-03	8.00E-03	
BATCH-1143	1/14/33	136	14.2	2.0	0.24	4.08E+02	4.31E+00	7.56E-04	4.80E-02	2.00E-03	3.67E-06	1.47E-07	6.97E-06	3.73E-06	2.45E-05	7.59E-06	2.88E-04	2.00E-03	8.00E-03
BATCH-1144	1/26/33	19	2.0	1.8	0.24	5.63E+01	2.03E-01	5.19E-05	4.00E-03	3.79E-04	8.96E-07	1.29E-08	9.41E-07	7.46E-07	3.48E-06	1.43E-06	8.97E-07	1.73E-05	9.66E-05
BATCH-1145	1/28/33	17	1.8	4.3	0.24	5.07E+01	1.69E-01	5.37E-05	4.00E-03	2.44E-04	5.91E-07	9.23E-09	7.42E-07	4.56E-07	2.04E-06	8.97E-07	1.73E-05	9.66E-05	3.87E-04
BATCH-1146	1/28/33	41	4.3	4.1	0.24	1.24E+02	5.87E-01	2.18E-04	1.60E-02	6.43E-04	1.61E-06	2.79E-08	2.46E-06	1.10E-06	4.58E-06	2.27E-06	4.76E-05	2.65E-04	2.00E-03
BATCH-1147	1/30/33	39	4.1	4.1	0.24	1.17E+02	6.58E-01	2.29E-04	1.70E-02	4.80E-04	1.23E-06	2.66E-08	2.26E-06	7.96E-07	3.37E-06	1.71E-06	4.38E-05	2.44E-04	2.00E-03
BATCH-1148	2/2/33	39	4.1	4.1	0.24	1.17E+02	1.09E+00	1.91E-04	1.20E-02	3.87E-04	9.27E-07	3.71E-08	1.76E-06	9.42E-07	6.17E-06	1.92E-06	7.26E-05	4.05E-04	2.00E-03
BATCH-1149	2/3/33	39	4.1	4.2	0.24	1.17E+02	1.09E+00	1.91E-04	1.20E-02	3.86E-04	9.26E-07	3.71E-08	1.76E-06	9.41E-07	6.17E-06	1.91E-06	7.25E-05	4.04E-04	2.00E-03
BATCH-1150	2/6/33	56	5.9	5.9	0.24	1.69E+02	1.60E+01	1.00E-03	4.90E-02	2.00E-03	4.34E-06	4.89E-07	9.30E-06	1.08E-05	9.62E-05	2.06E-05	1.00E-03	6.00E-03	1.40E-02
BATCH-1151	2/8/33	56	5.9	5.9	0.24	1.69E+02	1.60E+01	1.00E-03	4.90E-02	2.00E-03	4.34E-06	4.90E-07	9.30E-06	1.08E-05	9.61E-05	2.06E-05	1.00E-03	6.00E-03	1.40E-02
BATCH-1152	2/12/33	15	1.6	1.5	0.24	4.52E+01	1.39E-01	5.15E-05	4.00E-03	1.52E-04	3.80E-07	6.59E-09	5.82E-07	2.61E-07	1.08E-06	5.36E-07	1.12E-05	6.27E-05	4.41E-04
BATCH-1153	2/14/33	14	1.5	1.5	0.24	4.29E+01	1.55E-01	5.41E-05	4.00E-03	1.14E-04	2.91E-07	6.29E-09	5.35E-07	1.88E-07	7.95E-07	4.04E-07	1.04E-05	5.77E-05	5.07E-04
BATCH-1154	2/14/33	14	1.5	1.5	0.24	4.26E+01	2.57E-01	4.52E-05	3.00E-03	9.16E-05	2.20E-07	8.78E-09	4.17E-07	2.23E-07	1.46E-06	4.54E-07	1.72E-05	9.57E-05	4.51E-04
BATCH-1155	2/15/33	14	1.5	4.2	0.24	4.26E+01	2.57E-01	4.51E-05	3.00E-03	9.14E-05	2.19E-07	8.77E-09	4.16E-07	2.23E-07	1.46E-06	4.53E-07	1.72E-05	9.56E-05	4.50E-04
BATCH-1156	2/15/33	40	4.2	4.2	0.24	1.20E+02	1.14E+01	8.77E-04	3.50E-02	2.00E-03	3.08E-06	3.47E-07	6.60E-06	7.62E-06	6.82E-05	1.46E-05	7.60E-04	4.00E-03	1.00E-02
BATCH-1157	2/17/33	40	4.2	6.0	0.24	1.20E+02	1.14E+01	8.77E-04	3.50E-02	2.00E-03	3.07E-06	3.47E-07	6.59E-06	7.62E-06	6.81E-05	1.46E-05	7.59E-04	4.00E-03	1.00E-02
BATCH-1158	2/20/33	58	6.0	7.4	0.24	1.73E+02	1.10E+01	2.00E-03	1.97E-01	5.00E-03	1.52E-05	3.44E-07	8.65E-06	7.90E-06	6.73E-05	1.50E-05	7.85E-04	4.00E-03	1.00E-02
BATCH-1159	2/21/33	71	7.4	7.4	0.24	2.13E+02	9.40E+00	4.00E-03	3.55E-01	8.00E-03	2.69E-05	3.03E-07	1.00E-05	7.35E-06	5.91E-05	1.39E-05	7.27E-04	4.00E-03	9.00E-03
BATCH-1160	2/26/33	71	7.4	7.4	0.24	2.13E+02	9.40E+00	4.00E-03	3.54E-01	8.00E-03	2.69E-05	3.03E-07	9.99E-06	7.34E-06	5.91E-05	1.39E-05	7.27E-04	4.00E-03	9.00E-03
BATCH-1161	3/1/33	71	7.4	14.5	0.24	2.13E+02	9.39E+00	4.00E-03	3.54E-01	8.00E-03	2.69E-05	3.02E-07	9.99E-06	7.34E-06	5.91E-05	1.38E-05	7.27E-04	4.00E-03	9.00E-03
BATCH-1162	3/5/33	139	14.5	14.5	0.24	4.16E+02	7.56E+00	5.83E-04	2.30E-02	1.00E-03	2.04E-06	2.31E-07	4.38E-06	5.07E-06	4.53E-05	9.71E-06	5.05E-04	3.00E-03	7.00E-03
BATCH-1163	3/8/33	139	14.5	4.7	0.24	4.16E+02	7.54E+00	5.82E-04	2.30E-02	1.00E-03	2.04E-06	2.30E-07	4.37E-06	5.05E-06	4.52E-05	9.69E-06	5.04E-04	3.00E-03	7.00E-03
BATCH-1164	3/20/33	45	4.7	5.3	0.24	1.36E+02	6.00E+00	2.00E-03	2.26E-01	5.00E-03	1.72E-05	1.93E-07	6.38E-06	4.69E-06	3.78E-05	8.85E-06	4.64E-04	3.00E-03	6.00E-03
BATCH-1165	3/23/33	51	5.3	5.3	0.24	1.52E+02	6.73E+00	3.00E-03	2.54E-01	5.00E-03	1.93E-05	2.17E-07	7.16E-06	5.26E-06	4.23E-05	9.92E-06	5.21E-04	3.00E-03	6.00E-03
BATCH-1166	3/25/33	51	5.3	3.3	0.24	1.52E+02	6.72E+00	3.00E-03	2.53E-01	5.00E-03	1.92E-05	2.16E-07	7.15E-06	5.25E-06	4.23E-05	9.90E-06	5.20E-04	3.00E-03	6.00E-03
BATCH-1167	3/29/33	31	3.3	3.9	0.24	9.35E+01	8.74E-01	9.41E-04	5.00E-02	2.00E-03	8.19E-06	3.14E-08	2.08E-06	1.04E-06	1.91E-05	1.80E-06	1.07E-04	5.98E-04	4.00E-03
BATCH-1168	3/31/33	37	3.9	3.9	0.24	1.12E+02	1.79E+00	1.38E-04	6.00E-03	2.55E-04	4.85E-07	5.47E-08	1.04E-06	1.20E-06	1.08E-05	2.31E-06	1.20E-04	6.68E-04	2.00E-03
BATCH-1169	4/1/33	37	3.9	3.9	0.24	1.12E+02	1.79E+00	1.38E-04	6.00E-03	2.55E-04	4.84E-07	5.46E-08	1.04E-06	1.20E-06	1.07E-05	2.30E-06	1.20E-04	6.67E-04	2.00E-03
BATCH-1170	4/4/33	139	14.5	14.5	0.24	4.17E+02	6.65E+00	1.00E-03	9.50E-02	2.00E-03	2.07E-07	1.24E-07	4.91E-06	4.70E-06	4.05E-05	8.96E-06	4.68E-04	3.00E-03	6.00E-03
BATCH-1171	4/5/33	120	12.5	12.5	0.24	3.60E+02	3.86E+00	2.00E-03	1.45E-01	3.00E-03	1.10E-05	1.24E-07	4.10E-06	3.01E-06	2.43E-05	5.69E-06	2.98E-04	2.00E-03	4.00E-03
BATCH-1172	4/18/33	124	12.9	12.9	0.24	3.72E+02	2.82E+00	1.00E-03	1.11E-01	3.00E-03	9.40E-06	9.16E-08	3.27E-06	2.29E-06	2.09E-05	4.28E-06	2.28E-04	1.00E-03	3.00E-03
BATCH-1173	4/18/33	14	1.4	1.4	0.24	4.07E+01	4.25E-01	3.28E-05	1.00E-03	6.05E-05	1.15E-07	1.30E-08	2.47E-07	2.85E-07	2.55E-06	5.47E-07	2.84E-05	1.58E-04	3.79E-04
BATCH-1174	5/1/33	14	1.4	1.4	0.24	4.06E+01	4.24E-01	3.27E-05	1.00E-03	6.04E-05	1.15E-07	1.30E-08	2.46E-07	2.84E-07	2.54E-06	5.45E-07	2.84E-05	1.58E-04	3.78E-04
BATCH-1175	5/2/33	14	1.4	1.4	0.24	4.06E+01	4.24E-01	3.27E-05	1.00E-03	6.04E-05	1.15E-07	1.30E-08	2.46E-07	2.84E-07	2.54E-06	5.45E-07	2.84E-05	1.58E-04	3.78E-04

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1127	11/21/32	29	3.0	0.24	5.09E-04	8.54E-05	4.79E-04	1.80E-02	1.20E-02	1.91E+00	2.07E-01	5.68E-01	2.10E-01	3.74E-29	6.95E-06	4.26E-05	3.85E-05	4.83E-04	1.97E-12
BATCH-1128	11/23/32	44	4.6	0.24	6.40E-04	1.08E-04	6.93E-04	2.20E-02	1.50E-02	2.46E+00	2.65E-01	6.93E-01	2.65E-01	6.10E-29	8.72E-06	5.17E-05	6.92E-05	1.00E-03	2.36E-12
BATCH-1129	11/24/32	42	4.4	0.24	7.33E-04	1.23E-04	6.90E-04	2.60E-02	1.70E-02	2.74E+00	2.98E-01	8.18E-01	3.03E-01	5.38E-29	1.00E-05	6.13E-05	5.53E-05	6.92E-04	2.83E-12
BATCH-1130	11/28/32	42	4.4	0.24	7.32E-04	1.23E-04	6.89E-04	2.50E-02	1.70E-02	2.74E+00	2.98E-01	8.18E-01	3.03E-01	5.37E-29	1.00E-05	6.13E-05	5.53E-05	6.92E-04	2.83E-12
BATCH-1131	11/28/32	42	4.4	0.24	7.32E-04	1.23E-04	6.89E-04	2.50E-02	1.70E-02	2.74E+00	2.98E-01	8.17E-01	3.03E-01	5.37E-29	1.00E-05	6.13E-05	5.52E-05	6.92E-04	2.83E-12
BATCH-1132	12/2/32	115	12.0	0.24	1.01E-04	2.03E-05	3.96E-04	4.00E-03	2.00E-03	5.98E-01	5.50E-02	4.30E-02	4.20E-02	5.42E-29	1.31E-06	2.06E-06	7.72E-05	2.00E-03	1.01E-14
BATCH-1133	12/3/32	124	12.9	0.24	2.02E-04	3.60E-05	3.81E-04	7.00E-03	5.00E-03	8.96E-01	9.10E-02	1.82E-01	8.40E-02	4.44E-29	2.72E-06	1.29E-05	5.92E-05	1.00E-03	5.41E-13
BATCH-1134	12/15/32	28	2.9	0.24	4.85E-04	8.14E-05	4.57E-04	1.70E-02	1.10E-02	1.82E+00	1.97E-01	5.41E-01	2.01E-01	3.56E-29	6.63E-06	4.06E-05	3.66E-05	4.58E-04	1.88E-12
BATCH-1135	12/16/32	29	3.0	0.24	4.07E-04	9.97E-05	8.71E-04	1.80E-02	9.00E-03	1.05E+00	1.37E-01	1.02E+00	2.43E-01	3.44E-28	9.34E-06	5.85E-05	5.56E-04	1.20E-02	8.94E-13
BATCH-1136	12/18/32	39	4.1	0.24	4.33E-04	1.50E-04	2.00E-03	2.40E-02	1.00E-02	4.55E-01	1.07E-01	1.87E+00	3.62E-01	8.05E-28	1.52E-05	9.63E-05	1.00E-03	2.90E-02	1.51E-15
BATCH-1137	12/19/32	39	4.1	0.24	4.33E-04	1.50E-04	2.00E-03	2.40E-02	1.00E-02	4.55E-01	1.07E-01	1.87E+00	3.63E-01	8.05E-28	1.52E-05	9.63E-05	1.00E-03	2.90E-02	1.51E-15
BATCH-1138	12/22/32	52	5.4	0.24	4.10E-05	8.24E-06	1.61E-04	2.00E-03	9.43E-04	2.43E-01	2.30E-02	1.70E-02	1.70E-02	2.20E-29	5.30E-07	8.37E-07	3.14E-05	6.56E-04	4.08E-15
BATCH-1139	12/24/32	48	5.0	0.24	6.95E-05	1.24E-05	1.31E-04	3.00E-03	2.00E-03	3.08E-01	3.10E-02	6.20E-02	2.90E-02	1.53E-29	9.34E-07	4.43E-06	2.04E-05	3.96E-04	1.86E-13
BATCH-1140	12/28/32	139	14.5	0.24	3.19E-04	5.44E-05	3.87E-04	1.10E-02	7.00E-03	1.26E+00	1.34E-01	3.36E-01	1.32E-01	3.69E-29	4.34E-06	2.48E-05	4.41E-05	7.39E-04	1.12E-12
BATCH-1141	12/29/32	150	15.6	0.24	4.21E-04	7.42E-05	4.51E-04	1.50E-02	1.00E-02	1.52E+00	1.68E-01	5.33E-01	1.82E-01	6.65E-29	6.18E-06	3.80E-05	9.13E-05	2.00E-03	1.55E-12
BATCH-1142	1/1/33	136	14.2	0.24	3.36E-04	7.75E-05	6.44E-04	1.40E-02	8.00E-03	9.39E-01	1.18E-01	7.51E-01	1.80E-01	4.98E-29	7.12E-06	4.45E-05	3.69E-04	8.00E-03	8.42E-13
BATCH-1143	1/14/33	136	14.2	0.24	3.35E-04	7.74E-05	6.43E-04	1.40E-02	8.00E-03	9.37E-01	1.18E-01	7.50E-01	1.80E-01	4.98E-29	7.11E-06	4.44E-05	3.69E-04	8.00E-03	8.40E-13
BATCH-1144	1/26/33	19	2.0	0.24	1.12E-05	2.25E-06	4.40E-05	4.41E-04	2.57E-04	6.60E-02	6.00E-03	5.00E-03	4.00E-03	1.27E-30	1.45E-07	2.29E-07	8.37E-06	1.72E-04	1.12E-15
BATCH-1145	1/28/33	17	1.8	0.24	1.73E-05	3.08E-06	3.25E-05	6.23E-04	3.94E-04	7.70E-02	8.00E-03	1.50E-02	7.00E-03	8.02E-31	2.32E-07	1.10E-06	4.94E-06	9.46E-05	4.63E-14
BATCH-1146	1/28/33	41	4.3	0.24	8.35E-05	1.43E-05	1.01E-04	3.00E-03	2.00E-03	3.29E-01	3.50E-02	8.80E-02	3.30E-02	2.04E-30	1.14E-06	6.51E-06	1.13E-05	1.86E-04	2.94E-13
BATCH-1147	1/30/33	39	4.1	0.24	9.60E-05	1.69E-05	1.03E-04	3.00E-03	2.00E-03	3.47E-01	3.80E-02	1.22E-01	4.00E-02	3.21E-30	1.41E-06	8.67E-06	2.03E-05	3.73E-04	3.54E-13
BATCH-1148	2/2/33	39	4.1	0.24	8.46E-05	1.95E-05	1.62E-04	4.00E-03	2.00E-03	2.37E-01	3.00E-02	1.89E-01	4.50E-02	1.26E-29	1.80E-06	1.12E-05	9.30E-05	2.00E-03	2.12E-13
BATCH-1149	2/3/33	39	4.1	0.24	8.45E-05	1.95E-05	1.62E-04	4.00E-03	2.00E-03	2.36E-01	3.00E-02	1.89E-01	4.50E-02	1.26E-29	1.79E-06	1.12E-05	9.29E-05	2.00E-03	2.12E-13
BATCH-1150	2/6/33	56	5.9	0.24	6.25E-04	2.17E-04	2.00E-03	3.50E-02	1.40E-02	6.56E-01	1.55E-01	2.70E+00	4.99E-01	2.46E-28	2.20E-05	1.39E-04	2.00E-03	4.00E-02	1.07E-17
BATCH-1151	2/8/33	56	5.9	0.24	6.25E-04	2.17E-04	2.00E-03	3.50E-02	1.40E-02	6.56E-01	1.54E-01	2.69E+00	4.99E-01	2.46E-28	2.20E-05	1.39E-04	2.00E-03	4.00E-02	1.64E-17
BATCH-1152	2/12/33	15	1.6	0.24	1.97E-05	3.37E-06	2.40E-05	6.91E-04	4.49E-04	7.80E-02	8.00E-03	2.10E-02	8.00E-03	4.83E-31	2.69E-07	1.54E-06	2.67E-06	4.40E-05	6.96E-14
BATCH-1153	2/14/33	14	1.5	0.24	2.27E-05	4.00E-06	2.43E-05	8.06E-04	5.15E-04	8.20E-02	9.00E-03	2.90E-02	9.00E-03	7.58E-31	3.33E-07	2.05E-06	4.80E-06	8.81E-05	8.36E-14
BATCH-1154	2/14/33	14	1.5	0.24	2.00E-05	4.62E-06	3.84E-05	8.41E-04	4.56E-04	5.60E-02	7.00E-03	4.50E-02	1.10E-02	2.97E-30	4.25E-07	2.66E-06	2.20E-05	4.61E-04	5.02E-14
BATCH-1155	2/15/33	14	1.5	0.24	2.00E-05	4.62E-06	3.84E-05	8.40E-04	4.55E-04	5.60E-02	7.00E-03	4.50E-02	1.10E-02	2.97E-30	4.25E-07	2.65E-06	2.20E-05	4.61E-04	5.01E-14
BATCH-1156	2/15/33	40	4.2	0.24	4.43E-04	1.54E-04	2.00E-03	2.50E-02	1.00E-02	4.65E-01	1.10E-01	1.91E+00	3.54E-01	1.75E-28	1.56E-05	9.87E-05	1.00E-03	2.80E-02	7.45E-18
BATCH-1157	2/17/33	40	4.2	0.24	4.43E-04	1.54E-04	2.00E-03	2.50E-02	1.00E-02	4.65E-01	1.09E-01	1.91E+00	3.54E-01	1.75E-28	1.56E-05	9.86E-05	1.00E-03	2.80E-02	7.45E-18
BATCH-1158	2/20/33	58	6.0	0.24	4.35E-04	1.60E-04	2.00E-03	3.00E-02	1.00E-02	5.38E-01	1.27E-01	2.64E+00	4.21E-01	2.58E-28	1.87E-05	1.08E-04	2.00E-03	3.60E-02	6.85E-14
BATCH-1159	2/21/33	71	7.4	0.24	3.79E-04	1.49E-04	1.00E-03	3.20E-02	9.00E-03	5.61E-01	1.33E-01	3.16E+00	4.49E-01	3.23E-28	2.02E-05	1.07E-04	2.00E-03	4.00E-02	1.37E-13
BATCH-1160	2/26/33	71	7.4	0.24	3.79E-04	1.49E-04	1.00E-03	3.20E-02	9.00E-03	5.61E-01	1.33E-01	3.16E+00	4.49E-01	3.23E-28	2.02E-05	1.07E-04	2.00E-03	4.00E-02	1.37E-13
BATCH-1161	3/1/33	71	7.4	0.24	3.79E-04	1.49E-04	1.00E-03	3.20E-02	9.00E-03	5.61E-01	1.33E-01	3.15E+00	4.49E-01	3.23E-28	2.02E-05	1.07E-04	2.00E-03	4.00E-02	1.37E-13
BATCH-1162	3/5/33	139	14.5	0.24	2.94E-04	1.02E-04	1.00E-03	1.60E-02	7.00E-03	3.09E-01	7.30E-02	1.27E+00	2.35E-01	1.16E-28	1.04E-05	6.56E-05	8.81E-04	1.90E-02	5.00E-18
BATCH-1163	3/8/33	139	14.5	0.24	2.94E-04	1.02E-04	1.00E-03	1.60E-02	7.00E-03	3.08E-01	7.30E-02	1.27E+00	2.35E-01	1.16E-28	1.03E-05	6.55E-05	8.79E-04	1.90E-02	6.57E-18
BATCH-1164	3/20/33	45	4.7	0.24	2.42E-04	9.51E-05	8.91E-04	2.00E-02	6.00E-03	3.58E-01	8.50E-02	2.02E+00	2.87E-01	2.06E-28	1.29E-05	6.82E-05	1.00E-03	2.50E-02	8.74E-14
BATCH-1165	3/23/33	51	5.3	0.24	2.72E-04	1.07E-04	9.98E-04	2.30E-02	6.00E-03	4.02E-01	9.50E-02	2.26E+00	3.22E-01	2.31E-28	1.44E-05	7.65E-05	1.00E-03	2.90E-02	9.81E-14
BATCH-1166	3/25/33	51	5.3	0.24	2.71E-04	1.07E-04	9.97E-04	2.30E-02	6.00E-03	4.01E-01	9.50E-02	2.26E+00	3.21E-01	2.31E-28	1.44E-05	7.63E-05	1.00E-03	2.90E-02	9.79E-14
BATCH-1167	3/29/33	31	3.3	0.24	1.53E-04	6.44E-05	3.09E-04	1.70E-02	3.00E-03	2.75E-01	6.90E-02	1.21E+00	2.37E-01	1.76E-28	1.07E-05	5.57E-05	1.00E-03	2.20E-02	4.99E-14
BATCH-1168	3/31/33	37	3.9	0.24	6.99E-05	2.43E-05	2.60E-04	4.00E-03	2.00E-03	7.30E-02	1.70E-02	3.01E-01	5.60E-02	2.76E-29	2.46E-06	1.56E-05	2.09E-04	4.00E-03	1.19E-18
BATCH-1169	4/1/33	37	3.9	0.24	6.97E-05	2.42E-05	2.60E-04	4.00E-03	2.00E-03	7.30E-02	1.70E-02	3.01E-01	5.60E-02	2.75E-29	2.45E-06	1.55E-05	2.09E-04	4.00E-03	1.56E-18
BATCH-1170	4/4/33	139	14.5	0.24	2.62E-04	9.51E-05	9.73E-04	1.70E-02	6.00E-03	3.13E-01	7.40E-02	1.48E+00	2.43E-01	1.43E-28	1.08E-05	6.36E-05	9.83E-04	2.00E-02	3.15E-14
BATCH-1171	4/5/33	120	12.5	0.24	1.56E-04	6.11E-05	5.72E-04	1.30E-02	4.00E-03	2.30E-01	5.50E-02	1.30E+00	1.84E-01	1.33E-28	8.27E-06	4.38E-05	8.18E-04	1.60E-02	5.62E-14
BATCH-1172	4/18/33	120	12.5	0.24	1.55E-04	6.10E-05	5.71E-04	1.30E-02	4.00E-03	2.30E-01	5.40E-02	1.29E+00	1.84E-01	1.32E-28	8.25E-06	4.37E-05	8.16E-04	1.60E-02	5.61E-14
BATCH-1173	4/18/33	124	12.9	0.24	1.41E-04	5.65E-05	4.61E-04	1.30E-02	3.00E-03	2.20E-01	5.30E-02	1.16E+00	1.81E-01	1.31E-28	8.11E-06	4.28E-05	8.22E-04	1.60E-02	4.98E-14
BATCH-1174	5/1/33	14	1.4	0.24	1.66E-05	5.76E-06	6.17E-05	9.25E-04	3.80E-04	1.70E-02	4.00E-03	7.10E-02	1.30E-02	6.53E-30	5.83E-07	3.69E-06	4.96E-05	1.00E-03	2.81E-19
BATCH-1175	5/2/33	14	1.4	0.24	1.65E-05	5.74E-06	6.16E-05	9.22E-04	3.79E-04	1.70E-02	4.00E-03	7.10E-02	1.30E-02	6.52E-30	5.82E-07	3.69E-06	4.95E-05	1.00E-03	3.70E-19

Appendix A Nominal ILAW inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ca+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1127	11/21/32	29	3.0	0.24	1.50E-06	1.07E+01	1.98E-13	3.34E-10	2.11E-13	7.76E-73	1.30E-02	8.99E-01	2.39E-12	8.00E-03	5.23E+00	0.00E+00	5.41E-08	1.46E+00	5.30E-07
BATCH-1128	11/23/32	44	4.6	0.24	3.00E-03	1.58E+01	2.52E-13	4.30E-10	2.59E-13	1.08E-80	2.50E-02	1.29E+00	2.88E-12	1.20E-02	7.22E+00	0.00E+00	3.39E-05	1.88E+00	7.21E-07
BATCH-1129	11/24/32	42	4.4	0.24	5.00E-03	1.54E+01	2.85E-13	4.81E-10	3.04E-13	7.41E-76	1.90E-02	1.30E+00	3.44E-12	1.20E-02	7.52E+00	0.00E+00	5.48E-05	2.10E+00	7.63E-07
BATCH-1130	11/28/32	42	4.4	0.24	5.00E-03	1.54E+01	2.85E-13	4.81E-10	3.04E-13	2.55E-76	1.90E-02	1.29E+00	3.44E-12	1.20E-02	7.52E+00	0.00E+00	5.47E-05	2.10E+00	7.62E-07
BATCH-1131	11/28/32	42	4.4	0.24	5.00E-03	1.54E+01	2.85E-13	4.81E-10	3.04E-13	8.80E-71	1.90E-02	1.29E+00	3.44E-12	1.20E-02	7.52E+00	0.00E+00	5.45E-05	2.10E+00	7.62E-07
BATCH-1132	12/2/32	115	12.0	0.24	3.31E-02	0.00E+00	4.87E-14	9.69E-11	1.96E-14	1.04E-70	9.40E-02	1.07E+00	6.85E-14	8.00E-03	3.18E+00	0.00E+00	2.15E+00	0.00E+00	2.87E-07
BATCH-1133	12/3/32	124	12.9	0.24	4.42E-02	0.00E+00	8.45E-14	1.52E-10	6.98E-14	4.01E-70	8.50E-02	1.14E+00	6.93E-13	8.00E-03	3.43E+00	0.00E+00	3.44E+00	0.00E+00	3.26E-07
BATCH-1134	12/15/32	28	2.9	0.24	1.60E-06	1.02E+01	1.88E-13	3.19E-10	2.01E-13	5.86E-84	1.30E-02	8.57E-01	2.28E-12	8.00E-03	4.98E+00	0.00E+00	1.84E-08	1.39E+00	5.05E-07
BATCH-1135	12/16/32	29	3.0	0.24	1.79E-06	1.90E+01	8.98E-14	1.94E-10	9.59E-14	2.69E-79	2.40E-02	4.76E-01	1.10E-12	5.00E-03	4.98E+00	0.00E+00	1.99E-08	2.05E+00	1.07E-06
BATCH-1136	12/18/32	39	4.1	0.24	2.62E-06	3.48E+01	1.54E-16	1.05E-10	1.69E-16	1.36E-79	4.40E-02	1.68E-01	3.66E-14	4.00E-03	6.42E+00	0.00E+00	2.91E-08	3.41E+00	2.05E-06
BATCH-1137	12/19/32	39	4.1	0.24	2.61E-06	3.48E+01	1.54E-16	1.05E-10	1.69E-16	4.67E-74	4.40E-02	1.68E-01	3.66E-14	4.00E-03	6.42E+00	0.00E+00	2.90E-08	3.41E+00	2.05E-06
BATCH-1138	12/22/32	52	5.4	0.24	1.34E+02	0.00E+00	1.98E-14	3.94E-11	7.97E-15	4.23E-71	3.80E-02	4.34E-01	2.78E-14	3.00E-03	1.29E+00	0.00E+00	8.71E-01	0.00E+00	1.17E-07
BATCH-1139	12/24/32	48	5.0	0.24	1.52E+02	0.00E+00	2.91E-14	5.23E-11	2.40E-14	1.38E-70	2.90E-02	3.91E-01	2.38E-13	3.00E-03	1.18E+00	0.00E+00	1.18E+00	0.00E+00	1.12E-07
BATCH-1140	12/28/32	139	14.5	0.24	5.78E+02	0.00E+00	1.27E-13	2.18E-10	1.26E-13	1.04E-80	7.40E-02	1.26E+00	1.38E-12	7.00E-03	3.89E+00	0.00E+00	5.04E+00	0.00E+00	3.84E-07
BATCH-1141	12/29/32	150	15.6	0.24	6.42E+02	0.00E+00	1.56E-13	2.68E-10	1.66E-13	2.26E-76	6.40E-02	1.29E+00	1.88E-12	7.00E-03	4.41E+00	0.00E+00	6.81E+00	0.00E+00	5.12E-07
BATCH-1142	1/11/33	136	14.2	0.24	6.37E+02	0.00E+00	8.46E-14	1.72E-10	9.03E-14	7.59E-77	5.30E-02	9.54E-01	1.03E-12	5.00E-03	3.99E+00	0.00E+00	8.60E+00	0.00E+00	7.85E-07
BATCH-1143	1/14/33	136	14.2	0.24	6.36E+02	0.00E+00	8.44E-14	1.71E-10	9.01E-14	2.61E-71	5.30E-02	9.52E-01	1.03E-12	5.00E-03	3.98E+00	0.00E+00	8.60E+00	0.00E+00	7.84E-07
BATCH-1144	1/26/33	19	2.0	0.24	3.67E+01	0.00E+00	5.41E-15	1.08E-11	2.18E-15	1.16E-71	1.00E-02	1.18E-01	7.60E-15	9.41E-04	3.53E-01	0.00E+00	2.38E-01	0.00E+00	3.19E-08
BATCH-1145	1/28/33	17	1.8	0.24	3.78E+01	0.00E+00	7.22E-15	1.30E-11	5.96E-15	3.43E-71	7.00E-03	9.70E-02	5.92E-14	6.46E-04	2.93E-01	0.00E+00	2.94E-01	0.00E+00	2.78E-08
BATCH-1146	1/28/33	41	4.3	0.24	1.51E+02	0.00E+00	3.32E-14	5.72E-11	3.30E-14	2.72E-81	1.90E-02	3.31E-01	3.62E-13	2.00E-03	1.02E+00	0.00E+00	1.32E+00	0.00E+00	1.01E-07
BATCH-1147	1/30/33	39	4.1	0.24	1.46E+02	0.00E+00	3.55E-14	6.12E-11	3.79E-14	5.15E-77	1.50E-02	2.95E-01	4.30E-13	2.00E-03	1.01E+00	0.00E+00	1.55E+00	0.00E+00	1.17E-07
BATCH-1148	2/2/33	39	4.1	0.24	1.61E+02	0.00E+00	2.13E-14	4.33E-11	2.28E-14	1.91E-77	1.30E-02	2.40E-01	2.60E-13	1.00E-03	1.01E+00	0.00E+00	2.17E+00	0.00E+00	1.98E-07
BATCH-1149	2/3/33	39	4.1	0.24	1.60E+02	0.00E+00	2.13E-14	4.32E-11	2.27E-14	6.58E-72	1.30E-02	2.40E-01	2.60E-13	1.00E-03	1.00E+00	0.00E+00	2.17E+00	0.00E+00	1.98E-07
BATCH-1150	2/6/33	56	5.9	0.24	5.00E-03	5.04E+01	4.21E-18	1.52E-10	1.15E-17	1.68E-75	6.40E-02	2.41E-01	5.03E-14	6.00E-03	9.29E+00	0.00E+00	3.47E-05	4.93E+00	2.96E-06
BATCH-1151	2/8/33	56	5.9	0.24	5.00E-03	5.04E+01	4.34E-18	1.52E-10	1.20E-17	4.37E-75	6.40E-02	2.41E-01	5.03E-14	6.00E-03	9.28E+00	0.00E+00	3.75E-05	4.93E+00	2.96E-06
BATCH-1152	2/12/33	15	1.6	0.24	3.58E+01	0.00E+00	7.85E-15	1.35E-11	7.80E-15	6.42E-82	5.00E-03	7.80E-02	8.55E-14	4.38E-04	2.41E-01	0.00E+00	3.12E-01	0.00E+00	2.38E-08
BATCH-1153	2/14/33	14	1.5	0.24	3.46E+01	0.00E+00	8.40E-15	1.45E-11	8.96E-15	1.22E-77	3.00E-03	7.00E-02	1.02E-13	3.56E-04	2.38E-01	0.00E+00	3.67E-01	0.00E+00	2.76E-08
BATCH-1154	2/14/33	14	1.5	0.24	3.80E+01	0.00E+00	5.05E-15	1.02E-11	5.39E-15	4.53E-78	3.00E-03	5.70E-02	6.16E-14	2.80E-04	2.38E-01	0.00E+00	5.13E-01	0.00E+00	4.68E-08
BATCH-1155	2/15/33	14	1.5	0.24	3.80E+01	0.00E+00	5.04E-15	1.02E-11	5.38E-15	1.56E-72	3.00E-03	5.70E-02	6.14E-14	2.79E-04	2.38E-01	0.00E+00	5.13E-01	0.00E+00	4.68E-08
BATCH-1156	2/15/33	40	4.2	0.24	2.77E-06	3.57E+01	2.43E-18	1.08E-10	7.95E-18	8.72E-79	4.50E-02	1.71E-01	3.57E-14	5.00E-03	6.58E+00	0.00E+00	1.80E-08	3.50E+00	2.10E-06
BATCH-1157	2/17/33	40	4.2	0.24	2.50E-06	3.57E+01	2.43E-18	1.08E-10	7.94E-18	2.26E-78	4.50E-02	1.71E-01	3.56E-14	5.00E-03	6.58E+00	0.00E+00	1.95E-08	3.50E+00	2.10E-06
BATCH-1158	2/20/33	58	6.0	0.24	3.00E-03	4.51E+01	1.54E-16	6.27E-11	4.13E-16	4.97E-86	6.10E-02	1.23E+00	2.79E-14	4.00E-03	7.24E+00	0.00E+00	2.41E-05	3.41E+00	2.02E-06
BATCH-1159	2/21/33	71	7.4	0.24	4.00E-03	5.05E+01	3.04E-16	6.03E-12	8.18E-16	1.41E-81	7.30E-02	2.28E+00	1.62E-14	3.00E-03	7.18E+00	0.00E+00	4.24E-05	2.94E+00	1.72E-06
BATCH-1160	2/26/33	71	7.4	0.24	5.00E-03	5.05E+01	3.04E-16	6.03E-12	8.17E-16	5.38E-82	7.30E-02	2.28E+00	1.62E-14	3.00E-03	7.18E+00	0.00E+00	6.10E-05	2.94E+00	1.72E-06
BATCH-1161	3/1/33	71	7.4	0.24	5.00E-03	5.05E+01	3.03E-16	6.03E-12	8.17E-16	1.85E-76	7.30E-02	2.28E+00	1.62E-14	3.00E-03	7.18E+00	0.00E+00	6.10E-05	2.94E+00	1.72E-06
BATCH-1162	3/5/33	139	14.5	0.24	6.73E+02	0.00E+00	1.83E-18	7.15E-11	5.37E-18	4.64E-76	3.40E-02	5.59E-01	2.37E-14	3.00E-03	4.37E+00	0.00E+00	1.33E+01	0.00E+00	1.39E-06
BATCH-1163	3/8/33	139	14.5	0.24	6.72E+02	0.00E+00	1.86E-18	7.14E-11	5.48E-18	1.20E-75	3.40E-02	5.58E-01	2.37E-14	3.00E-03	4.36E+00	0.00E+00	1.33E+01	0.00E+00	1.39E-06
BATCH-1164	3/20/33	45	4.7	0.24	1.61E-06	3.23E+01	1.93E-16	3.88E-12	5.21E-16	2.89E-89	4.70E-02	1.45E+00	1.04E-14	2.00E-03	4.59E+00	0.00E+00	1.40E-08	1.88E+00	1.10E-06
BATCH-1165	3/23/33	51	5.3	0.24	2.07E-06	3.62E+01	2.17E-16	4.32E-12	5.85E-16	7.28E-85	5.20E-02	1.63E+00	1.16E-14	2.00E-03	5.14E+00	0.00E+00	2.20E-08	2.11E+00	1.23E-06
BATCH-1166	3/25/33	51	5.3	0.24	2.34E-06	3.61E+01	2.17E-16	4.31E-12	5.84E-16	2.79E-85	5.20E-02	1.63E+00	1.16E-14	2.00E-03	5.13E+00	0.00E+00	3.16E-08	2.10E+00	1.23E-06
BATCH-1167	3/29/33	31	3.3	0.24	1.46E-06	2.82E+01	6.42E-14	1.05E-11	3.73E-14	6.00E-80	3.60E-02	8.05E-01	5.62E-14	6.43E-04	4.96E+00	0.00E+00	1.98E-08	3.14E+00	1.60E-07
BATCH-1168	3/31/33	37	3.9	0.24	1.60E-02	0.00E+00	4.35E-19	1.70E-11	1.28E-18	1.10E-76	8.00E-03	1.33E-01	5.62E-15	5.63E-15	7.20E-04	1.04E+00	0.00E+00	3.16E+00	3.31E-07
BATCH-1169	4/1/33	37	3.9	0.24	1.60E-02	0.00E+00	4.42E-19	1.69E-11	1.30E-18	2.85E-76	8.00E-03	1.33E-01	5.62E-15	7.19E-04	1.04E+00	0.00E+00	3.15E+00	0.00E+00	3.30E-07
BATCH-1170	4/4/33	139	14.5	0.24	5.43E+02	0.00E+00	7.11E-17	4.39E-11	1.92E-16	3.54E-86	4.20E-02	1.17E+00	1.78E-14	3.00E-03	4.25E+00	0.00E+00	9.26E+00	0.00E+00	1.22E-06
BATCH-1171	4/5/33	120	12.5	0.24	4.72E+02	0.00E+00	1.25E-16	2.48E-12	3.35E-16	3.37E-82	3.90E-02	1.58E+00	6.65E-15	1.00E-03	2.95E+00	0.00E+00	6.56E+00	0.00E+00	7.05E-07
BATCH-1172	4/18/33	120	12.5	0.24	4.71E+02	0.00E+00	1.24E-16	2.47E-12	3.34E-16	1.29E-82	3.80E-02	1.57E+00	6.64E-15	1.00E-03	2.94E+00	0.00E+00	6.55E+00	0.00E+00	7.03E-07
BATCH-1173	4/18/33	124	12.9	0.24	5.19E+02	0.00E+00	1.51E-14	4.12E-12	8.92E-15	4.54E-77	3.60E-02	1.60E+00	1.76E-14	1.00E-03	3.16E+00	0.00E+00	6.77E+00	0.00E+00	5.16E-07
BATCH-1174	5/1/33	14	1.4	0.24	3.79E+01	0.00E+00	1.03E-19	4.03E-12	3.02E-19	2.61E-77	2.00E-03	3.10E-02	1.33E-15	1.71E-04	2.46E-01	0.00E+00	7.48E-01	0.00E+00	7.84E-08
BATCH-1175	5/2/33	14	1.4	0.24	3.78E+01	0.00E+00	1.05E-19	4.02E-12	3.08E-19	6.77E-77	2.00E-03	3.10E-02	1.33E-15	1.70E-04	2.46E-01	0.00E+00	7.47E-01	0.00E+00	7.83E-08

Appendix A Nominal /LAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date.

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1127	11/21/32	29	3.0	0.24	4.69E-14	2.13E+01	4.59E-01	0.00E+00	0.00E+00	6.00E-04	1.24E+00	5.12E-06	7.60E-12	1.19E-10	1.10E-02	4.27E-11	4.98E+02	0.00E+00	7.70E-02
BATCH-1128	11/23/32	44	4.6	0.24	5.62E-14	3.29E+01	6.99E-01	0.00E+00	0.00E+00	6.00E-04	1.76E+00	9.79E-06	9.18E-12	1.43E-10	1.50E-02	5.11E-11	7.59E+02	0.00E+00	1.02E-01
BATCH-1129	11/24/32	42	4.4	0.24	6.76E-14	3.07E+01	6.60E-01	0.00E+00	0.00E+00	8.00E-04	1.78E+00	7.36E-06	1.09E-11	1.71E-10	1.50E-02	6.15E-11	7.17E+02	0.00E+00	1.10E-01
BATCH-1130	11/28/32	42	4.4	0.24	6.75E-14	3.07E+01	6.60E-01	0.00E+00	0.00E+00	8.00E-04	1.78E+00	7.36E-06	1.09E-11	1.71E-10	1.50E-02	6.14E-11	7.17E+02	0.00E+00	1.10E-01
BATCH-1131	11/28/32	42	4.4	0.24	6.75E-14	3.07E+01	6.59E-01	0.00E+00	0.00E+00	8.00E-04	1.78E+00	7.35E-06	1.09E-11	1.71E-10	1.50E-02	6.14E-11	7.17E+02	0.00E+00	1.10E-01
BATCH-1132	12/2/32	115	12.0	0.24	8.06E-17	2.44E+01	1.69E+00	0.00E+00	0.00E+00	1.55E-04	9.22E-01	1.22E-05	2.61E-13	2.75E-12	7.00E-03	4.61E-18	1.97E+03	0.00E+00	3.30E-02
BATCH-1133	12/3/32	124	12.9	0.24	1.28E-14	2.12E+01	1.47E+00	0.00E+00	0.00E+00	2.00E-04	9.18E-01	9.09E-06	2.23E-12	3.40E-11	7.00E-03	1.16E-11	2.12E+03	0.00E+00	4.20E-02
BATCH-1134	12/15/32	28	2.9	0.24	4.47E-14	2.03E+01	4.37E-01	0.00E+00	0.00E+00	6.00E-04	1.18E+00	4.87E-06	7.24E-12	1.13E-10	1.00E-02	4.07E-11	4.75E+02	0.00E+00	7.30E-02
BATCH-1135	12/16/32	29	3.0	0.24	2.13E-14	1.10E+01	2.93E-01	0.00E+00	0.00E+00	2.00E-04	1.42E+00	2.49E-06	3.45E-12	5.40E-11	7.00E-03	1.94E-11	4.97E+02	0.00E+00	4.70E-02
BATCH-1136	12/18/32	39	4.1	0.24	4.21E-17	3.37E+00	2.08E-01	0.00E+00	0.00E+00	2.86E-05	2.11E+00	4.17E-07	6.04E-15	1.90E-13	6.00E-03	3.27E-14	6.67E+02	0.00E+00	3.00E-02
BATCH-1137	12/19/32	39	4.1	0.24	4.20E-17	3.37E+00	2.08E-01	0.00E+00	0.00E+00	2.87E-05	2.11E+00	4.17E-07	6.03E-15	1.90E-13	6.00E-03	3.27E-14	6.67E+02	0.00E+00	3.00E-02
BATCH-1138	12/22/32	52	5.4	0.24	3.28E-17	9.90E+00	6.88E-01	0.00E+00	0.00E+00	6.30E-05	3.75E-01	4.95E-06	1.06E-13	1.12E-12	3.00E-03	1.87E-18	8.84E+02	0.00E+00	1.40E-02
BATCH-1139	12/24/32	48	5.0	0.24	4.40E-15	7.29E+00	5.05E-01	0.00E+00	0.00E+00	8.32E-05	3.16E-01	3.13E-06	7.67E-13	1.17E-11	2.00E-03	3.99E-12	8.18E+02	0.00E+00	1.40E-02
BATCH-1140	12/28/32	139	14.5	0.24	2.67E-14	1.92E+01	1.20E+00	0.00E+00	0.00E+00	4.00E-04	9.69E-01	6.42E-06	4.40E-12	6.85E-11	8.00E-03	2.43E-11	2.37E+03	0.00E+00	5.30E-02
BATCH-1141	12/29/32	150	15.6	0.24	3.70E-14	1.69E+01	1.04E+00	0.00E+00	0.00E+00	4.00E-04	1.07E+00	4.05E-06	5.99E-12	9.36E-11	9.00E-03	3.36E-11	2.55E+03	0.00E+00	6.20E-02
BATCH-1142	1/11/33	136	14.2	0.24	2.01E-14	1.00E+01	7.49E-01	0.00E+00	0.00E+00	2.00E-04	1.10E+00	2.30E-06	3.25E-12	5.09E-11	6.00E-03	1.83E-11	2.32E+03	0.00E+00	4.10E-02
BATCH-1143	1/14/33	136	14.2	0.24	2.00E-14	1.00E+01	7.48E-01	0.00E+00	0.00E+00	2.00E-04	1.10E+00	2.29E-06	3.24E-12	5.08E-11	6.00E-03	1.82E-11	2.32E+03	0.00E+00	4.10E-02
BATCH-1144	1/26/33	19	2.0	0.24	8.96E-18	2.71E+00	1.88E-01	0.00E+00	0.00E+00	1.72E-05	1.02E-01	1.35E-06	2.89E-14	3.05E-13	7.64E-04	5.12E-19	3.21E+02	0.00E+00	4.00E-03
BATCH-1145	1/28/33	17	1.8	0.24	1.09E-15	1.81E+00	1.26E-01	0.00E+00	0.00E+00	2.07E-05	7.90E-02	7.77E-07	1.91E-13	2.91E-12	6.19E-04	9.92E-13	2.89E+02	0.00E+00	4.00E-03
BATCH-1146	1/28/33	41	4.3	0.24	7.01E-15	5.02E+00	3.14E-01	0.00E+00	0.00E+00	9.07E-05	2.54E-01	1.68E-06	1.15E-12	1.79E-11	2.00E-03	6.37E-12	7.08E+02	0.00E+00	1.40E-02
BATCH-1147	1/30/33	39	4.1	0.24	8.43E-15	3.87E+00	2.37E-01	0.00E+00	0.00E+00	9.55E-05	2.44E-01	9.23E-07	1.37E-12	2.14E-11	2.00E-03	7.67E-12	6.67E+02	0.00E+00	1.40E-02
BATCH-1148	2/2/33	39	4.1	0.24	5.06E-15	2.53E+00	1.89E-01	0.00E+00	0.00E+00	5.91E-05	2.78E-01	5.80E-07	8.20E-13	1.28E-11	2.00E-03	4.60E-12	6.67E+02	0.00E+00	1.00E-02
BATCH-1149	2/3/33	39	4.1	0.24	5.05E-15	2.52E+00	1.89E-01	0.00E+00	0.00E+00	5.89E-05	2.78E-01	5.78E-07	8.18E-13	1.28E-11	2.00E-03	4.59E-12	6.67E+02	0.00E+00	1.00E-02
BATCH-1150	2/6/33	56	5.9	0.24	8.92E-18	4.86E+00	3.00E-01	0.00E+00	0.00E+00	4.09E-05	3.05E+00	5.98E-07	3.29E-16	1.43E-13	8.00E-03	3.93E-17	9.64E+02	0.00E+00	4.30E-02
BATCH-1151	2/8/33	56	5.9	0.24	9.05E-18	4.85E+00	3.00E-01	0.00E+00	0.00E+00	4.08E-05	3.05E+00	5.98E-07	3.49E-16	1.44E-13	8.00E-03	1.66E-16	9.64E+02	0.00E+00	4.30E-02
BATCH-1152	2/12/33	15	1.6	0.24	1.66E-15	1.19E+00	7.40E-02	0.00E+00	0.00E+00	2.14E-05	6.00E-02	3.98E-07	2.73E-13	4.24E-12	4.98E-04	1.51E-12	2.57E+02	0.00E+00	3.00E-03
BATCH-1153	2/14/33	14	1.5	0.24	1.99E-15	9.13E-01	5.60E-02	0.00E+00	0.00E+00	2.26E-05	5.80E-02	2.18E-07	3.23E-13	5.05E-12	4.65E-04	1.81E-12	2.45E+02	0.00E+00	3.00E-03
BATCH-1154	2/14/33	14	1.5	0.24	1.20E-15	5.99E-01	4.50E-02	0.00E+00	0.00E+00	1.40E-05	6.60E-02	1.37E-07	1.94E-13	3.04E-12	3.63E-04	1.09E-12	2.43E+02	0.00E+00	2.00E-03
BATCH-1155	2/15/33	14	1.5	0.24	1.20E-15	5.98E-01	4.50E-02	0.00E+00	0.00E+00	1.40E-05	6.60E-02	1.37E-07	1.94E-13	3.03E-12	3.62E-04	1.09E-12	2.43E+02	0.00E+00	2.00E-03
BATCH-1156	2/15/33	40	4.2	0.24	6.32E-18	3.44E+00	2.13E-01	0.00E+00	0.00E+00	2.90E-05	2.16E+00	4.24E-07	2.30E-16	1.02E-13	6.00E-03	2.79E-17	6.84E+02	0.00E+00	3.00E-02
BATCH-1157	2/17/33	40	4.2	0.24	6.32E-18	3.44E+00	2.13E-01	0.00E+00	0.00E+00	2.89E-05	2.16E+00	4.23E-07	2.30E-16	1.01E-13	6.00E-03	2.79E-17	6.83E+02	0.00E+00	3.00E-02
BATCH-1158	2/20/33	58	6.0	0.24	9.16E-18	3.00E+01	1.83E-01	0.00E+00	0.00E+00	6.00E-04	2.72E+00	2.57E-06	3.50E-15	5.75E-14	6.00E-03	4.18E-13	9.86E+02	0.00E+00	5.10E-02
BATCH-1159	2/21/33	71	7.4	0.24	1.13E-17	5.61E+01	1.30E-01	0.00E+00	0.00E+00	1.40E-03	3.05E+00	4.67E-06	6.74E-15	2.35E-15	6.00E-03	8.37E-13	1.21E+03	0.00E+00	6.80E-02
BATCH-1160	2/26/33	71	7.4	0.24	1.12E-17	5.61E+01	1.30E-01	0.00E+00	0.00E+00	1.40E-03	3.05E+00	4.67E-06	6.72E-15	2.12E-15	6.00E-03	8.36E-13	1.21E+03	0.00E+00	6.80E-02
BATCH-1161	3/1/33	71	7.4	0.24	1.12E-17	5.60E+01	1.30E-01	0.00E+00	0.00E+00	1.40E-03	3.05E+00	4.67E-06	6.72E-15	2.12E-15	6.00E-03	8.36E-13	1.21E+03	0.00E+00	6.70E-02
BATCH-1162	3/5/33	139	14.5	0.24	4.20E-18	2.29E+00	3.00E-01	0.00E+00	0.00E+00	1.92E-05	1.44E+00	2.82E-07	1.54E-16	6.75E-14	4.00E-03	1.85E-17	2.37E+03	0.00E+00	2.00E-02
BATCH-1163	3/8/33	139	14.5	0.24	4.23E-18	2.28E+00	2.99E-01	0.00E+00	0.00E+00	1.92E-05	1.43E+00	2.81E-07	1.59E-16	6.74E-14	4.00E-03	5.33E-17	2.37E+03	0.00E+00	2.00E-02
BATCH-1164	3/20/33	45	4.7	0.24	7.06E-18	3.58E+01	8.30E-02	0.00E+00	0.00E+00	8.00E-04	1.95E+00	2.98E-06	4.28E-15	1.16E-15	4.00E-03	5.34E-13	7.75E+02	0.00E+00	4.30E-02
BATCH-1165	3/23/33	51	5.3	0.24	7.91E-18	4.01E+01	9.30E-02	0.00E+00	0.00E+00	1.00E-03	2.18E+00	3.34E-06	4.80E-15	1.26E-15	5.00E-03	5.99E-13	8.69E+02	0.00E+00	4.80E-02
BATCH-1166	3/25/33	51	5.3	0.24	7.90E-18	4.01E+01	9.30E-02	0.00E+00	0.00E+00	1.00E-03	2.18E+00	3.34E-06	4.79E-15	1.26E-15	5.00E-03	5.98E-13	8.68E+02	0.00E+00	4.80E-02
BATCH-1167	3/29/33	31	3.3	0.24	4.41E-16	1.22E+01	2.30E-02	0.00E+00	0.00E+00	2.20E-03	1.43E+00	1.23E-04	2.10E-14	1.58E-12	3.00E-03	1.37E-13	5.33E+02	0.00E+00	2.90E-02
BATCH-1168	3/31/33	37	3.9	0.24	9.97E-19	5.43E-01	7.10E-02	0.00E+00	0.00E+00	4.57E-06	3.41E-01	6.69E-08	3.66E-17	1.60E-14	9.07E-04	4.40E-18	6.40E+02	0.00E+00	5.00E-03
BATCH-1169	4/1/33	37	3.9	0.24	1.00E-18	5.42E-01	7.10E-02	0.00E+00	0.00E+00	4.56E-06	3.40E-01	6.67E-08	3.78E-17	1.60E-14	9.04E-04	1.27E-17	6.39E+02	0.00E+00	5.00E-03
BATCH-1170	4/4/33	139	14.5	0.24	5.13E-18	1.43E+01	6.80E-01	0.00E+00	0.00E+00	4.00E-04	1.55E+00	1.24E-06	1.65E-15	4.07E-14	4.00E-03	1.93E-13	2.38E+03	0.00E+00	2.80E-02
BATCH-1171	4/5/33	120	12.5	0.24	4.59E-18	2.30E+01	8.08E-01	0.00E+00	0.00E+00	6.00E-04	1.25E+00	1.92E-06	2.76E-15	8.62E-16	3.00E-03	3.43E-13	2.05E+03	0.00E+00	2.80E-02
BATCH-1172	4/18/33	120	12.5	0.24	4.56E-18	2.30E+01	8.07E-01	0.00E+00	0.00E+00	6.00E-04	1.25E+00	1.91E-06	2.75E-15	8.07E-16	3.00E-03	3.42E-13	2.05E+03	0.00E+00	2.80E-02
BATCH-1173	4/18/33	124	12.9	0.24	1.06E-16	1.85E+01	8.36E-01	0.00E+00	0.00E+00	8.00E-04	1.18E+00	3.00E-05	6.76E-15	3.69E-13	2.00E-03	2.65E-13	2.12E+03	0.00E+00	2.60E-02
BATCH-1174	5/1/33	14	1.4	0.24	2.36E-19	1.29E+01	1.70E-02	0.00E+00	0.00E+00	1.08E-06	8.10E-02	1.59E-08	8.67E-18	3.80E-15	2.15E-04	1.04E-18	2.32E+02	0.00E+00	1.00E-03
BATCH-1175	5/2/33	14	1.4	0.24	2.38E-19	1.28E+01	1.70E-02	0.00E+00	0.00E+00	1.08E-06	8.10E-02	1.58E-08	8.97E-18	3.79E-15	2.14E-04	3.00E-18	2.31E+02	0.00E+00	1.00E-03

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1127	11/21/32	29	3.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.17E+01	4.14E-14	8.47E+00	9.47E+00	1.80E-02	5.23E-12	0.00E+00	7.55E-04	2.84E-10	1.40E-02
BATCH-1128	11/23/32	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-02	4.66E+01	4.96E-14	1.20E+01	2.01E+01	3.40E-02	6.27E-12	0.00E+00	9.92E-04	3.41E-10	2.10E-02
BATCH-1129	11/24/32	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	4.56E+01	5.96E-14	1.22E+01	1.36E+01	2.60E-02	7.54E-12	0.00E+00	1.00E-03	4.09E-10	2.00E-02
BATCH-1130	11/28/32	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	4.56E+01	5.95E-14	1.22E+01	1.36E+01	2.60E-02	7.53E-12	0.00E+00	1.00E-03	4.09E-10	2.00E-02
BATCH-1131	11/28/32	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-02	4.56E+01	5.95E-14	1.22E+01	1.36E+01	2.60E-02	7.53E-12	0.00E+00	1.00E-03	4.09E-10	2.00E-02
BATCH-1132	12/2/32	115	12.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.06E+02	1.97E-19	5.19E+01	3.05E+01	4.10E-02	5.78E-20	0.00E+00	3.17E-04	1.77E-12	1.50E-02
BATCH-1133	12/3/32	124	12.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	9.45E+01	1.13E-14	5.35E+01	2.19E+01	3.10E-02	1.42E-12	0.00E+00	4.32E-04	7.84E-11	1.30E-02
BATCH-1134	12/15/32	28	2.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.02E+01	3.94E-14	8.07E+00	9.00E+00	1.70E-02	4.99E-12	0.00E+00	7.20E-04	2.71E-10	1.30E-02
BATCH-1135	12/16/32	29	3.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.79E+01	1.88E-14	6.37E+00	9.16E+00	1.70E-02	2.38E-12	0.00E+00	1.00E-03	1.30E-10	6.00E-03
BATCH-1136	12/18/32	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.70E+00	3.17E-17	6.22E+00	1.20E+01	2.10E-02	4.01E-15	0.00E+00	2.00E-03	1.85E-12	6.41E-04
BATCH-1137	12/19/32	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.70E+00	3.17E-17	6.23E+00	1.20E+01	2.10E-02	4.00E-15	0.00E+00	2.00E-03	1.85E-12	6.41E-04
BATCH-1138	12/22/32	52	5.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.30E+01	8.01E-20	2.11E+01	1.24E+01	1.60E-02	2.35E-20	0.00E+00	1.29E-04	7.20E-13	6.00E-03
BATCH-1139	12/24/32	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	3.25E+01	3.87E-15	1.84E+01	7.54E+00	1.10E-02	4.89E-13	0.00E+00	1.49E-04	2.70E-11	5.00E-03
BATCH-1140	12/28/32	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	8.04E+01	2.36E-14	5.51E+01	1.41E+01	2.20E-02	2.98E-12	0.00E+00	5.78E-04	1.62E-10	1.20E-02
BATCH-1141	12/29/32	150	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	7.16E+01	3.28E-14	6.58E+01	8.23E+00	1.50E-02	4.12E-12	0.00E+00	7.58E-04	2.24E-10	1.10E-02
BATCH-1142	1/1/33	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	5.06E+01	1.77E-14	7.87E+01	7.57E+00	1.40E-02	2.24E-12	0.00E+00	9.02E-04	1.22E-10	6.00E-03
BATCH-1143	1/14/33	136	14.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	5.05E+01	1.77E-14	7.87E+01	7.56E+00	1.40E-02	2.24E-12	0.00E+00	9.01E-04	1.22E-10	6.00E-03
BATCH-1144	1/26/33	19	2.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.17E+01	2.19E-20	5.76E+00	3.39E+00	5.00E-03	6.42E-21	0.00E+00	3.52E-05	1.97E-13	2.00E-03
BATCH-1145	1/28/33	17	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.76E-04	8.08E+00	9.61E-16	4.58E+00	1.87E+00	3.00E-03	1.22E-13	0.00E+00	3.69E-05	6.70E-12	1.00E-03
BATCH-1146	1/28/33	41	4.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	2.11E+01	6.17E-15	1.44E+01	3.71E+00	6.00E-03	7.81E-13	0.00E+00	1.52E-04	4.25E-11	3.00E-03
BATCH-1147	1/30/33	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	1.63E+01	7.43E-15	1.50E+01	1.88E+00	4.00E-03	9.41E-13	0.00E+00	1.73E-04	5.11E-11	2.00E-03
BATCH-1148	2/2/33	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.28E+01	4.46E-15	1.98E+01	1.91E+00	3.00E-03	5.65E-13	0.00E+00	2.27E-04	3.08E-11	2.00E-03
BATCH-1149	2/3/33	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	1.27E+01	4.45E-15	1.98E+01	1.91E+00	3.00E-03	5.63E-13	0.00E+00	2.27E-04	3.07E-11	2.00E-03
BATCH-1150	2/6/33	56	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.26E+01	9.30E-20	9.00E+00	1.74E+01	3.10E-02	4.14E-18	0.00E+00	3.00E-03	2.37E-12	9.13E-04
BATCH-1151	2/8/33	56	5.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.25E+01	2.16E-19	8.99E+00	1.73E+01	3.10E-02	1.96E-17	0.00E+00	3.00E-03	2.37E-12	9.12E-04
BATCH-1152	2/12/33	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.59E-04	4.98E+00	1.46E-15	3.41E+00	8.77E-01	1.00E-03	1.85E-13	0.00E+00	3.58E-05	1.01E-11	7.54E-04
BATCH-1153	2/14/33	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.36E-04	3.86E+00	1.76E-15	3.55E+00	4.44E-01	8.29E-04	2.22E-13	0.00E+00	4.09E-05	1.21E-11	5.85E-04
BATCH-1154	2/14/33	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.61E-04	3.02E+00	1.06E-15	4.70E+00	4.52E-01	8.11E-04	1.34E-13	0.00E+00	5.38E-05	7.28E-12	3.61E-04
BATCH-1155	2/15/33	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-04	3.01E+00	1.05E-15	4.69E+00	4.51E-01	8.09E-04	1.33E-13	0.00E+00	5.37E-05	7.27E-12	3.60E-04
BATCH-1156	2/15/33	40	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.90E+00	6.65E-20	6.38E+00	1.23E+01	2.20E-02	2.93E-18	0.00E+00	2.00E-03	1.68E-12	6.47E-04
BATCH-1157	2/17/33	40	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	8.89E+00	6.65E-20	6.37E+00	1.23E+01	2.20E-02	2.94E-18	0.00E+00	2.00E-03	1.68E-12	6.46E-04
BATCH-1158	2/20/33	58	6.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	2.07E+01	3.01E-19	1.09E+01	4.05E+01	4.90E-02	1.98E-17	0.00E+00	2.00E-03	3.17E-12	2.00E-03
BATCH-1159	2/21/33	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.16E+01	5.06E-19	1.48E+01	6.75E+01	7.30E-02	3.35E-17	0.00E+00	2.00E-03	4.48E-12	3.00E-03
BATCH-1160	2/26/33	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.16E+01	4.29E-19	1.48E+01	6.74E+01	7.30E-02	2.37E-17	0.00E+00	2.00E-03	4.48E-12	3.00E-03
BATCH-1161	3/1/33	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.16E+01	4.28E-19	1.48E+01	6.74E+01	7.30E-02	2.37E-17	0.00E+00	2.00E-03	4.47E-12	3.00E-03
BATCH-1162	3/5/33	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.77E+01	4.42E-20	1.13E+02	8.50E+00	1.40E-02	1.95E-18	0.00E+00	1.00E-03	1.12E-12	4.30E-04
BATCH-1163	3/8/33	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.77E+01	7.78E-20	1.13E+02	8.48E+00	1.40E-02	6.22E-18	0.00E+00	1.00E-03	1.11E-12	4.29E-04
BATCH-1164	3/20/33	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	2.02E+01	1.94E-19	9.45E+00	4.31E+01	4.70E-02	4.98E-18	0.00E+00	1.00E-03	2.86E-12	2.00E-03
BATCH-1165	3/23/33	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	2.26E+01	2.17E-19	1.06E+01	4.83E+01	5.30E-02	5.59E-18	0.00E+00	1.00E-03	3.21E-12	2.00E-03
BATCH-1166	3/25/33	51	5.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	2.26E+01	2.17E-19	1.06E+01	4.82E+01	5.20E-02	5.58E-18	0.00E+00	1.00E-03	3.20E-12	2.00E-03
BATCH-1167	3/29/33	31	3.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.27E+01	3.61E-15	8.53E+00	1.86E+01	2.30E-02	5.88E-19	0.00E+00	1.53E-04	3.77E-12	4.00E-03
BATCH-1168	3/31/33	37	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.40E-04	4.20E+00	1.05E-20	2.69E+01	2.02E+00	3.00E-03	4.63E-19	0.00E+00	3.18E-04	2.65E-13	1.02E-04
BATCH-1169	4/1/33	37	3.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-04	4.19E+00	1.85E-20	2.69E+01	2.01E+00	3.00E-03	1.48E-18	0.00E+00	3.17E-04	2.64E-13	1.02E-04
BATCH-1170	4/4/33	139	14.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	3.07E+01	1.76E-19	7.90E+01	2.19E+01	2.50E-02	1.31E-17	0.00E+00	1.00E-03	1.69E-12	9.59E-04
BATCH-1171	4/5/33	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.67E+01	1.73E-19	6.07E+01	2.97E+01	3.00E-02	9.35E-18	0.00E+00	7.71E-04	1.84E-12	1.00E-03
BATCH-1172	4/18/33	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.66E+01	1.54E-19	6.06E+01	2.96E+01	3.00E-02	6.99E-18	0.00E+00	7.69E-04	1.83E-12	1.00E-03
BATCH-1173	4/18/33	124	12.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	3.18E+01	8.41E-16	4.68E+01	2.46E+01	2.60E-02	6.19E-18	0.00E+00	5.66E-04	2.13E-12	2.00E-03
BATCH-1174	5/1/33	14	1.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E-04	9.95E-01	2.49E-21	6.38E+00	4.79E-01	8.09E-04	1.10E-19	0.00E+00	7.54E-05	6.28E-14	2.42E-05
BATCH-1175	5/2/33	14	1.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.51E-04	9.94E-01	4.38E-21	6.37E+00	4.77E-01	8.07E-04	3.50E-19	0.00E+00	7.53E-05	6.26E-14	2.41E-05

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1176	5/2/33	47	4.9	0.24	0.00E+00	0.00E+00	3.00E-03	4.93E-05	2.22E-01	1.53E-01	9.37E+02	7.60E-02	3.70E-02	5.82E-01	8.71E-18	9.00E-03	3.44E-04	1.90E-02	2.29E-04
BATCH-1177	5/3/33	40	4.2	0.24	0.00E+00	0.00E+00	5.00E-03	5.62E-05	3.33E-01	1.32E-01	8.01E+02	7.50E-02	1.60E-02	6.41E-01	2.80E-17	7.00E-03	1.43E-04	1.30E-02	2.40E-04
BATCH-1178	5/7/33	47	4.9	0.24	0.00E+00	0.00E+00	3.00E-03	4.91E-05	2.22E-01	1.53E-01	9.35E+02	7.60E-02	3.60E-02	5.81E-01	8.69E-18	9.00E-03	3.43E-04	1.90E-02	2.29E-04
BATCH-1179	5/7/33	45	4.7	0.24	0.00E+00	0.00E+00	3.00E-03	3.54E-05	2.13E-01	1.31E-01	9.01E+02	6.30E-02	2.60E-02	4.88E-01	7.39E-18	7.00E-03	2.43E-04	1.50E-02	1.85E-04
BATCH-1180	5/12/33	42	4.4	0.24	0.00E+00	0.00E+00	1.90E-02	6.00E-05	1.38E+00	6.07E-01	8.40E+02	2.70E-01	4.40E-02	2.17E+00	3.43E-17	1.40E-02	3.27E-04	5.20E-02	7.50E-04
BATCH-1181	5/12/33	42	4.4	0.24	0.00E+00	0.00E+00	1.90E-02	6.00E-05	1.38E+00	6.07E-01	8.40E+02	2.70E-01	4.40E-02	2.17E+00	3.42E-17	1.40E-02	3.27E-04	5.20E-02	7.50E-04
BATCH-1182	5/17/33	16	1.7	0.24	0.00E+00	0.00E+00	7.08E-04	1.15E-05	5.20E-02	3.60E-02	3.23E+02	1.80E-02	9.00E-03	1.36E-01	2.03E-18	2.00E-03	8.03E-05	5.00E-03	5.35E-05
BATCH-1183	5/17/33	15	1.5	0.24	0.00E+00	0.00E+00	1.00E-03	1.33E-05	7.90E-02	3.15E-02	2.91E+02	1.80E-02	4.00E-03	1.52E-01	6.63E-18	2.00E-03	3.39E-05	3.00E-03	5.68E-05
BATCH-1184	5/19/33	16	1.6	0.24	0.00E+00	0.00E+00	6.80E-04	8.28E-06	5.00E-02	3.06E-02	3.16E+02	1.50E-02	6.00E-03	1.14E-01	1.73E-18	2.00E-03	5.68E-05	4.00E-03	4.32E-05
BATCH-1189	5/19/33	16	1.7	0.24	0.00E+00	0.00E+00	7.06E-04	1.15E-05	5.20E-02	3.60E-02	3.23E+02	1.80E-02	9.00E-03	1.36E-01	2.03E-18	2.00E-03	8.01E-05	5.00E-03	5.34E-05
BATCH-1185	5/19/33	16	1.7	0.24	0.00E+00	0.00E+00	7.06E-04	1.15E-05	5.20E-02	3.60E-02	3.23E+02	1.80E-02	9.00E-03	1.36E-01	2.03E-18	2.00E-03	8.01E-05	5.00E-03	5.34E-05
BATCH-1186	5/20/33	30	3.1	0.24	0.00E+00	0.00E+00	1.30E-02	4.22E-05	9.69E-01	4.27E-01	5.90E+02	1.90E-01	3.10E-02	1.52E+00	2.41E-17	1.00E-02	2.30E-04	3.60E-02	5.00E-04
BATCH-1187	5/21/33	30	3.1	0.24	0.00E+00	0.00E+00	1.30E-02	4.22E-05	9.68E-01	4.27E-01	5.90E+02	1.90E-01	3.10E-02	1.52E+00	2.41E-17	1.00E-02	2.30E-04	3.60E-02	5.00E-04
BATCH-1188	5/24/33	42	4.4	0.24	0.00E+00	0.00E+00	1.90E-02	5.99E-05	1.38E+00	6.05E-01	8.38E+02	2.70E-01	4.40E-02	2.16E+00	3.42E-17	1.40E-02	3.27E-04	5.20E-02	7.50E-04
BATCH-1189	5/24/33	39	4.0	0.24	0.00E+00	0.00E+00	2.20E-02	7.61E-05	1.57E+00	7.97E-01	7.70E+02	4.10E-01	1.80E-02	3.24E+00	1.53E-17	1.20E-02	1.27E-04	5.70E-02	1.00E-03
BATCH-1190	5/28/33	44	4.6	0.24	0.00E+00	0.00E+00	2.80E-02	1.05E-04	2.05E+00	1.11E+00	4.82E+02	6.05E-01	1.00E-03	4.40E+00	4.11E-18	1.56E-17	6.00E-03	1.49E-04	2.40E-02	2.50E-04
BATCH-1191	5/28/33	120	12.5	0.24	0.00E+00	0.00E+00	9.00E-03	2.73E-05	6.26E-01	2.75E-01	2.40E+03	1.23E-01	2.00E-02	9.82E-01	1.55E-17	6.00E-03	1.48E-04	2.30E-02	2.50E-04
BATCH-1192	6/2/33	120	12.5	0.24	0.00E+00	0.00E+00	9.00E-03	2.72E-05	6.25E-01	2.75E-01	2.40E+03	1.23E-01	2.00E-02	9.82E-01	1.55E-17	6.00E-03	1.48E-04	2.30E-02	2.50E-04
BATCH-1193	6/10/33	44	4.6	0.24	0.00E+00	0.00E+00	2.80E-02	1.05E-04	2.05E+00	1.11E+00	4.82E+02	6.05E-01	1.00E-03	4.40E+00	4.11E-18	1.40E-02	1.54E-06	7.30E-02	1.75E-03
BATCH-1194	6/15/33	31	3.2	0.24	0.00E+00	0.00E+00	2.00E-02	7.38E-05	1.45E+00	7.84E-01	3.48E+02	4.26E-01	8.83E-04	3.10E+00	2.91E-18	1.00E-02	1.24E-06	5.10E-02	1.25E-03
BATCH-1195	6/15/33	27	2.8	0.24	0.00E+00	0.00E+00	1.70E-02	6.48E-05	1.27E+00	6.88E-01	3.01E+02	3.73E-01	7.65E-04	2.72E+00	2.54E-18	9.00E-03	1.02E-06	4.50E-02	1.00E-03
BATCH-1196	6/18/33	30	3.1	0.24	0.00E+00	0.00E+00	1.90E-02	7.16E-05	1.40E+00	7.61E-01	3.29E+02	4.13E-01	8.34E-04	3.00E+00	2.80E-18	1.00E-02	1.05E-06	5.00E-02	1.25E-03
BATCH-1197	6/18/33	42	4.4	0.24	0.00E+00	0.00E+00	3.00E-03	8.33E-06	1.91E-01	8.46E-02	8.38E+02	3.80E-02	6.00E-03	3.00E-01	4.75E-18	2.00E-03	4.54E-05	7.00E-03	9.57E-05
BATCH-1198	6/21/33	42	4.4	0.24	0.00E+00	0.00E+00	3.00E-03	8.31E-06	1.91E-01	8.37E-02	8.38E+02	3.70E-02	6.00E-03	3.00E-01	4.74E-18	2.00E-03	4.54E-05	7.00E-03	9.55E-05
BATCH-1199	6/23/33	30	3.1	0.24	0.00E+00	0.00E+00	1.90E-02	7.15E-05	1.40E+00	7.60E-01	3.29E+02	4.12E-01	8.34E-04	3.00E+00	2.80E-18	1.00E-02	1.05E-06	5.00E-02	1.25E-03
BATCH-1200	6/26/33	157	16.4	0.24	0.00E+00	0.00E+00	1.40E-02	4.84E-05	1.01E+00	5.05E-01	3.15E+03	2.55E-01	1.40E-02	2.02E+00	1.20E-17	8.00E-03	1.04E-04	3.70E-02	7.50E-04
BATCH-1201	6/26/33	137	14.3	0.24	0.00E+00	0.00E+00	1.10E-02	3.96E-05	8.31E-01	4.11E-01	2.74E+03	2.07E-01	1.30E-02	1.64E+00	1.05E-17	7.00E-03	9.19E-05	3.00E-02	5.00E-04
BATCH-1202	7/11/33	160	16.7	0.24	0.00E+00	0.00E+00	1.50E-02	5.80E-05	1.14E+00	6.17E-01	2.67E+02	3.35E-01	6.77E-04	2.64E+00	2.27E-18	8.00E-03	8.51E-07	4.00E-02	1.00E-03
BATCH-1203	7/13/33	15	1.6	0.24	0.00E+00	0.00E+00	6.16E-04	1.96E-06	4.50E-02	1.98E-02	3.04E+02	9.00E-03	1.00E-03	7.10E-02	1.12E-18	4.44E-04	1.07E-05	2.00E-03	2.25E-05
BATCH-1204	7/14/33	160	16.7	0.24	0.00E+00	0.00E+00	1.60E-02	5.79E-05	1.13E+00	6.15E-01	2.66E+02	3.34E-01	6.75E-04	2.63E+00	2.27E-18	8.00E-03	8.50E-07	4.00E-02	1.00E-03
BATCH-1205	7/27/33	15	1.6	0.24	0.00E+00	0.00E+00	6.15E-04	1.96E-06	4.50E-02	1.98E-02	3.04E+02	9.00E-03	1.00E-03	7.10E-02	1.12E-18	4.43E-04	1.07E-05	2.00E-03	2.25E-05
BATCH-1206	7/29/33	39	4.0	0.24	0.00E+00	0.00E+00	3.00E-03	9.81E-06	2.06E-01	1.02E-01	7.75E+02	5.10E-02	3.00E-03	4.07E-01	2.60E-18	2.00E-03	2.28E-05	8.00E-03	1.37E-04
BATCH-1207	7/31/33	34	3.5	0.24	0.00E+00	0.00E+00	3.00E-03	9.14E-06	1.91E-01	9.54E-02	6.80E+02	4.80E-02	3.00E-03	3.82E-01	2.26E-18	2.00E-03	1.96E-05	7.00E-03	1.29E-04
BATCH-1208	8/2/33	34	3.5	0.24	0.00E+00	0.00E+00	3.00E-03	1.07E-05	2.10E-01	1.13E-01	4.93E+01	6.20E-02	1.25E-04	4.87E-01	4.20E-19	1.00E-03	1.57E-07	7.00E-03	1.70E-04
BATCH-1209	8/4/33	34	3.5	0.24	0.00E+00	0.00E+00	3.00E-03	1.07E-05	2.09E-01	1.13E-01	4.92E+01	6.20E-02	1.25E-04	4.86E-01	4.19E-19	1.00E-03	1.57E-07	7.00E-03	1.70E-04
BATCH-1210	8/6/33	14	1.5	0.24	0.00E+00	0.00E+00	6.70E-04	2.32E-06	4.90E-02	2.43E-02	2.84E+02	1.20E-02	7.45E-04	9.60E-02	6.15E-19	4.02E-04	5.40E-06	2.00E-03	3.26E-05
BATCH-1211	8/8/33	13	1.3	0.24	0.00E+00	0.00E+00	6.21E-04	2.17E-06	4.50E-02	2.25E-02	2.50E+02	1.10E-02	6.43E-04	9.00E-02	5.36E-19	3.69E-04	4.65E-06	2.00E-03	3.07E-05
BATCH-1212	8/8/33	12	1.3	0.24	0.00E+00	0.00E+00	6.85E-04	2.55E-06	5.00E-02	2.70E-02	1.17E+01	1.50E-02	2.97E-05	1.16E-01	9.96E-20	3.40E-04	3.73E-08	2.00E-03	4.04E-05
BATCH-1213	8/9/33	12	1.3	0.24	0.00E+00	0.00E+00	6.83E-04	2.54E-06	5.00E-02	2.70E-02	1.17E+01	1.50E-02	2.96E-05	1.16E-01	9.94E-20	3.40E-04	3.73E-08	2.00E-03	4.03E-05
BATCH-1214	8/13/33	42	4.4	0.24	0.00E+00	0.00E+00	1.60E-02	1.28E-04	1.17E+00	7.45E-01	3.60E+02	4.81E-01	9.08E-04	3.87E+00	8.29E-18	3.50E-02	1.51E-06	3.40E-02	1.50E-03
BATCH-1215	8/15/33	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.63E-04	8.98E-01	6.80E-01	3.58E+02	4.99E-01	9.00E-04	4.06E+00	1.20E-17	5.20E-02	1.76E-06	2.00E-02	1.75E-03
BATCH-1216	8/18/33	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.63E-04	8.97E-01	6.80E-01	3.58E+02	4.99E-01	8.99E-04	4.06E+00	1.20E-17	5.20E-02	1.76E-06	2.00E-02	1.75E-03
BATCH-1217	8/20/33	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.63E-04	8.97E-01	6.79E-01	3.58E+02	4.98E-01	8.99E-04	4.06E+00	1.20E-17	5.20E-02	1.76E-06	2.00E-02	1.75E-03
BATCH-1218	8/23/33	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.63E-04	8.96E-01	6.79E-01	3.57E+02	4.98E-01	8.98E-04	4.06E+00	1.19E-17	5.20E-02	1.76E-06	2.00E-02	1.75E-03
BATCH-1219	8/25/33	48	5.0	0.24	0.00E+00	0.00E+00	1.20E-02	1.62E-04	8.95E-01	6.78E-01	3.57E+02	4.97E-01	8.97E-04	4.05E+00	1.19E-17	5.20E-02	1.76E-06	2.00E-02	1.75E-03
BATCH-1220	8/29/33	32	3.3	0.24	0.00E+00	0.00E+00	1.00E-03	1.92E-05	7.90E-02	5.34E-01	6.30E+02	5.50E-02	3.00E-03	3.14E+00	2.10E-17	2.60E-02	2.22E-05	2.00E-03	1.00E-03
BATCH-1221	8/31/33	36	3.8	0.24	0.00E+00	0.00E+00	5.72E-04	1.38E-05	4.10E-02	6.26E-01	7.28E+02	3.70E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.77E-05	1.00E-03	1.00E-03
BATCH-1222	9/1/33	36	3.8	0.24	0.00E+00	0.00E+00	5.72E-04	1.38E-05	4.10E-02	6.26E-01	7.28E+02	3.70E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.77E-05	1.00E-03	1.00E-03
BATCH-1223	9/3/33	36	3.8	0.24	0.00E+00	0.00E+00	5.72E-04	1.38E-05	4.10E-02	6.26E-01	7.28E+02	3.70E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.77E-05	1.00E-03	1.00E-03
BATCH-1224	9/5/33	36	3.8	0.24	0.00E+00	0.00E+00	5.72E-04	1.38E-05	4.10E-02	6.26E-01	7.28E+02	3.70E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.77E-05	1.00E-03	1.00E-03

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1176	5/2/33	47	4.9	0.24	6.84E-10	1.40E+02	1.33E+00	5.19E-04	5.00E-02	1.00E-03	3.80E-06	4.28E-08	1.41E-06	1.04E-06	8.36E-06	1.96E-06	1.03E-04	5.74E-04	1.00E-03
BATCH-1177	5/3/33	40	4.2	0.24	7.50E-10	1.20E+02	1.68E+00	3.01E-04	2.40E-02	6.02E-04	1.87E-06	5.23E-08	1.24E-06	1.19E-06	1.03E-05	2.27E-06	1.18E-04	6.60E-04	2.00E-03
BATCH-1178	5/7/33	47	4.9	0.24	6.82E-10	1.40E+02	1.33E+00	5.18E-04	5.00E-02	1.00E-03	3.79E-06	4.27E-08	1.41E-06	1.04E-06	8.34E-06	1.95E-06	1.03E-04	5.72E-04	1.00E-03
BATCH-1179	5/7/33	45	4.7	0.24	5.76E-10	1.35E+02	9.02E-01	3.97E-04	3.50E-02	8.18E-04	3.00E-06	2.93E-08	1.05E-06	7.32E-07	6.69E-06	1.37E-06	7.27E-05	4.06E-04	1.00E-03
BATCH-1180	5/12/33	42	4.4	0.24	2.59E-09	1.26E+02	4.97E-01	1.00E-03	4.50E-02	2.00E-03	1.03E-05	2.10E-08	2.31E-06	9.41E-07	2.42E-05	1.53E-06	1.00E-04	5.58E-04	5.00E-03
BATCH-1181	5/12/33	42	4.4	0.24	2.59E-09	1.26E+02	4.96E-01	1.00E-03	4.50E-02	2.00E-03	1.03E-05	2.10E-08	2.31E-06	9.41E-07	2.42E-05	1.53E-06	1.00E-04	5.58E-04	5.00E-03
BATCH-1182	5/17/33	16	1.7	0.24	1.60E-10	4.85E+01	3.10E-01	1.21E-04	1.20E-02	2.49E-04	8.87E-07	9.98E-09	3.30E-07	2.42E-07	1.95E-06	4.57E-07	2.40E-05	1.34E-04	2.91E-04
BATCH-1183	5/17/33	15	1.5	0.24	1.77E-10	4.36E+01	3.98E-01	7.13E-05	6.00E-03	1.42E-04	4.43E-07	1.24E-08	2.94E-07	2.82E-07	2.43E-06	5.37E-07	2.80E-05	1.56E-04	3.61E-04
BATCH-1184	5/19/33	16	1.6	0.24	1.35E-10	4.74E+01	2.11E-01	9.27E-05	8.00E-03	1.91E-04	7.02E-07	6.84E-09	2.44E-07	1.71E-07	1.56E-06	3.20E-07	1.70E-05	9.49E-05	2.45E-04
BATCH-1185	5/19/33	16	1.7	0.24	1.59E-10	4.85E+01	3.09E-01	1.21E-04	1.20E-02	2.49E-04	8.85E-07	9.96E-09	3.29E-07	2.42E-07	1.95E-06	4.56E-07	2.39E-05	1.34E-04	2.91E-04
BATCH-1186	5/20/33	30	3.1	0.24	1.82E-09	8.85E+01	3.49E-01	7.92E-04	3.20E-02	2.00E-03	7.22E-06	1.47E-08	1.62E-06	6.62E-07	1.70E-05	1.08E-06	7.03E-05	3.92E-04	3.00E-03
BATCH-1187	5/21/33	30	3.1	0.24	1.82E-09	8.85E+01	3.49E-01	7.92E-04	3.20E-02	2.00E-03	7.21E-06	1.47E-08	1.62E-06	6.61E-07	1.70E-05	1.07E-06	7.03E-05	3.92E-04	3.00E-03
BATCH-1188	5/24/33	42	4.4	0.24	2.59E-09	1.26E+02	4.95E-01	1.00E-03	4.50E-02	2.00E-03	1.03E-05	2.09E-08	2.31E-06	9.39E-07	2.42E-05	1.53E-06	9.98E-05	5.57E-04	5.00E-03
BATCH-1189	5/24/33	39	4.0	0.24	4.41E-09	1.15E+02	6.39E-01	4.71E-04	1.90E-02	9.72E-04	1.05E-05	2.14E-08	4.35E-06	1.40E-06	7.87E-05	2.45E-06	1.06E-04	5.89E-04	4.00E-03
BATCH-1190	5/28/33	44	4.6	0.24	6.76E-09	1.32E+02	8.87E-01	7.07E-05	3.00E-03	1.44E-04	1.29E-05	2.63E-08	6.85E-06	2.05E-06	1.38E-04	3.69E-06	1.33E-04	7.40E-04	4.00E-03
BATCH-1191	5/28/33	120	12.5	0.24	1.18E-09	3.60E+02	2.26E-01	5.12E-04	2.10E-02	1.00E-03	4.66E-06	9.53E-09	1.05E-06	4.28E-07	1.10E-05	6.95E-07	4.54E-05	2.54E-04	2.00E-03
BATCH-1192	6/2/33	120	12.5	0.24	1.18E-09	3.59E+02	2.25E-01	5.11E-04	2.10E-02	1.00E-03	4.66E-06	9.51E-09	1.05E-06	4.27E-07	1.10E-05	6.93E-07	4.54E-05	2.53E-04	2.00E-03
BATCH-1193	6/10/33	44	4.6	0.24	6.76E-09	1.32E+02	8.87E-01	7.07E-05	3.00E-03	1.44E-04	1.28E-05	2.63E-08	6.85E-06	2.05E-06	1.38E-04	3.69E-06	1.33E-04	7.40E-04	4.00E-03
BATCH-1194	6/15/33	31	3.2	0.24	4.75E-09	9.32E+01	6.24E-01	5.03E-05	2.00E-03	1.02E-04	9.04E-06	1.85E-08	4.82E-06	1.44E-06	9.68E-05	2.59E-06	9.36E-05	5.21E-04	3.00E-03
BATCH-1195	6/15/33	27	2.8	0.24	4.17E-09	8.18E+01	5.48E-01	4.39E-05	2.00E-03	8.92E-05	7.93E-06	1.62E-08	4.23E-06	1.27E-06	8.49E-05	2.28E-06	8.21E-05	4.57E-04	2.00E-03
BATCH-1196	6/18/33	30	3.1	0.24	4.61E-09	9.04E+01	6.05E-01	4.82E-05	2.00E-03	9.80E-05	8.77E-06	1.79E-08	4.67E-06	1.40E-06	9.38E-05	2.52E-06	9.07E-05	5.05E-04	2.00E-03
BATCH-1197	6/18/33	42	4.4	0.24	3.60E-10	1.26E+02	6.90E-02	1.56E-04	6.00E-03	3.23E-04	1.43E-06	2.91E-09	3.21E-07	1.31E-07	3.36E-06	2.12E-07	1.39E-05	7.73E-05	6.47E-04
BATCH-1198	6/21/33	42	4.4	0.24	3.60E-10	1.26E+02	6.90E-02	1.56E-04	6.00E-03	3.23E-04	1.42E-06	2.91E-09	3.20E-07	1.30E-07	3.36E-06	2.12E-07	1.39E-05	7.73E-05	6.47E-04
BATCH-1199	6/23/33	30	3.1	0.24	4.61E-09	9.03E+01	6.05E-01	4.82E-05	2.00E-03	9.79E-05	8.76E-06	1.79E-08	4.67E-06	1.40E-06	9.37E-05	2.51E-06	9.06E-05	5.04E-04	2.00E-03
BATCH-1200	6/26/33	157	16.4	0.24	2.72E-09	4.72E+02	4.06E-01	3.76E-04	1.50E-02	7.78E-04	6.86E-06	1.40E-08	2.65E-06	8.74E-07	4.63E-05	1.52E-06	6.90E-05	3.84E-04	2.00E-03
BATCH-1201	6/26/33	137	14.3	0.24	2.19E-09	4.11E+02	3.32E-01	3.31E-04	1.30E-02	6.83E-04	5.66E-06	1.16E-08	2.13E-06	7.09E-07	3.66E-05	1.23E-06	5.69E-05	3.17E-04	2.00E-03
BATCH-1202	7/11/33	160	16.7	0.24	3.74E-09	4.80E+02	4.90E-01	3.91E-05	2.00E-03	7.94E-05	7.11E-06	1.45E-08	3.79E-06	1.14E-06	7.61E-05	2.04E-06	7.35E-05	4.09E-04	2.00E-03
BATCH-1203	7/13/33	15	1.6	0.24	8.46E-11	4.56E+01	1.60E-02	3.68E-05	1.00E-03	7.60E-05	3.35E-07	6.84E-10	7.53E-08	3.07E-08	7.90E-07	4.99E-08	3.26E-06	1.82E-05	1.52E-04
BATCH-1204	7/14/33	160	16.7	0.24	3.73E-09	4.80E+02	4.89E-01	3.90E-05	2.00E-03	7.93E-05	7.09E-06	1.45E-08	3.78E-06	1.13E-06	7.59E-05	2.04E-06	7.34E-05	4.08E-04	2.00E-03
BATCH-1205	7/27/33	15	1.6	0.24	8.45E-11	4.56E+01	1.60E-02	3.67E-05	1.00E-03	7.59E-05	3.35E-07	6.83E-10	7.53E-08	3.07E-08	7.89E-07	4.98E-08	3.26E-06	1.82E-05	1.52E-04
BATCH-1206	7/29/33	39	4.0	0.24	5.43E-10	1.16E+02	8.20E-02	8.19E-05	3.00E-03	1.69E-04	1.40E-06	2.87E-09	5.29E-07	1.76E-07	9.08E-06	3.04E-07	1.41E-05	7.85E-05	5.17E-04
BATCH-1207	7/31/33	34	3.5	0.24	5.13E-10	1.02E+02	7.70E-02	7.10E-05	3.00E-03	1.47E-04	1.29E-06	2.65E-09	5.01E-07	1.65E-07	8.74E-06	2.87E-07	1.30E-05	7.26E-05	4.70E-04
BATCH-1208	8/2/33	34	3.5	0.24	6.90E-10	1.01E+02	9.10E-02	7.22E-06	2.93E-04	1.47E-05	1.31E-06	2.69E-09	7.00E-07	2.10E-07	1.41E-05	3.77E-07	1.35E-05	7.56E-05	3.67E-04
BATCH-1209	8/4/33	34	3.5	0.24	6.89E-10	1.01E+02	9.00E-02	7.21E-06	2.93E-04	1.46E-05	1.31E-06	2.68E-09	6.98E-07	2.09E-07	1.40E-05	3.76E-07	1.35E-05	7.54E-05	3.67E-04
BATCH-1210	8/6/33	14	1.5	0.24	1.29E-10	4.26E+01	1.90E-02	1.94E-05	7.83E-04	4.01E-05	3.33E-07	6.80E-10	1.25E-07	4.16E-08	2.15E-06	7.21E-08	3.34E-06	1.86E-05	1.23E-04
BATCH-1211	8/8/33	13	1.3	0.24	1.22E-10	3.76E+01	1.80E-02	1.68E-05	6.79E-04	3.48E-05	3.07E-07	6.27E-10	1.19E-07	3.91E-08	2.07E-06	6.79E-08	3.08E-06	1.72E-05	1.11E-04
BATCH-1212	8/8/33	12	1.3	0.24	1.64E-10	3.68E+01	2.20E-02	1.72E-06	6.96E-05	3.48E-06	3.12E-07	6.38E-10	1.66E-07	4.98E-08	3.34E-06	8.95E-08	3.23E-06	1.80E-05	8.72E-05
BATCH-1213	8/9/33	12	1.3	0.24	1.64E-10	3.67E+01	2.10E-02	1.71E-06	6.95E-05	3.48E-06	3.11E-07	6.36E-10	1.66E-07	4.97E-08	3.33E-06	8.93E-08	3.22E-06	1.79E-05	8.70E-05
BATCH-1214	8/13/33	42	4.4	0.24	4.56E-09	1.26E+02	5.29E-01	4.13E-04	2.00E-03	9.63E-04	7.08E-06	1.64E-08	1.25E-05	3.11E-06	1.17E-04	5.23E-06	6.78E-05	3.77E-04	2.00E-03
BATCH-1215	8/15/33	48	5.0	0.24	4.19E-09	1.44E+02	4.32E-01	6.67E-04	2.00E-03	2.00E-03	5.26E-06	1.40E-08	1.77E-05	4.22E-06	1.27E-04	6.97E-06	4.51E-05	2.51E-04	1.00E-03
BATCH-1216	8/18/33	48	5.0	0.24	4.19E-09	1.44E+02	4.32E-01	6.67E-04	2.00E-03	2.00E-03	5.26E-06	1.40E-08	1.77E-05	4.21E-06	1.27E-04	6.96E-06	4.50E-05	2.51E-04	1.00E-03
BATCH-1217	8/20/33	48	5.0	0.24	4.19E-09	1.44E+02	4.32E-01	6.66E-04	2.00E-03	2.00E-03	5.25E-06	1.40E-08	1.77E-05	4.21E-06	1.27E-04	6.96E-06	4.50E-05	2.51E-04	1.00E-03
BATCH-1218	8/23/33	48	5.0	0.24	4.18E-09	1.44E+02	4.31E-01	6.65E-04	2.00E-03	2.00E-03	5.24E-06	1.39E-08	1.77E-05	4.21E-06	1.27E-04	6.95E-06	4.49E-05	2.50E-04	1.00E-03
BATCH-1219	8/25/33	48	5.0	0.24	1.60E-09	9.46E+01	2.08E-01	5.33E-04	6.00E-03	2.00E-03	1.02E-06	7.14E-09	1.04E-06	2.55E-06	1.27E-05	1.25E-05	8.36E-05	4.66E-04	3.00E-03
BATCH-1220	8/29/33	32	3.3	0.24	1.74E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.38E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.52E-05	1.02E-04	5.68E-04	4.00E-03
BATCH-1221	8/31/33	36	3.8	0.24	1.74E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.38E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.52E-05	1.02E-04	5.68E-04	4.00E-03
BATCH-1222	9/1/33	36	3.8	0.24	1.74E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.38E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.51E-05	1.02E-04	5.68E-04	4.00E-03
BATCH-1223	9/3/33	36	3.8	0.24	1.73E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.38E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.51E-05	1.02E-04	5.68E-04	4.00E-03
BATCH-1224	9/5/33	36	3.8	0.24	1.73E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.38E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.51E-05	1.02E-04	5.68E-04	4.00E-03

Appendix A Nominal ILAW Inventory

TWRSQ&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1176	5/2/33	47	4.9	0.24	5.37E-05	2.11E-05	1.97E-04	4.00E-03	1.00E-03	7.90E-02	1.90E-02	4.46E-01	6.40E-02	4.57E-29	2.85E-06	1.51E-05	2.82E-04	6.00E-03	1.94E-14
BATCH-1177	5/3/33	40	4.2	0.24	6.64E-05	2.41E-05	2.46E-04	4.00E-03	2.00E-03	7.90E-02	1.90E-02	3.75E-01	6.20E-02	3.63E-29	2.73E-06	1.61E-05	2.49E-04	5.00E-03	7.98E-15
BATCH-1178	5/7/33	47	4.9	0.24	5.35E-05	2.10E-05	1.97E-04	4.00E-03	1.00E-03	7.90E-02	1.90E-02	4.45E-01	6.30E-02	4.55E-29	2.84E-06	1.51E-05	2.81E-04	6.00E-03	1.93E-14
BATCH-1179	5/7/33	45	4.7	0.24	4.51E-05	1.81E-05	1.47E-04	4.00E-03	1.00E-03	7.00E-02	1.70E-02	3.71E-01	5.80E-02	4.19E-29	2.59E-06	1.37E-05	2.63E-04	5.00E-03	1.59E-14
BATCH-1180	5/12/33	42	4.4	0.24	2.02E-04	8.66E-05	3.53E-04	2.30E-02	5.00E-03	3.76E-01	9.50E-02	1.60E+00	3.28E-01	2.44E-28	1.48E-05	7.69E-05	2.00E-03	3.00E-02	6.50E-14
BATCH-1181	5/12/33	42	4.4	0.24	2.02E-04	8.65E-05	3.53E-04	2.30E-02	5.00E-03	3.76E-01	9.50E-02	1.60E+00	3.28E-01	2.44E-28	1.48E-05	7.68E-05	2.00E-03	3.00E-02	6.50E-14
BATCH-1182	5/17/33	16	1.7	0.24	1.25E-05	4.91E-06	4.60E-05	1.00E-03	2.92E-04	1.90E-02	4.00E-03	1.04E-01	1.50E-02	1.07E-29	6.65E-07	3.52E-06	6.58E-05	1.00E-03	4.52E-15
BATCH-1183	5/17/33	15	1.5	0.24	1.57E-05	5.69E-06	5.83E-05	1.00E-03	3.62E-04	1.90E-02	4.00E-03	8.90E-02	1.50E-02	8.58E-30	6.47E-07	3.81E-06	5.88E-05	1.00E-03	1.89E-15
BATCH-1184	5/19/33	16	1.6	0.24	1.06E-05	4.22E-06	3.44E-05	9.47E-04	2.44E-04	1.60E-02	4.00E-03	8.70E-02	1.30E-02	9.78E-30	6.06E-07	3.19E-06	6.14E-05	1.00E-03	3.72E-15
BATCH-1185	5/19/33	16	1.7	0.24	1.25E-05	4.90E-06	4.59E-05	1.00E-03	2.91E-04	1.80E-02	4.00E-03	1.04E-01	1.50E-02	1.06E-29	6.64E-07	3.51E-06	6.56E-05	1.00E-03	4.51E-15
BATCH-1186	5/20/33	30	3.1	0.24	1.42E-04	6.08E-05	2.48E-04	1.60E-02	3.00E-03	2.64E-01	6.70E-02	1.12E+00	2.31E-01	1.72E-28	1.04E-05	5.40E-05	1.00E-03	2.10E-02	4.57E-14
BATCH-1187	5/21/33	30	3.1	0.24	1.42E-04	6.08E-05	2.48E-04	1.60E-02	3.00E-03	2.64E-01	6.70E-02	1.12E+00	2.31E-01	1.72E-28	1.04E-05	5.40E-05	1.00E-03	2.10E-02	4.57E-14
BATCH-1188	5/24/33	42	4.4	0.24	2.02E-04	8.63E-05	3.52E-04	2.30E-02	5.00E-03	3.75E-01	9.50E-02	1.59E+00	3.27E-01	2.44E-28	1.47E-05	7.67E-05	2.00E-03	3.00E-02	6.49E-14
BATCH-1189	5/24/33	39	4.0	0.24	1.53E-04	8.63E-05	3.45E-04	9.00E-03	3.00E-03	1.69E-01	4.10E-02	1.03E+00	1.33E-01	1.11E-28	5.90E-06	4.89E-05	7.26E-04	1.40E-02	2.67E-14
BATCH-1190	5/28/33	44	4.6	0.24	1.49E-04	1.05E-04	4.13E-04	1.00E-03	3.00E-03	4.60E-02	7.00E-03	8.23E-01	1.20E-02	3.26E-29	4.14E-07	3.82E-05	2.18E-04	4.00E-03	3.12E-15
BATCH-1191	5/28/33	120	12.5	0.24	9.19E-05	3.93E-05	1.60E-04	1.00E-02	2.00E-03	1.71E-01	4.30E-02	7.25E-01	1.49E-01	1.11E-28	6.70E-06	3.49E-05	7.24E-04	1.40E-02	2.95E-14
BATCH-1192	6/2/33	120	12.5	0.24	9.18E-05	3.93E-05	1.60E-04	1.00E-02	2.00E-03	1.71E-01	4.30E-02	7.24E-01	1.49E-01	1.11E-28	6.69E-06	3.49E-05	7.23E-04	1.40E-02	2.95E-14
BATCH-1193	6/10/33	44	4.6	0.24	1.49E-04	1.05E-04	4.13E-04	1.00E-03	3.00E-03	4.60E-02	7.00E-03	8.23E-01	1.20E-02	3.25E-29	4.14E-07	3.82E-05	2.18E-04	4.00E-03	3.12E-15
BATCH-1194	6/15/33	31	3.2	0.24	1.05E-04	7.38E-05	2.91E-04	7.88E-04	2.00E-03	3.30E-02	5.00E-03	5.80E-01	8.00E-03	2.30E-29	2.99E-07	2.69E-05	1.54E-04	3.00E-03	2.23E-15
BATCH-1195	6/15/33	27	2.8	0.24	9.18E-05	6.47E-05	2.55E-04	6.86E-04	2.00E-03	2.90E-02	5.00E-03	5.08E-01	7.00E-03	2.02E-29	2.59E-07	2.36E-05	1.35E-04	2.00E-03	1.94E-15
BATCH-1196	6/18/33	30	3.1	0.24	1.01E-04	7.15E-05	2.82E-04	7.53E-04	2.00E-03	3.20E-02	5.00E-03	5.61E-01	8.00E-03	2.22E-29	2.83E-07	2.61E-05	1.49E-04	3.00E-03	2.13E-15
BATCH-1197	6/18/33	42	4.4	0.24	2.81E-05	1.20E-05	4.90E-05	3.00E-03	6.31E-04	5.20E-02	1.30E-02	2.22E-01	4.60E-02	3.39E-29	2.05E-06	1.07E-05	2.21E-04	4.00E-03	9.02E-15
BATCH-1198	6/21/33	42	4.4	0.24	2.80E-05	1.20E-05	4.89E-05	3.00E-03	6.30E-04	5.20E-02	1.30E-02	2.21E-01	4.50E-02	3.38E-29	2.04E-06	1.07E-05	2.21E-04	4.00E-03	9.01E-15
BATCH-1199	6/23/33	30	3.1	0.24	1.01E-04	7.14E-05	2.82E-04	7.52E-04	2.00E-03	3.20E-02	5.00E-03	5.61E-01	8.00E-03	2.22E-29	2.82E-07	2.60E-05	1.48E-04	3.00E-03	2.13E-15
BATCH-1200	6/26/33	157	16.4	0.24	1.06E-04	5.68E-05	2.28E-04	8.00E-03	2.00E-03	1.32E-01	3.20E-02	7.36E-01	1.07E-01	8.64E-29	4.78E-06	3.50E-05	5.66E-04	1.10E-02	2.14E-14
BATCH-1201	6/26/33	137	14.3	0.24	8.89E-05	4.70E-05	1.89E-04	7.00E-03	2.00E-03	1.15E-01	2.80E-02	6.26E-01	9.40E-02	7.54E-29	4.22E-06	2.98E-05	4.94E-04	9.00E-03	1.89E-14
BATCH-1202	7/11/33	160	16.7	0.24	8.22E-05	5.80E-05	2.29E-04	6.10E-04	2.00E-03	2.60E-02	4.00E-03	4.55E-01	6.00E-03	1.80E-29	2.29E-07	2.11E-05	1.20E-04	2.00E-03	1.73E-15
BATCH-1203	7/13/33	15	1.6	0.24	6.60E-06	2.82E-06	1.15E-05	7.46E-04	1.48E-04	1.20E-02	3.00E-03	5.20E-02	1.10E-02	7.97E-30	4.81E-07	2.51E-06	5.20E-05	9.85E-04	2.12E-15
BATCH-1204	7/14/33	160	16.7	0.24	8.20E-05	5.78E-05	2.28E-04	6.09E-04	2.00E-03	2.60E-02	4.00E-03	4.54E-01	6.00E-03	1.80E-29	2.29E-07	2.11E-05	1.20E-04	2.00E-03	1.72E-15
BATCH-1205	7/27/33	15	1.6	0.24	6.59E-06	2.82E-06	1.15E-05	7.45E-04	1.48E-04	1.20E-02	3.00E-03	5.20E-02	1.10E-02	7.96E-30	4.81E-07	2.50E-06	5.19E-05	9.84E-04	2.12E-15
BATCH-1206	7/29/33	39	4.0	0.24	2.20E-05	1.16E-05	4.67E-05	2.00E-03	4.94E-04	2.90E-02	7.00E-03	1.55E-01	2.30E-02	1.87E-29	1.05E-06	7.38E-06	1.22E-04	2.00E-03	4.68E-15
BATCH-1207	7/31/33	34	3.5	0.24	2.00E-05	1.07E-05	4.30E-05	1.00E-03	4.48E-04	2.50E-02	6.00E-03	1.39E-01	2.00E-02	1.63E-29	9.03E-07	6.61E-06	1.07E-04	2.00E-03	4.05E-15
BATCH-1208	8/2/33	34	3.5	0.24	1.52E-05	1.07E-05	4.22E-05	1.13E-04	3.40E-04	5.00E-03	7.62E-04	8.40E-02	1.00E-03	3.33E-30	4.23E-08	3.90E-06	2.22E-05	3.83E-04	3.19E-16
BATCH-1209	8/4/33	34	3.5	0.24	1.52E-05	1.07E-05	4.21E-05	1.13E-04	3.39E-04	5.00E-03	7.61E-04	8.40E-02	1.00E-03	3.32E-30	4.22E-08	3.89E-06	2.22E-05	3.82E-04	3.18E-16
BATCH-1210	8/6/33	14	1.5	0.24	5.22E-06	2.76E-06	1.11E-05	3.90E-04	1.17E-04	7.00E-03	2.00E-03	3.70E-02	6.00E-03	4.43E-30	2.48E-07	1.75E-06	2.90E-05	5.44E-04	1.11E-15
BATCH-1211	8/8/33	13	1.3	0.24	4.73E-06	2.54E-06	1.02E-05	3.37E-04	1.06E-04	6.00E-03	1.00E-03	3.30E-02	5.00E-03	3.86E-30	2.14E-07	1.57E-06	2.53E-05	4.74E-04	9.59E-16
BATCH-1212	8/8/33	12	1.3	0.24	3.61E-06	2.54E-06	1.00E-05	2.68E-05	8.07E-05	1.00E-03	1.81E-04	2.00E-02	2.84E-04	7.90E-31	1.01E-08	9.26E-07	5.28E-06	9.09E-05	7.58E-17
BATCH-1213	8/9/33	12	1.3	0.24	3.60E-06	2.54E-06	1.00E-05	2.67E-05	8.05E-05	1.00E-03	1.81E-04	2.00E-02	2.83E-04	7.88E-31	1.00E-08	9.24E-07	5.27E-06	9.07E-05	7.56E-17
BATCH-1214	8/13/33	42	4.4	0.24	7.76E-05	4.59E-05	2.69E-04	2.00E-03	2.00E-03	1.08E-01	1.20E-02	4.20E-01	1.40E-02	1.83E-29	4.95E-07	1.83E-05	1.21E-04	2.00E-03	1.55E-15
BATCH-1215	8/15/33	48	5.0	0.24	5.36E-05	2.26E-05	2.39E-04	3.00E-03	1.00E-03	1.59E-01	1.70E-02	2.79E-01	1.80E-02	1.38E-29	6.25E-07	1.10E-05	9.13E-05	2.00E-03	9.88E-16
BATCH-1216	8/18/33	48	5.0	0.24	5.35E-05	2.26E-05	2.39E-04	3.00E-03	1.00E-03	1.59E-01	1.70E-02	2.79E-01	1.80E-02	1.38E-29	6.25E-07	1.10E-05	9.12E-05	2.00E-03	9.87E-16
BATCH-1217	8/20/33	48	5.0	0.24	5.35E-05	2.25E-05	2.39E-04	3.00E-03	1.00E-03	1.59E-01	1.70E-02	2.79E-01	1.80E-02	1.38E-29	6.24E-07	1.10E-05	9.12E-05	2.00E-03	9.86E-16
BATCH-1218	8/23/33	48	5.0	0.24	5.34E-05	2.25E-05	2.39E-04	3.00E-03	1.00E-03	1.59E-01	1.70E-02	2.79E-01	1.80E-02	1.38E-29	6.24E-07	1.10E-05	9.10E-05	2.00E-03	9.85E-16
BATCH-1219	8/25/33	48	5.0	0.24	5.34E-05	2.25E-05	2.39E-04	3.00E-03	1.00E-03	1.59E-01	1.70E-02	2.79E-01	1.80E-02	1.38E-29	6.24E-07	1.10E-05	9.10E-05	2.00E-03	9.85E-16
BATCH-1220	8/29/33	32	3.3	0.24	1.38E-04	3.64E-05	3.00E-03	7.00E-03	3.00E-03	3.66E-01	4.90E-02	2.75E+00	7.90E-02	2.56E-30	2.89E-06	8.96E-05	1.78E-05	3.26E-04	3.18E-16
BATCH-1221	8/31/33	36	3.8	0.24	1.70E-04	4.41E-05	4.00E-03	8.00E-03	4.00E-03	4.48E-01	6.00E-02	3.43E+00	9.70E-02	2.33E-30	3.58E-06	1.12E-04	1.65E-05	3.08E-04	3.35E-16
BATCH-1222	9/1/33	36	3.8	0.24	1.70E-04	4.41E-05	4.00E-03	8.00E-03	4.00E-03	4.48E-01	6.00E-02	3.43E+00	9.70E-02	2.33E-30	3.58E-06	1.12E-04	1.65E-05	3.08E-04	3.35E-16
BATCH-1223	9/3/33	36	3.8	0.24	1.70E-04	4.41E-05	4.00E-03	8.00E-03	4.00E-03	4.48E-01	6.00E-02	3.43E+00	9.70E-02	2.33E-30	3.58E-06	1.12E-04	1.65E-05	3.08E-04	3.35E-16
BATCH-1224	9/5/33	36	3.8	0.24	1.70E-04	4.41E-05	4.00E-03	8.00E-03	4.00E-03	4.48E-01	6.00E-02	3.43E+00	9.70E-02	2.33E-30	3.58E-06	1.12E-04	1.65E-05	3.08E-04	3.35E-16

Appendix A Nominal ILAW Inventory

TWRS0&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ce+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1176	5/2/33	47	4.9	0.24	1.63E+02	0.00E+00	4.29E-17	8.53E-13	1.16E-16	1.16E-82	1.30E-02	5.43E-01	2.29E-15	4.61E-04	1.02E+00	0.00E+00	2.26E+00	0.00E+00	2.43E-07
BATCH-1177	5/3/33	40	4.2	0.24	1.37E+02	0.00E+00	1.80E-17	1.11E-11	4.85E-17	8.96E-87	1.10E-02	2.97E-01	4.51E-15	6.46E-04	1.08E+00	0.00E+00	2.34E+00	0.00E+00	3.10E-07
BATCH-1178	5/7/33	47	4.9	0.24	1.62E+02	0.00E+00	4.28E-17	8.51E-13	1.15E-16	4.44E-83	1.30E-02	5.42E-01	2.29E-15	4.60E-04	1.01E+00	0.00E+00	2.26E+00	0.00E+00	2.42E-07
BATCH-1179	5/7/33	45	4.7	0.24	1.66E+02	0.00E+00	4.81E-15	1.32E-12	2.85E-15	1.45E-77	1.10E-02	5.11E-01	5.63E-15	3.38E-04	1.01E+00	0.00E+00	2.16E+00	0.00E+00	1.65E-07
BATCH-1180	5/12/33	42	4.4	0.24	5.00E-03	3.92E+01	9.99E-14	1.58E-11	5.79E-14	3.23E-81	4.90E-02	1.04E+00	8.60E-14	7.00E-04	7.05E+00	0.00E+00	9.24E-05	4.61E+00	9.04E-08
BATCH-1181	5/12/33	42	4.4	0.24	5.00E-03	3.92E+01	9.99E-14	1.57E-11	5.79E-14	8.38E-81	4.90E-02	1.04E+00	8.60E-14	7.00E-04	7.05E+00	0.00E+00	9.24E-05	4.61E+00	9.04E-08
BATCH-1182	5/17/33	16	1.7	0.24	3.79E+01	0.00E+00	1.00E-17	1.99E-13	2.70E-17	2.71E-83	3.00E-03	1.27E-01	5.35E-16	1.08E-04	2.37E-01	0.00E+00	5.28E-01	0.00E+00	5.67E-08
BATCH-1183	5/17/33	15	1.5	0.24	3.25E+01	0.00E+00	4.26E-18	2.63E-12	1.15E-17	2.12E-87	2.00E-03	7.00E-02	1.07E-15	1.53E-04	2.55E-01	0.00E+00	5.55E-01	0.00E+00	7.33E-08
BATCH-1184	5/19/33	16	1.6	0.24	3.88E+01	0.00E+00	1.13E-15	3.08E-13	6.66E-16	3.39E-78	3.00E-03	1.19E-01	1.32E-15	7.91E-05	2.36E-01	0.00E+00	5.05E-01	0.00E+00	3.85E-08
BATCH-1185	5/19/33	16	1.7	0.24	3.79E+01	0.00E+00	9.98E-18	1.99E-13	2.69E-17	1.04E-83	3.00E-03	1.26E-01	5.34E-16	1.07E-04	2.36E-01	0.00E+00	5.27E-01	0.00E+00	5.65E-08
BATCH-1186	5/20/33	30	3.1	0.24	2.42E-06	2.75E+01	7.02E-14	1.11E-11	4.07E-14	1.67E-84	3.40E-02	7.33E-01	6.04E-14	4.92E-04	4.96E+00	0.00E+00	4.79E-08	3.24E+00	6.35E-08
BATCH-1187	5/21/33	30	3.1	0.24	2.43E-06	2.75E+01	7.02E-14	1.11E-11	4.07E-14	4.34E-84	3.40E-02	7.33E-01	6.04E-14	4.92E-04	4.95E+00	0.00E+00	4.79E-08	3.24E+00	6.35E-08
BATCH-1188	5/24/33	42	4.4	0.24	4.00E-03	3.91E+01	9.97E-14	1.57E-11	5.78E-14	2.42E-91	4.90E-02	1.04E+00	8.58E-14	6.98E-04	7.04E+00	0.00E+00	6.34E-05	4.60E+00	9.02E-08
BATCH-1189	5/24/33	39	4.0	0.24	3.00E-03	3.29E+01	4.36E-14	6.92E-12	2.65E-14	2.12E-87	2.00E-02	1.03E+00	6.74E-14	3.81E-04	8.95E+00	0.00E+00	4.13E-05	5.72E+00	1.20E-07
BATCH-1190	5/28/33	44	4.6	0.24	4.00E-03	3.53E+01	9.95E-15	1.66E-12	8.16E-15	3.76E-82	3.00E-03	1.25E+00	6.78E-14	2.19E-04	1.23E+01	0.00E+00	5.61E-05	7.80E+00	1.69E-07
BATCH-1191	5/28/33	120	12.5	0.24	5.85E+02	0.00E+00	4.54E-14	7.15E-12	2.63E-14	8.61E-82	2.60E-02	1.47E+00	3.91E-14	3.18E-04	3.20E+00	0.00E+00	6.87E+00	0.00E+00	4.10E-08
BATCH-1192	6/2/33	120	12.5	0.24	5.85E+02	0.00E+00	4.53E-14	7.14E-12	2.63E-14	2.23E-81	2.60E-02	1.47E+00	3.90E-14	3.17E-04	3.20E+00	0.00E+00	6.87E+00	0.00E+00	4.10E-08
BATCH-1193	6/10/33	44	4.6	0.24	4.00E-03	3.53E+01	9.94E-15	1.66E-12	8.16E-15	1.16E-87	3.00E-03	1.25E+00	6.78E-14	2.19E-04	1.23E+01	0.00E+00	5.91E-05	7.80E+00	1.69E-07
BATCH-1194	6/15/33	31	3.2	0.24	1.88E-06	2.48E+01	7.05E-15	1.17E-12	5.77E-15	1.22E-94	2.00E-03	8.81E-01	4.78E-14	1.55E-04	8.69E+00	0.00E+00	3.20E-08	5.49E+00	1.19E-07
BATCH-1195	6/15/33	27	2.8	0.24	1.71E-06	2.18E+01	6.16E-15	1.03E-12	5.05E-15	1.22E-90	2.00E-03	7.73E-01	4.19E-14	1.36E-04	7.62E+00	0.00E+00	2.37E-08	4.82E+00	1.04E-07
BATCH-1196	6/18/33	30	3.1	0.24	2.24E-06	2.41E+01	6.79E-15	1.13E-12	5.57E-15	1.96E-85	2.00E-03	8.54E-01	4.63E-14	1.50E-04	8.43E+00	0.00E+00	2.92E-08	5.32E+00	1.15E-07
BATCH-1197	6/18/33	42	4.4	0.24	1.79E+02	0.00E+00	1.39E-14	2.19E-12	8.04E-15	2.63E-82	8.00E-03	4.49E-01	1.19E-14	9.71E-05	9.78E-01	0.00E+00	2.10E+00	0.00E+00	1.25E-08
BATCH-1198	6/21/33	42	4.4	0.24	1.79E+02	0.00E+00	1.38E-14	2.18E-12	8.02E-15	6.82E-82	8.00E-03	4.48E-01	1.19E-14	9.70E-05	9.77E-01	0.00E+00	2.10E+00	0.00E+00	1.25E-08
BATCH-1199	6/23/33	30	3.1	0.24	2.21E-06	2.40E+01	6.78E-15	1.13E-12	5.56E-15	6.04E-91	2.00E-03	8.53E-01	4.62E-14	1.50E-04	8.42E+00	0.00E+00	3.07E-08	5.32E+00	1.15E-07
BATCH-1200	6/26/33	157	16.4	0.24	7.88E+02	0.00E+00	3.44E-14	5.45E-12	2.06E-14	1.74E-87	1.90E-02	1.30E+00	4.62E-14	2.83E-04	5.70E+00	0.00E+00	1.07E+01	0.00E+00	7.60E-08
BATCH-1201	6/26/33	137	14.3	0.24	7.20E+02	0.00E+00	3.01E-14	4.77E-12	1.80E-14	6.80E-92	1.70E-02	1.34E+00	3.88E-14	2.44E-04	4.65E+00	0.00E+00	9.25E+00	0.00E+00	6.20E-08
BATCH-1202	7/11/33	160	16.7	0.24	9.13E+02	0.00E+00	5.50E-15	9.16E-13	4.51E-15	1.24E-82	3.00E-03	1.09E+00	3.75E-14	1.21E-04	6.83E+00	0.00E+00	1.28E+01	0.00E+00	2.95E-09
BATCH-1203	7/13/33	15	1.6	0.24	4.20E+01	0.00E+00	3.26E-15	5.14E-13	1.89E-15	6.18E-83	2.00E-03	1.06E-01	2.81E-15	2.28E-05	2.30E-01	0.00E+00	4.93E-01	0.00E+00	9.32E-08
BATCH-1204	7/14/33	160	16.7	0.24	9.12E+02	0.00E+00	5.49E-15	9.14E-13	4.50E-15	3.82E-88	3.00E-03	1.09E+00	3.74E-14	1.21E-04	6.81E+00	0.00E+00	1.27E+01	0.00E+00	2.95E-09
BATCH-1205	7/27/33	15	1.6	0.24	4.20E+01	0.00E+00	3.26E-15	5.13E-13	1.89E-15	1.60E-82	2.00E-03	1.05E-01	2.80E-15	2.28E-05	2.30E-01	0.00E+00	4.93E-01	0.00E+00	2.95E-09
BATCH-1206	7/29/33	39	4.0	0.24	1.78E+02	0.00E+00	7.46E-15	1.18E-12	4.46E-15	1.68E-92	4.00E-03	3.31E-01	9.61E-15	6.03E-05	1.15E+00	0.00E+00	2.29E+00	0.00E+00	1.54E-08
BATCH-1207	7/31/33	34	3.5	0.24	1.49E+02	0.00E+00	6.50E-15	1.03E-12	3.89E-15	3.28E-88	4.00E-03	2.45E-01	8.73E-15	5.34E-05	1.08E+00	0.00E+00	2.01E+00	0.00E+00	1.44E-08
BATCH-1208	8/2/33	34	3.5	0.24	1.69E+02	0.00E+00	1.02E-15	1.69E-13	8.34E-16	2.29E-83	6.06E-04	2.01E-01	6.93E-15	2.24E-05	1.26E+00	0.00E+00	2.36E+00	0.00E+00	1.73E-08
BATCH-1209	8/4/33	34	3.5	0.24	1.68E+02	0.00E+00	1.01E-15	1.69E-13	8.32E-16	7.05E-89	6.06E-04	2.01E-01	6.91E-15	2.24E-05	1.26E+00	0.00E+00	2.35E+00	0.00E+00	1.72E-08
BATCH-1210	8/6/33	14	1.5	0.24	4.23E+01	0.00E+00	1.77E-15	2.80E-13	1.06E-15	3.99E-93	1.00E-03	7.80E-02	2.28E-15	1.43E-05	2.73E-01	0.00E+00	5.43E-01	0.00E+00	3.64E-09
BATCH-1211	8/8/33	13	1.3	0.24	3.52E+01	0.00E+00	1.54E-15	2.44E-13	9.22E-16	7.76E-89	8.42E-04	5.80E-02	2.07E-15	1.27E-05	2.55E-01	0.00E+00	4.77E-01	0.00E+00	3.40E-09
BATCH-1212	8/8/33	12	1.3	0.24	4.01E+01	0.00E+00	2.41E-16	4.02E-14	1.98E-16	5.43E-84	1.44E-04	4.80E-02	1.65E-15	5.32E-06	3.00E-01	0.00E+00	5.59E-01	0.00E+00	4.10E-09
BATCH-1213	8/9/33	12	1.3	0.24	4.00E+01	0.00E+00	2.41E-16	4.01E-14	1.98E-16	1.68E-89	1.44E-04	4.80E-02	1.64E-15	5.31E-06	2.99E-01	0.00E+00	5.59E-01	0.00E+00	4.09E-09
BATCH-1214	8/13/33	42	4.4	0.24	3.00E-03	2.02E+01	3.29E-15	5.93E-13	3.69E-15	4.31E-87	1.10E-02	1.12E+00	2.94E-14	4.00E-03	9.49E+00	0.00E+00	3.44E-05	4.29E+00	1.08E-07
BATCH-1215	8/15/33	48	5.0	0.24	5.00E-03	1.57E+01	3.31E-16	1.32E-13	1.97E-15	1.73E-86	1.70E-02	1.25E+00	1.41E-14	7.00E-03	9.63E+00	0.00E+00	5.33E-05	3.17E+00	9.46E-08
BATCH-1216	8/18/33	48	5.0	0.24	5.00E-03	1.57E+01	3.30E-16	1.32E-13	1.96E-15	4.49E-97	1.70E-02	1.25E+00	1.41E-14	7.00E-03	9.62E+00	0.00E+00	6.12E-05	3.17E+00	9.46E-08
BATCH-1217	8/20/33	48	5.0	0.24	4.00E-03	1.57E+01	3.30E-16	1.31E-13	1.96E-15	9.81E-93	1.70E-02	1.25E+00	1.41E-14	7.00E-03	9.62E+00	0.00E+00	6.03E-05	3.17E+00	9.45E-08
BATCH-1218	8/23/33	48	5.0	0.24	5.00E-03	1.57E+01	3.30E-16	1.31E-13	1.96E-15	7.20E-88	1.70E-02	1.25E+00	1.41E-14	7.00E-03	9.61E+00	0.00E+00	7.41E-05	3.16E+00	9.44E-08
BATCH-1219	8/25/33	48	5.0	0.24	5.00E-03	1.57E+01	3.29E-16	1.31E-13	1.96E-15	2.22E-93	1.70E-02	1.25E+00	1.41E-14	7.00E-03	9.60E+00	0.00E+00	7.42E-05	3.16E+00	9.43E-08
BATCH-1220	8/29/33	32	3.3	0.24	1.00E-06	4.50E+00	1.43E-16	1.01E-10	5.37E-16	1.48E-90	2.09E-01	6.70E-01	5.07E-15	5.00E-03	5.46E+00	0.00E+00	1.18E-08	1.16E+00	3.82E-08
BATCH-1221	8/31/33	36	3.8	0.24	2.37E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	9.03E-90	2.60E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	2.78E-08	1.26E+00	4.19E-08
BATCH-1222	9/1/33	36	3.8	0.24	2.48E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	2.34E-100	2.60E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	3.19E-08	1.26E+00	4.18E-08
BATCH-1223	9/3/33	36	3.8	0.24	2.32E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	5.11E-96	2.60E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	3.14E-08	1.26E+00	4.18E-08
BATCH-1224	9/5/33	36	3.8	0.24	2.77E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	3.75E-91	2.60E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	3.86E-08	1.26E+00	4.18E-08

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill tank	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1176	5/2/33	47	4.9	0.24	1.58E-18	7.93E+00	2.79E-01	0.00E+00	0.00E+00	1.89E-04	4.32E-01	6.60E-07	9.50E-16	2.97E-16	9.13E-04	1.18E-13	8.01E+02	0.00E+00	1.00E-02
BATCH-1177	5/3/33	40	4.2	0.24	1.30E-18	3.61E+00	1.72E-01	0.00E+00	0.00E+00	8.06E-05	3.94E-01	3.14E-07	4.17E-16	1.03E-14	9.50E-04	4.87E-14	6.85E+02	0.00E+00	7.00E-03
BATCH-1178	5/7/33	47	4.9	0.24	1.57E-18	7.91E+00	2.78E-01	0.00E+00	0.00E+00	1.88E-04	4.30E-01	6.59E-07	9.47E-16	2.78E-16	9.10E-04	1.18E-13	7.99E+02	0.00E+00	1.00E-02
BATCH-1179	5/7/33	45	4.7	0.24	3.38E-17	5.90E+00	2.67E-01	0.00E+00	0.00E+00	2.00E-04	3.79E-01	9.59E-06	2.16E-15	1.18E-13	7.91E-04	8.47E-14	7.70E+02	0.00E+00	8.00E-03
BATCH-1180	5/12/33	42	4.4	0.24	6.85E-16	1.38E+01	2.40E-02	0.00E+00	0.00E+00	3.20E-03	1.95E+00	1.91E-04	3.20E-14	2.46E-12	4.00E-03	1.36E-13	7.18E+02	0.00E+00	4.00E-02
BATCH-1181	5/12/33	42	4.4	0.24	6.85E-16	1.38E+01	2.40E-02	0.00E+00	0.00E+00	3.20E-03	1.95E+00	1.91E-04	3.20E-14	2.46E-12	4.00E-03	1.36E-13	7.18E+02	0.00E+00	4.00E-02
BATCH-1182	5/17/33	16	1.7	0.24	3.69E-19	1.85E+00	6.50E-02	0.00E+00	0.00E+00	4.40E-05	1.01E-01	1.54E-07	2.22E-16	6.93E-17	2.13E-04	2.76E-14	2.76E+02	0.00E+00	2.00E-03
BATCH-1183	5/17/33	15	1.5	0.24	3.07E-19	8.54E-01	4.10E-02	0.00E+00	0.00E+00	1.91E-05	9.30E-02	7.44E-08	9.87E-17	2.44E-15	2.25E-04	1.15E-14	2.49E+02	0.00E+00	2.00E-03
BATCH-1184	5/19/33	16	1.6	0.24	7.91E-18	1.38E+00	6.20E-02	0.00E+00	0.00E+00	6.60E-05	8.80E-02	2.24E-06	5.05E-16	2.75E-14	1.85E-04	1.98E-14	2.70E+02	0.00E+00	2.00E-03
BATCH-1185	5/19/33	16	1.7	0.24	3.67E-19	1.85E+00	6.50E-02	0.00E+00	0.00E+00	4.39E-05	1.00E-01	1.54E-07	2.21E-16	6.49E-17	2.12E-04	2.75E-14	2.76E+02	0.00E+00	2.00E-03
BATCH-1186	5/20/33	30	3.1	0.24	4.81E-16	9.68E+00	1.70E-02	0.00E+00	0.00E+00	2.40E-03	1.37E+00	1.34E-04	2.25E-14	1.73E-12	3.00E-03	9.55E-14	5.05E+02	0.00E+00	2.80E-02
BATCH-1187	5/21/33	30	3.1	0.24	4.81E-16	9.67E+00	1.70E-02	0.00E+00	0.00E+00	2.40E-03	1.37E+00	1.34E-04	2.25E-14	1.73E-12	3.00E-03	9.55E-14	5.05E+02	0.00E+00	2.80E-02
BATCH-1188	5/24/33	42	4.4	0.24	6.83E-16	1.37E+01	2.40E-02	0.00E+00	0.00E+00	3.20E-03	1.95E+00	1.91E-04	3.19E-14	2.45E-12	4.00E-03	1.36E-13	7.17E+02	0.00E+00	4.00E-02
BATCH-1189	5/24/33	39	4.0	0.24	7.27E-16	7.32E+00	3.10E-02	0.00E+00	0.00E+00	1.40E-03	1.78E+00	7.49E-05	4.85E-14	1.10E-12	4.00E-03	5.25E-14	6.58E+02	0.00E+00	3.70E-02
BATCH-1190	5/28/33	44	4.6	0.24	9.16E-16	3.98E+00	4.30E-02	0.00E+00	0.00E+00	1.26E-04	2.03E+00	2.12E-06	7.16E-14	2.92E-13	5.00E-03	1.07E-16	7.55E+02	0.00E+00	4.30E-02
BATCH-1191	5/28/33	120	12.5	0.24	3.11E-16	6.25E+00	8.49E-01	0.00E+00	0.00E+00	1.40E-03	8.66E-01	8.68E-05	1.45E-14	1.12E-12	2.00E-03	6.17E-14	2.05E+03	0.00E+00	1.80E-02
BATCH-1192	6/2/33	120	12.5	0.24	3.11E-16	6.24E+00	8.48E-01	0.00E+00	0.00E+00	1.40E-03	8.85E-01	8.67E-05	1.45E-14	1.11E-12	2.00E-03	6.16E-14	2.05E+03	0.00E+00	1.80E-02
BATCH-1193	6/10/33	44	4.6	0.24	9.16E-16	3.98E+00	4.30E-02	0.00E+00	0.00E+00	1.26E-04	2.03E+00	2.12E-06	7.16E-14	2.91E-13	5.00E-03	1.08E-16	7.54E+02	0.00E+00	4.30E-02
BATCH-1194	6/15/33	31	3.2	0.24	6.45E-16	2.81E+00	3.00E-02	0.00E+00	0.00E+00	9.05E-05	1.43E+00	1.59E-06	5.04E-14	2.06E-13	4.00E-03	1.42E-16	5.31E+02	0.00E+00	3.00E-02
BATCH-1195	6/15/33	27	2.8	0.24	5.66E-16	2.46E+00	2.60E-02	0.00E+00	0.00E+00	7.87E-05	1.25E+00	1.35E-06	4.42E-14	1.81E-13	3.00E-03	9.46E-17	4.66E+02	0.00E+00	2.60E-02
BATCH-1196	6/18/33	30	3.1	0.24	6.25E-16	2.71E+00	2.90E-02	0.00E+00	0.00E+00	8.62E-05	1.38E+00	1.44E-06	4.89E-14	1.99E-13	4.00E-03	7.13E-17	5.15E+02	0.00E+00	2.90E-02
BATCH-1197	6/18/33	42	4.4	0.24	9.50E-17	1.91E+00	2.59E-01	0.00E+00	0.00E+00	4.00E-04	2.71E-01	2.65E-05	4.44E-15	3.41E-13	5.43E-04	1.89E-14	7.17E+02	0.00E+00	6.00E-03
BATCH-1198	6/21/33	42	4.4	0.24	9.49E-17	1.91E+00	2.59E-01	0.00E+00	0.00E+00	4.00E-04	2.70E-01	2.65E-05	4.43E-15	3.40E-13	5.42E-04	1.88E-14	7.16E+02	0.00E+00	5.00E-03
BATCH-1199	6/23/33	30	3.1	0.24	6.24E-16	2.71E+00	2.90E-02	0.00E+00	0.00E+00	8.61E-05	1.38E+00	1.44E-06	4.88E-14	1.99E-13	4.00E-03	7.12E-17	5.15E+02	0.00E+00	2.90E-02
BATCH-1200	6/26/33	157	16.4	0.24	4.74E-16	5.47E+00	4.88E-01	0.00E+00	0.00E+00	1.00E-03	1.19E+00	6.11E-05	3.02E-14	8.59E-13	3.00E-03	4.30E-14	2.69E+03	0.00E+00	2.50E-02
BATCH-1201	6/26/33	137	14.3	0.24	3.91E-16	4.72E+00	6.33E-01	0.00E+00	0.00E+00	1.00E-03	9.86E-01	5.39E-05	2.45E-14	7.50E-13	2.00E-03	3.81E-14	2.34E+03	0.00E+00	2.00E-02
BATCH-1202	7/11/33	160	16.7	0.24	5.07E-16	2.20E+00	2.74E-01	0.00E+00	0.00E+00	6.98E-05	1.12E+00	1.17E-06	3.96E-14	1.61E-13	3.00E-03	5.85E-17	2.60E+02	0.00E+00	2.40E-02
BATCH-1203	7/13/33	15	1.6	0.24	2.23E-17	4.49E-01	6.10E-02	0.00E+00	0.00E+00	1.08E-04	6.40E-02	6.23E-06	1.04E-15	8.01E-14	1.28E-04	4.43E-15	2.60E+02	0.00E+00	1.00E-03
BATCH-1204	7/14/33	160	16.7	0.24	2.23E-17	4.49E-01	6.10E-02	0.00E+00	0.00E+00	6.97E-05	1.12E+00	1.17E-06	3.95E-14	1.61E-13	3.00E-03	5.87E-17	2.73E+03	0.00E+00	2.40E-02
BATCH-1205	7/27/33	15	1.6	0.24	5.06E-16	2.20E+00	2.73E-01	0.00E+00	0.00E+00	1.07E-04	6.40E-02	6.23E-06	1.04E-15	8.00E-14	1.28E-04	4.43E-15	2.60E+02	0.00E+00	1.00E-03
BATCH-1206	7/29/33	39	4.0	0.24	2.23E-17	4.48E-01	6.10E-02	0.00E+00	0.00E+00	2.00E-04	2.44E-01	1.34E-05	6.07E-15	1.86E-13	5.49E-04	9.43E-15	6.62E+02	0.00E+00	5.00E-03
BATCH-1207	7/31/33	34	3.5	0.24	9.68E-17	1.17E+00	1.57E-01	0.00E+00	0.00E+00	2.00E-04	2.24E-01	1.15E-05	5.71E-15	1.62E-13	5.07E-04	8.12E-15	5.81E+02	0.00E+00	5.00E-03
BATCH-1208	8/2/33	34	3.5	0.24	8.95E-17	1.03E+00	9.20E-02	0.00E+00	0.00E+00	2.00E-04	2.24E-01	1.16E-07	7.32E-15	2.98E-14	5.27E-04	1.08E-17	5.76E+02	0.00E+00	4.00E-03
BATCH-1209	8/4/33	34	3.5	0.24	9.36E-17	4.06E-01	5.10E-02	0.00E+00	0.00E+00	1.29E-05	2.07E-01	2.16E-07	7.30E-15	2.97E-14	5.26E-04	1.08E-17	5.75E+02	0.00E+00	4.00E-03
BATCH-1210	8/6/33	14	1.5	0.24	9.34E-17	2.77E-01	5.00E-02	0.00E+00	0.00E+00	5.58E-05	5.80E-02	3.17E-06	1.44E-15	4.41E-14	1.30E-04	2.23E-15	2.43E+02	0.00E+00	1.00E-03
BATCH-1211	8/8/33	13	1.3	0.24	2.29E-17	2.77E-01	3.70E-02	0.00E+00	0.00E+00	4.82E-05	5.30E-02	2.73E-06	1.35E-15	3.84E-14	1.20E-04	1.92E-15	2.14E+02	0.00E+00	1.00E-03
BATCH-1212	8/8/33	12	1.3	0.24	2.12E-17	2.45E-01	2.20E-02	0.00E+00	0.00E+00	3.06E-06	4.90E-02	5.13E-08	1.74E-15	7.07E-15	1.25E-04	2.57E-18	2.10E+02	0.00E+00	1.00E-03
BATCH-1213	8/9/33	12	1.3	0.24	2.22E-17	9.70E-02	1.20E-02	0.00E+00	0.00E+00	3.06E-06	4.90E-02	5.12E-08	1.73E-15	7.06E-15	1.25E-04	2.57E-18	2.09E+02	0.00E+00	1.00E-03
BATCH-1214	8/13/33	42	4.4	0.24	9.01E-16	1.18E+01	1.63E-01	0.00E+00	0.00E+00	4.00E-04	1.62E+00	1.46E-04	3.36E-14	9.58E-14	6.00E-03	5.28E-15	7.17E+02	0.00E+00	8.00E-02
BATCH-1215	8/15/33	48	5.0	0.24	1.05E-15	1.80E+01	2.55E-01	0.00E+00	0.00E+00	6.00E-04	1.68E+00	2.48E-04	1.93E-14	8.52E-15	8.00E-03	8.95E-15	8.23E+02	0.00E+00	1.13E-01
BATCH-1216	8/18/33	48	5.0	0.24	1.05E-15	1.80E+01	2.55E-01	0.00E+00	0.00E+00	6.00E-04	1.68E+00	2.48E-04	1.93E-14	8.51E-15	8.00E-03	8.95E-15	8.23E+02	0.00E+00	1.13E-01
BATCH-1217	8/20/33	48	5.0	0.24	1.05E-15	1.80E+01	2.55E-01	0.00E+00	0.00E+00	6.00E-04	1.68E+00	2.48E-04	1.93E-14	8.51E-15	8.00E-03	8.94E-15	8.22E+02	0.00E+00	1.13E-01
BATCH-1218	8/23/33	48	5.0	0.24	1.05E-15	1.80E+01	2.55E-01	0.00E+00	0.00E+00	6.00E-04	1.68E+00	2.48E-04	1.92E-14	8.49E-15	8.00E-03	8.93E-15	8.21E+02	0.00E+00	1.13E-01
BATCH-1219	8/25/33	48	5.0	0.24	1.05E-15	1.80E+01	2.55E-01	0.00E+00	0.00E+00	6.00E-04	1.68E+00	2.47E-04	1.92E-14	8.49E-15	8.00E-03	8.93E-15	8.21E+02	0.00E+00	1.13E-01
BATCH-1220	8/29/33	32	3.3	0.24	3.00E-16	2.02E+01	1.79E-01	0.00E+00	0.00E+00	4.00E-04	3.78E+00	5.00E-03	6.03E-15	6.88E-15	2.22E-01	2.46E-15	5.39E+02	0.00E+00	8.00E-03
BATCH-1221	8/31/33	36	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.63E+00	6.00E-03	6.32E-15	8.04E-15	2.78E-01	2.51E-15	6.23E+02	0.00E+00	3.00E-03
BATCH-1222	9/1/33	36	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.63E+00	6.00E-03	6.32E-15	8.04E-15	2.78E-01	2.51E-15	6.23E+02	0.00E+00	3.00E-03
BATCH-1223	9/3/33	36	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.63E+00	6.00E-03	6.32E-15	8.04E-15	2.78E-01	2.51E-15	6.23E+02	0.00E+00	3.00E-03
BATCH-1224	9/5/33	36	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.63E+00	6.00E-03	6.32E-15	8.04E-15	2.78E-01	2.51E-15	6.23E+02	0.00E+00	3.00E-03

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUND) kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	Ti+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1176	5/2/33	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.26E+01	5.97E-20	2.09E+01	1.02E+01	1.00E-02	3.22E-18	0.00E+00	2.66E-04	6.33E-13	4.33E-04
BATCH-1177	5/3/33	40	4.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	7.78E+00	4.47E-20	2.00E+01	5.53E+00	6.00E-03	3.32E-18	0.00E+00	3.04E-04	4.29E-13	2.43E-04
BATCH-1178	5/7/33	47	4.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.26E+01	5.31E-20	2.09E+01	1.02E+01	1.00E-02	2.41E-18	0.00E+00	2.65E-04	6.32E-13	4.32E-04
BATCH-1179	5/7/33	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	1.02E+01	2.69E-16	1.50E+01	7.87E+00	8.00E-03	1.98E-18	0.00E+00	1.81E-04	6.80E-13	5.83E-04
BATCH-1180	5/12/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.68E+01	5.62E-15	1.19E+01	2.27E+01	2.80E-02	1.90E-19	0.00E+00	8.28E-05	5.45E-12	6.00E-03
BATCH-1181	5/12/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.68E+01	5.61E-15	1.19E+01	2.27E+01	2.80E-02	1.90E-19	0.00E+00	8.28E-05	5.45E-12	6.00E-03
BATCH-1182	5/17/33	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.14E-04	2.95E+00	1.39E-20	4.88E+00	2.39E+00	2.00E-03	7.51E-19	0.00E+00	6.20E-05	1.48E-13	1.01E-04
BATCH-1183	5/17/33	15	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.36E-04	1.84E+00	1.06E-20	4.73E+00	1.31E+00	2.00E-03	7.86E-19	0.00E+00	7.19E-05	1.01E-13	5.75E-05
BATCH-1184	5/19/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-04	2.37E+00	6.28E-17	3.50E+00	1.84E+00	2.00E-03	4.62E-19	0.00E+00	4.23E-05	1.59E-13	1.36E-04
BATCH-1185	5/19/33	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.12E-04	2.94E+00	1.24E-20	4.87E+00	2.38E+00	2.00E-03	5.62E-19	0.00E+00	6.18E-05	1.47E-13	1.01E-04
BATCH-1186	5/20/33	30	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.18E+01	3.95E-15	8.38E+00	1.59E+01	2.00E-02	1.33E-19	0.00E+00	5.82E-05	3.83E-12	4.00E-03
BATCH-1187	5/21/33	30	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.18E+01	3.94E-15	8.37E+00	1.59E+01	2.00E-02	1.33E-19	0.00E+00	5.82E-05	3.83E-12	4.00E-03
BATCH-1188	5/24/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.68E+01	5.60E-15	1.19E+01	2.26E+01	2.80E-02	1.89E-19	0.00E+00	8.26E-05	5.44E-12	6.00E-03
BATCH-1189	5/24/33	39	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	9.81E+00	2.73E-15	6.92E+00	1.14E+01	2.10E-02	8.84E-20	0.00E+00	1.71E-04	8.69E-12	3.00E-03
BATCH-1190	5/28/33	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	6.57E+00	1.11E-15	4.59E+00	5.21E+00	1.90E-02	3.01E-20	0.00E+00	2.75E-04	1.30E-11	1.00E-03
BATCH-1191	5/28/33	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	2.03E+01	2.55E-15	1.95E+01	1.08E+01	1.30E-02	8.61E-20	0.00E+00	6.13E-05	2.48E-12	3.00E-03
BATCH-1192	6/2/33	120	12.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	2.02E+01	2.55E-15	1.95E+01	1.08E+01	1.30E-02	8.60E-20	0.00E+00	6.13E-05	2.47E-12	3.00E-03
BATCH-1193	6/10/33	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	6.57E+00	1.11E-15	4.59E+00	5.21E+00	1.90E-02	3.01E-20	0.00E+00	2.75E-04	1.30E-11	1.00E-03
BATCH-1194	6/15/33	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.63E+00	7.80E-16	3.23E+00	3.67E+00	1.30E-02	2.12E-20	0.00E+00	1.94E-04	9.17E-12	7.19E-04
BATCH-1195	6/15/33	27	2.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	4.06E+00	6.83E-16	2.83E+00	3.22E+00	1.20E-02	1.86E-20	0.00E+00	1.70E-04	8.04E-12	6.30E-04
BATCH-1196	6/15/33	30	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.48E+00	7.54E-16	3.13E+00	3.55E+00	1.30E-02	2.05E-20	0.00E+00	1.88E-04	8.89E-12	6.94E-04
BATCH-1197	6/18/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.19E+00	7.79E-16	5.96E+00	3.31E+00	4.00E-03	2.63E-20	0.00E+00	1.87E-05	7.56E-13	8.60E-04
BATCH-1198	6/21/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	6.18E+00	7.78E-16	5.96E+00	3.31E+00	4.00E-03	2.63E-20	0.00E+00	1.87E-05	7.55E-13	8.59E-04
BATCH-1199	6/23/33	30	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	4.48E+00	7.53E-16	3.13E+00	3.55E+00	1.30E-02	2.05E-20	0.00E+00	1.87E-04	8.88E-12	6.94E-04
BATCH-1200	6/26/33	157	16.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.41E+01	2.09E-15	1.21E+01	8.90E+00	1.40E-02	6.85E-20	0.00E+00	1.28E-04	5.38E-12	2.00E-03
BATCH-1201	6/26/33	137	14.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.54E+01	1.81E-15	1.42E+01	7.85E+00	1.20E-02	5.96E-20	0.00E+00	1.07E-04	4.36E-12	2.00E-03
BATCH-1202	7/11/33	160	16.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	7.24E+00	6.11E-16	5.45E+00	2.99E+00	1.00E-02	1.66E-20	0.00E+00	1.77E-04	7.21E-12	5.63E-04
BATCH-1203	7/13/33	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-04	1.46E+00	1.83E-16	1.40E+00	7.79E-01	9.26E-04	6.19E-21	0.00E+00	4.41E-06	1.78E-13	2.02E-04
BATCH-1204	7/14/33	160	16.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	7.23E+00	6.10E-16	5.44E+00	2.98E+00	1.00E-02	1.66E-20	0.00E+00	1.77E-04	7.19E-12	5.62E-04
BATCH-1205	7/27/33	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-04	1.45E+00	1.83E-16	1.40E+00	7.78E-01	9.25E-04	6.18E-21	0.00E+00	4.40E-06	1.78E-13	2.02E-04
BATCH-1206	7/29/33	39	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.81E+00	4.49E-16	3.52E+00	1.95E+00	3.00E-03	1.48E-20	0.00E+00	2.66E-05	1.08E-12	4.85E-04
BATCH-1207	7/31/33	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	2.67E+00	3.94E-16	2.29E+00	1.68E+00	3.00E-03	1.29E-20	0.00E+00	2.41E-05	1.02E-12	4.24E-04
BATCH-1208	8/2/33	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.33E-04	1.34E+00	1.13E-16	1.01E+00	5.52E-01	2.00E-03	3.07E-21	0.00E+00	3.27E-05	1.33E-12	1.04E-04
BATCH-1209	8/4/33	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.31E-04	1.34E+00	1.13E-16	1.01E+00	5.51E-01	2.00E-03	3.06E-21	0.00E+00	3.26E-05	1.33E-12	1.04E-04
BATCH-1210	8/6/33	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.89E-04	9.02E-01	1.06E-16	8.33E-01	4.61E-01	7.08E-04	3.50E-21	0.00E+00	6.30E-06	2.56E-13	1.15E-04
BATCH-1211	8/8/33	13	1.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.62E-04	6.32E-01	9.32E-17	5.43E-01	3.98E-01	6.39E-04	3.06E-21	0.00E+00	5.71E-06	2.41E-13	1.00E-04
BATCH-1212	8/8/33	12	1.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-04	3.18E-01	2.68E-17	2.39E-01	1.31E-01	4.59E-04	7.29E-22	0.00E+00	7.76E-06	3.16E-13	2.47E-05
BATCH-1213	8/9/33	12	1.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-04	3.17E-01	2.68E-17	2.39E-01	1.31E-01	4.58E-04	7.27E-22	0.00E+00	7.75E-06	3.16E-13	2.46E-05
BATCH-1214	8/13/33	42	4.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	2.36E+01	3.57E-16	5.07E+00	7.42E+00	1.20E-02	5.52E-16	0.00E+00	1.41E-04	4.27E-12	2.00E-03
BATCH-1215	8/15/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.68E+01	2.14E-17	6.22E+00	9.89E+00	1.10E-02	9.42E-16	0.00E+00	9.43E-05	3.57E-13	3.00E-03
BATCH-1216	8/18/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.67E+01	2.14E-17	6.22E+00	9.88E+00	1.10E-02	9.41E-16	0.00E+00	9.43E-05	3.57E-13	3.00E-03
BATCH-1217	8/20/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.67E+01	2.13E-17	6.21E+00	9.87E+00	1.10E-02	9.41E-16	0.00E+00	9.42E-05	3.56E-13	3.00E-03
BATCH-1218	8/23/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.67E+01	2.13E-17	6.20E+00	9.86E+00	1.10E-02	9.40E-16	0.00E+00	9.41E-05	3.56E-13	3.00E-03
BATCH-1219	8/25/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	3.68E+01	8.94E-18	4.08E+00	1.00E+01	7.00E-03	2.52E-16	0.00E+00	2.51E-05	1.51E-12	2.00E-03
BATCH-1220	8/29/33	32	3.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.61E+01	8.94E-18	4.08E+00	1.00E+01	7.00E-03	2.52E-16	0.00E+00	2.51E-05	1.51E-12	2.00E-03
BATCH-1221	8/31/33	36	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.29E+01	9.69E-18	4.71E+00	1.19E+01	9.00E-03	2.55E-16	0.00E+00	2.54E-05	1.86E-12	2.00E-03
BATCH-1222	9/1/33	36	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.29E+01	9.69E-18	4.71E+00	1.19E+01	9.00E-03	2.55E-16	0.00E+00	2.54E-05	1.86E-12	2.00E-03
BATCH-1223	9/3/33	36	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.29E+01	9.69E-18	4.71E+00	1.19E+01	9.00E-03	2.55E-16	0.00E+00	2.54E-05	1.86E-12	2.00E-03
BATCH-1224	9/5/33	35	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	4.29E+01	9.69E-18	4.71E+00	1.19E+01	9.00E-03	2.55E-16	0.00E+00	2.54E-05	1.86E-12	2.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1225	9/7/33	36	3.8	0.24	0.00E+00	0.00E+00	5.72E-04	1.38E-05	4.10E-02	6.26E-01	7.29E+02	3.70E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.78E-05	1.00E-03	1.00E-03
BATCH-1226	9/9/33	149	15.6	0.24	0.00E+00	0.00E+00	1.00E-02	5.86E-05	7.34E-01	5.61E-01	5.89E+02	2.59E-01	1.00E-03	3.69E+00	8.65E-18	1.90E-02	6.78E-06	2.40E-02	1.00E-03
BATCH-1227	9/11/33	129	13.4	0.24	0.00E+00	0.00E+00	4.00E-03	5.11E-05	2.72E-01	3.76E-01	6.22E+02	1.55E-01	1.00E-03	3.40E+00	1.08E-17	2.40E-02	8.47E-06	6.00E-03	7.50E-04
BATCH-1228	9/25/33	129	13.4	0.24	0.00E+00	0.00E+00	4.00E-03	5.11E-05	2.72E-01	3.76E-01	6.21E+02	1.55E-01	1.00E-03	3.40E+00	1.08E-17	2.40E-02	8.46E-06	6.00E-03	7.50E-04
BATCH-1229	9/25/33	129	13.4	0.24	0.00E+00	0.00E+00	4.00E-03	5.10E-05	2.71E-01	3.75E-01	6.20E+02	1.55E-01	1.00E-03	3.39E+00	1.08E-17	2.40E-02	8.45E-06	6.00E-03	7.50E-04
BATCH-1230	10/8/33	128	13.4	0.24	0.00E+00	0.00E+00	4.00E-03	5.09E-05	2.71E-01	3.74E-01	6.20E+02	1.54E-01	1.00E-03	3.39E+00	1.08E-17	2.40E-02	8.44E-06	6.00E-03	7.50E-04
BATCH-1231	10/8/33	128	13.4	0.24	0.00E+00	0.00E+00	4.00E-03	5.07E-05	2.69E-01	3.74E-01	6.18E+02	1.54E-01	1.00E-03	3.38E+00	1.07E-17	2.40E-02	8.43E-06	6.00E-03	7.50E-04
BATCH-1232	10/22/33	39	4.0	0.24	0.00E+00	0.00E+00	2.00E-03	1.33E-05	1.66E-01	1.27E-01	1.33E+02	5.90E-02	2.82E-04	8.37E-01	1.96E-18	4.00E-03	1.54E-06	5.00E-03	2.27E-04
BATCH-1233	10/22/33	45	4.6	0.24	0.00E+00	0.00E+00	1.00E-03	1.55E-05	8.30E-02	1.14E-01	1.89E+02	4.70E-02	3.79E-04	1.03E+00	3.28E-18	7.00E-03	2.57E-06	2.00E-03	2.50E-04
BATCH-1234	10/26/33	45	4.6	0.24	0.00E+00	0.00E+00	1.00E-03	1.55E-05	8.20E-02	1.14E-01	1.89E+02	4.70E-02	3.79E-04	1.03E+00	3.28E-18	7.00E-03	2.57E-06	2.00E-03	2.50E-04
BATCH-1235	10/27/33	45	4.6	0.24	0.00E+00	0.00E+00	1.00E-03	1.55E-05	8.20E-02	1.14E-01	1.88E+02	4.70E-02	3.78E-04	1.03E+00	3.27E-18	7.00E-03	2.57E-06	2.00E-03	2.50E-04
BATCH-1236	10/31/33	45	4.6	0.24	0.00E+00	0.00E+00	1.00E-03	1.54E-05	8.20E-02	1.13E-01	1.88E+02	4.70E-02	3.78E-04	1.03E+00	3.27E-18	7.00E-03	2.57E-06	2.00E-03	2.50E-04
BATCH-1237	10/31/33	44	4.6	0.24	0.00E+00	0.00E+00	1.00E-03	1.54E-05	8.20E-02	1.13E-01	1.88E+02	4.70E-02	3.78E-04	1.03E+00	3.27E-18	7.00E-03	2.57E-06	2.00E-03	2.50E-04
BATCH-1238	11/5/33	14	1.5	0.24	0.00E+00	0.00E+00	5.41E-04	3.14E-06	3.90E-02	2.97E-02	3.16E+01	1.40E-02	6.66E-05	1.98E-01	4.64E-19	1.00E-03	3.64E-07	1.00E-03	5.37E-05
BATCH-1239	11/5/33	16	1.6	0.24	0.00E+00	0.00E+00	2.65E-04	3.64E-06	1.90E-02	2.70E-02	4.43E+01	1.10E-02	8.89E-05	2.42E-01	7.70E-19	2.00E-03	6.04E-07	4.37E-04	6.04E-05
BATCH-1240	11/6/33	16	1.6	0.24	0.00E+00	0.00E+00	2.65E-04	3.64E-06	1.90E-02	2.70E-02	4.42E+01	1.10E-02	8.88E-05	2.42E-01	7.69E-19	2.00E-03	6.03E-07	4.36E-04	6.03E-05
BATCH-1241	11/7/33	16	1.6	0.24	0.00E+00	0.00E+00	2.65E-04	3.63E-06	1.90E-02	2.70E-02	4.42E+01	1.10E-02	8.87E-05	2.42E-01	7.67E-19	2.00E-03	6.02E-07	4.35E-04	6.02E-05
BATCH-1242	11/8/33	16	1.6	0.24	0.00E+00	0.00E+00	2.64E-04	3.62E-06	1.90E-02	2.70E-02	4.41E+01	1.10E-02	8.85E-05	2.41E-01	7.66E-19	2.00E-03	6.01E-07	4.34E-04	6.00E-05
BATCH-1243	11/9/33	16	1.6	0.24	0.00E+00	0.00E+00	2.63E-04	3.61E-06	1.90E-02	2.70E-02	4.40E+01	1.10E-02	8.83E-05	2.40E-01	7.64E-19	2.00E-03	6.00E-07	4.32E-04	5.98E-05
BATCH-1244	11/10/33	53	5.5	0.24	0.00E+00	0.00E+00	8.24E-04	1.99E-05	6.00E-02	9.10E-01	1.06E+03	5.30E-02	5.00E-03	5.28E+00	3.72E-17	4.30E-02	4.04E-05	2.00E-03	1.50E-03
BATCH-1245	11/16/33	37	3.8	0.24	0.00E+00	0.00E+00	5.67E-04	1.37E-05	4.10E-02	6.26E-01	7.30E+02	3.60E-02	3.00E-03	3.63E+00	2.56E-17	3.00E-02	2.78E-05	1.00E-03	1.00E-03
BATCH-1246	11/20/33	108	11.2	0.24	0.00E+00	0.00E+00	3.56E-04	8.59E-06	2.60E-02	3.93E-01	1.14E+03	2.30E-02	2.00E-03	4.87E+00	1.61E-17	1.90E-02	1.75E-05	6.55E-04	7.50E-04
BATCH-1247	12/2/33	48	5.0	0.24	0.00E+00	0.00E+00	1.42E-04	3.43E-06	1.00E-02	1.57E-01	4.53E+02	9.00E-03	8.63E-04	1.94E+00	6.41E-18	7.00E-03	6.96E-06	2.61E-04	2.50E-04
BATCH-1248	12/7/33	18	1.9	0.24	0.00E+00	0.00E+00	3.90E-05	9.42E-07	3.00E-03	4.32E-02	1.25E+02	3.00E-03	2.37E-04	5.34E-01	1.76E-18	2.00E-03	1.91E-06	7.18E-05	7.41E-05
BATCH-1249	3/25/34	34	3.6	0.24	0.00E+00	0.00E+00	2.00E-03	1.61E-04	1.70E-01	3.28E-01	2.32E+02	5.50E-02	3.00E-03	3.41E+00	6.75E-18	1.30E-02	7.76E-06	5.00E-03	3.75E-03
BATCH-1250	3/26/34	34	3.5	0.24	0.00E+00	0.00E+00	2.00E-03	1.73E-04	1.80E-01	3.00E-01	9.89E+01	5.70E-02	3.00E-03	3.32E+00	6.18E-18	1.20E-02	6.52E-06	6.00E-03	3.75E-03
BATCH-1251	3/29/34	34	3.5	0.24	0.00E+00	0.00E+00	2.00E-03	1.73E-04	1.80E-01	3.00E-01	9.88E+01	5.70E-02	3.00E-03	3.31E+00	6.18E-18	1.20E-02	6.52E-06	6.00E-03	3.75E-03
BATCH-1252	3/30/34	34	3.5	0.24	0.00E+00	0.00E+00	2.00E-03	1.73E-04	1.80E-01	3.00E-01	9.87E+01	5.70E-02	3.00E-03	3.31E+00	6.17E-18	1.20E-02	6.51E-06	6.00E-03	3.75E-03
BATCH-1253	4/1/34	34	3.5	0.24	0.00E+00	0.00E+00	2.00E-03	1.73E-04	1.80E-01	3.00E-01	9.87E+01	5.70E-02	3.00E-03	3.31E+00	6.17E-18	1.20E-02	6.51E-06	6.00E-03	3.75E-03
BATCH-1254	4/2/34	23	2.4	0.24	0.00E+00	0.00E+00	2.00E-03	1.16E-04	1.21E-01	2.02E-01	6.64E+01	3.80E-02	2.00E-03	2.23E+00	4.15E-18	8.00E-03	4.38E-06	4.00E-03	2.50E-03
BATCH-1255	4/5/34	46	4.8	0.24	0.00E+00	0.00E+00	4.34E-04	5.25E-05	3.10E-02	3.39E-01	9.17E+02	1.80E-02	2.00E-03	4.57E+00	7.03E-18	4.40E-02	6.90E-06	9.56E-04	3.25E-03
BATCH-1256	4/5/34	49	5.1	0.24	0.00E+00	0.00E+00	3.52E-04	4.91E-05	2.60E-02	3.58E-01	9.74E+02	1.70E-02	2.00E-03	4.85E+00	7.42E-18	4.80E-02	7.27E-06	7.68E-04	3.50E-03
BATCH-1257	4/10/34	49	5.1	0.24	0.00E+00	0.00E+00	3.52E-04	4.91E-05	2.60E-02	3.58E-01	9.74E+02	1.70E-02	2.00E-03	4.85E+00	7.42E-18	4.80E-02	7.27E-06	7.68E-04	3.50E-03
BATCH-1258	4/10/34	151	15.7	0.24	0.00E+00	0.00E+00	1.00E-03	8.49E-05	9.10E-02	1.99E-01	1.98E+02	3.10E-02	2.00E-03	2.27E+00	4.09E-18	8.00E-03	5.00E-06	3.00E-03	2.00E-03
BATCH-1259	4/15/34	49	5.1	0.24	0.00E+00	0.00E+00	3.52E-04	4.91E-05	2.60E-02	3.58E-01	9.75E+02	1.70E-02	2.00E-03	4.86E+00	7.43E-18	4.80E-02	7.27E-06	7.68E-04	3.50E-03
BATCH-1260	4/21/34	130	13.5	0.24	0.00E+00	0.00E+00	9.26E-04	7.00E-05	6.70E-02	1.86E-01	7.22E+02	2.30E-02	1.00E-03	2.82E+00	3.86E-18	1.50E-02	3.93E-06	2.00E-03	2.00E-03
BATCH-1261	4/26/34	125	13.0	0.24	0.00E+00	0.00E+00	8.14E-04	6.34E-05	5.90E-02	1.87E-01	8.46E+02	2.10E-02	1.00E-03	2.97E+00	3.87E-18	1.70E-02	3.92E-06	2.00E-03	2.00E-03
BATCH-1262	5/4/34	125	13.0	0.24	0.00E+00	0.00E+00	8.13E-04	6.32E-05	5.90E-02	1.87E-01	8.46E+02	2.10E-02	1.00E-03	2.96E+00	3.86E-18	1.70E-02	3.91E-06	2.00E-03	2.00E-03
BATCH-1263	5/10/34	125	13.0	0.24	0.00E+00	0.00E+00	8.10E-04	6.31E-05	5.90E-02	1.86E-01	8.45E+02	2.10E-02	1.00E-03	2.96E+00	3.86E-18	1.70E-02	3.91E-06	2.00E-03	2.00E-03
BATCH-1264	5/18/34	36	3.7	0.24	0.00E+00	0.00E+00	2.61E-04	1.76E-05	1.90E-02	4.14E-02	4.11E+01	6.00E-03	3.54E-04	4.70E-01	8.49E-19	2.00E-03	1.04E-06	5.87E-04	5.00E-04
BATCH-1265	5/22/34	44	4.6	0.24	0.00E+00	0.00E+00	2.74E-04	2.07E-05	2.00E-02	5.49E-02	2.14E+02	7.00E-03	4.29E-04	8.34E-01	1.14E-18	5.00E-03	1.16E-06	6.18E-04	5.00E-04
BATCH-1266	5/23/34	45	4.7	0.24	0.00E+00	0.00E+00	2.58E-04	2.00E-05	1.90E-02	5.94E-02	2.68E+02	7.00E-03	4.38E-04	9.39E-01	1.23E-18	5.00E-03	1.24E-06	5.79E-04	7.50E-04
BATCH-1267	5/26/34	45	4.7	0.24	0.00E+00	0.00E+00	2.57E-04	2.00E-05	1.90E-02	5.94E-02	2.68E+02	7.00E-03	4.37E-04	9.38E-01	1.22E-18	5.00E-03	1.24E-06	5.79E-04	7.50E-04
BATCH-1268	5/28/34	13	1.4	0.24	0.00E+00	0.00E+00	6.19E-05	4.17E-06	4.00E-03	9.90E-03	9.74E+00	2.00E-03	8.40E-05	1.11E-01	2.01E-19	3.96E-04	2.46E-07	1.39E-04	9.61E-05
BATCH-1269	5/29/34	45	4.7	0.24	0.00E+00	0.00E+00	2.57E-04	2.00E-05	1.90E-02	5.94E-02	2.68E+02	7.00E-03	4.37E-04	9.37E-01	1.22E-18	5.00E-03	1.24E-06	5.78E-04	7.50E-04
BATCH-1270	5/31/34	15	1.6	0.24	0.00E+00	0.00E+00	6.38E-05	4.82E-06	5.00E-03	1.26E-02	4.97E+01	2.00E-03	9.98E-05	1.94E-01	2.66E-19	1.00E-03	2.71E-07	1.44E-04	1.45E-04
BATCH-1271	6/2/34	16	1.7	0.24	0.00E+00	0.00E+00	6.16E-05	4.80E-06	4.00E-03	1.44E-02	6.41E+01	2.00E-03	1.05E-04	2.25E-01	2.93E-19	1.00E-03	2.97E-07	1.39E-04	1.56E-04
BATCH-1272	6/3/34	16	1.7	0.24	0.00E+00	0.00E+00	6.15E-05	4.79E-06	4.00E-03	1.44E-02	6.40E+01	2.00E-03	1.05E-04	2.24E-01	2.92E-19	1.00E-03	2.97E-07	1.39E-04	1.56E-04
BATCH-1273	6/4/34	16	1.7	0.24	0.00E+00	0.00E+00	6.13E-05	4.78E-06	4.00E-03	1.44E-02	6.39E+01	2.00E-03	1.04E-04	2.24E-01	2.92E-19	1.00E-03	2.96E-07	1.38E-04	1.55E-04

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1225	9/7/33	36	3.8	0.24	1.74E-09	1.09E+02	2.32E-01	6.26E-04	7.00E-03	2.00E-03	9.36E-07	8.06E-09	1.81E-07	2.93E-06	7.86E-06	1.52E-05	1.02E-04	5.68E-04	4.00E-03
BATCH-1226	9/9/33	149	15.6	0.24	2.96E-09	4.47E+02	3.71E-01	2.63E-04	3.00E-03	7.04E-04	4.69E-06	1.14E-08	4.79E-06	1.89E-06	6.09E-05	5.46E-06	6.72E-05	3.74E-04	2.00E-03
BATCH-1227	9/11/33	129	13.4	0.24	1.71E-09	3.86E+02	1.92E-01	3.73E-04	3.00E-03	9.98E-04	1.79E-06	6.36E-09	5.19E-06	2.06E-06	3.91E-05	6.36E-06	4.22E-05	2.36E-04	1.00E-03
BATCH-1228	9/25/33	129	13.4	0.24	1.71E-09	3.86E+02	1.92E-01	3.72E-04	3.00E-03	9.97E-04	1.79E-06	6.35E-09	5.18E-06	2.06E-06	3.91E-05	6.36E-06	4.22E-05	2.35E-04	1.00E-03
BATCH-1229	9/25/33	129	13.4	0.24	1.71E-09	3.85E+02	1.91E-01	3.72E-04	3.00E-03	9.96E-04	1.79E-06	6.34E-09	5.18E-06	2.06E-06	3.90E-05	6.35E-06	4.22E-05	2.35E-04	1.00E-03
BATCH-1230	10/8/33	128	13.4	0.24	1.70E-09	3.85E+02	1.91E-01	3.71E-04	3.00E-03	9.94E-04	1.78E-06	6.33E-09	5.16E-06	2.05E-06	3.89E-05	6.34E-06	4.21E-05	2.35E-04	1.00E-03
BATCH-1231	10/8/33	128	13.4	0.24	1.70E-09	3.84E+02	1.90E-01	3.70E-04	3.00E-03	9.92E-04	1.78E-06	6.31E-09	5.14E-06	2.05E-06	3.88E-05	6.33E-06	4.20E-05	2.34E-04	1.00E-03
BATCH-1232	10/22/33	39	4.0	0.24	6.72E-10	1.16E-02	8.40E-02	5.95E-05	6.35E-04	1.60E-04	1.06E-06	2.59E-09	1.09E-06	4.29E-07	1.38E-05	1.24E-06	1.52E-05	8.48E-05	4.68E-04
BATCH-1233	10/22/33	45	4.6	0.24	5.21E-10	1.34E+02	5.80E-02	1.13E-04	8.47E-04	3.03E-04	5.45E-07	1.93E-09	1.58E-06	6.27E-07	1.19E-05	1.93E-06	1.28E-05	7.16E-05	4.46E-04
BATCH-1234	10/26/33	45	4.6	0.24	5.20E-10	1.34E+02	5.80E-02	1.13E-04	8.47E-04	3.03E-04	5.44E-07	1.93E-09	1.58E-06	6.26E-07	1.19E-05	1.93E-06	1.28E-05	7.16E-05	4.46E-04
BATCH-1235	10/27/33	45	4.6	0.24	5.19E-10	1.34E+02	5.80E-02	1.13E-04	8.46E-04	3.03E-04	5.43E-07	1.93E-09	1.57E-06	6.25E-07	1.19E-05	1.93E-06	1.28E-05	7.15E-05	4.45E-04
BATCH-1236	10/31/33	45	4.6	0.24	5.18E-10	1.33E+02	5.80E-02	1.13E-04	8.45E-04	3.02E-04	5.42E-07	1.93E-09	1.57E-06	6.25E-07	1.18E-05	1.93E-06	1.28E-05	7.14E-05	4.44E-04
BATCH-1237	10/31/33	44	4.6	0.24	5.17E-10	1.33E+02	5.80E-02	1.13E-04	8.44E-04	3.02E-04	5.41E-07	1.92E-09	1.57E-06	6.23E-07	1.18E-05	1.93E-06	1.28E-05	7.13E-05	4.44E-04
BATCH-1238	11/5/33	14	1.5	0.24	1.59E-10	4.28E+01	2.00E-02	1.41E-05	1.50E-04	3.78E-05	2.51E-07	6.13E-10	2.57E-07	1.01E-07	3.27E-06	2.93E-07	3.60E-06	2.01E-05	1.11E-04
BATCH-1239	11/5/33	16	1.6	0.24	1.22E-10	4.70E+01	1.40E-02	2.66E-05	1.99E-04	7.12E-05	1.28E-07	4.53E-10	3.70E-07	1.47E-07	2.79E-06	4.54E-07	3.01E-06	1.68E-05	1.05E-04
BATCH-1240	11/6/33	16	1.6	0.24	1.22E-10	4.70E+01	1.40E-02	2.65E-05	1.98E-04	7.11E-05	1.28E-07	4.52E-10	3.69E-07	1.47E-07	2.78E-06	4.53E-07	3.01E-06	1.68E-05	1.05E-04
BATCH-1241	11/7/33	16	1.6	0.24	1.22E-10	4.69E+01	1.40E-02	2.65E-05	1.98E-04	7.09E-05	1.27E-07	4.52E-10	3.69E-07	1.47E-07	2.78E-06	4.52E-07	3.00E-06	1.68E-05	1.04E-04
BATCH-1242	11/8/33	16	1.6	0.24	1.21E-10	4.69E+01	1.40E-02	2.64E-05	1.98E-04	7.08E-05	1.27E-07	4.51E-10	3.68E-07	1.46E-07	2.77E-06	4.51E-07	3.00E-06	1.67E-05	1.04E-04
BATCH-1243	11/9/33	16	1.6	0.24	1.21E-10	4.68E+01	1.40E-02	2.64E-05	1.97E-04	7.06E-05	1.26E-07	4.49E-10	3.66E-07	1.46E-07	2.76E-06	4.50E-07	2.99E-06	1.67E-05	1.04E-04
BATCH-1244	11/10/33	53	5.5	0.24	2.52E-09	1.59E+02	3.38E-01	9.10E-04	1.10E-02	3.00E-03	1.36E-06	1.17E-08	2.51E-07	4.26E-06	1.13E-05	2.20E-05	1.48E-04	8.27E-04	6.00E-03
BATCH-1245	11/16/33	37	3.8	0.24	1.74E-09	1.09E+02	2.33E-01	6.26E-04	7.00E-03	2.00E-03	9.36E-07	8.06E-09	1.72E-07	2.93E-06	7.80E-06	1.52E-05	1.02E-04	5.69E-04	4.00E-03
BATCH-1246	11/20/33	108	11.2	0.24	1.09E-09	3.23E+02	1.46E-01	3.93E-04	5.00E-03	1.00E-03	5.88E-07	5.06E-09	1.08E-07	1.84E-06	4.90E-06	9.52E-06	6.40E-05	3.57E-04	2.00E-03
BATCH-1247	12/2/33	48	5.0	0.24	4.34E-10	1.43E+02	5.80E-02	1.57E-04	2.00E-03	4.76E-04	2.34E-07	2.02E-09	4.32E-08	7.34E-07	1.95E-06	3.80E-06	2.55E-05	1.42E-04	9.67E-04
BATCH-1248	12/7/33	18	1.9	0.24	1.20E-10	5.33E+01	1.60E-02	4.31E-05	5.15E-04	1.31E-04	6.45E-08	5.55E-10	1.19E-08	2.02E-07	5.37E-07	1.04E-06	7.02E-06	3.92E-05	2.66E-04
BATCH-1249	3/25/34	34	3.6	0.24	3.56E-09	1.03E+02	6.16E+00	4.50E-04	1.80E-02	8.24E-04	6.23E-07	1.78E-07	1.73E-06	2.46E-06	1.51E-05	3.35E-04	2.00E-03	1.00E-02	1.00E-03
BATCH-1250	3/26/34	34	3.5	0.24	3.74E-09	1.01E+02	6.63E+00	4.35E-04	1.90E-02	7.48E-04	5.92E-07	1.91E-07	1.86E-06	2.40E-06	1.57E-05	3.53E-04	2.00E-03	7.96E-03	7.96E-04
BATCH-1251	3/29/34	34	3.5	0.24	3.74E-09	1.01E+02	6.63E+00	4.35E-04	1.90E-02	7.48E-04	5.92E-07	1.91E-07	1.86E-06	2.40E-06	1.57E-05	3.53E-04	2.00E-03	7.95E-03	7.95E-04
BATCH-1252	3/30/34	34	3.5	0.24	3.73E-09	1.01E+02	6.62E+00	4.34E-04	1.90E-02	7.47E-04	5.91E-07	1.91E-07	1.85E-06	2.40E-06	1.56E-05	3.52E-04	2.00E-03	7.95E-03	7.95E-04
BATCH-1253	4/1/34	34	3.5	0.24	2.51E-09	6.82E+01	4.45E+00	2.92E-04	1.30E-02	5.02E-04	3.97E-07	1.28E-07	1.25E-06	1.61E-06	1.05E-05	4.58E-06	2.37E-04	1.00E-03	5.34E-04
BATCH-1254	4/2/34	23	2.4	0.24	9.30E-10	1.37E+02	6.54E-01	3.00E-03	7.00E-03	9.39E-07	2.18E-08	4.35E-07	1.84E-06	2.62E-06	8.44E-06	8.24E-05	4.64E-04	3.00E-03	
BATCH-1255	4/5/34	46	4.8	0.24	8.36E-10	1.46E+02	3.88E-01	3.00E-03	6.00E-03	7.00E-03	1.00E-06	1.44E-08	3.85E-07	1.91E-06	2.10E-06	8.94E-06	7.30E-05	4.11E-04	4.00E-03
BATCH-1256	4/5/34	49	5.1	0.24	8.36E-10	1.46E+02	3.88E-01	3.00E-03	6.00E-03	7.00E-03	1.00E-06	1.44E-08	3.85E-07	1.91E-06	2.10E-06	8.94E-06	7.30E-05	4.11E-04	4.00E-03
BATCH-1257	4/10/34	49	5.1	0.24	8.36E-10	1.46E+02	3.88E-01	3.00E-03	6.00E-03	7.00E-03	1.00E-06	1.44E-08	3.85E-07	1.91E-06	2.10E-06	8.94E-06	7.30E-05	4.11E-04	4.00E-03
BATCH-1258	4/10/34	151	15.7	0.24	1.92E-09	4.52E+02	3.23E+00	2.61E-04	1.00E-02	5.03E-04	3.66E-07	9.33E-08	9.13E-07	1.41E-06	8.26E-06	4.60E-06	1.80E-04	1.00E-03	7.14E-04
BATCH-1259	4/15/34	49	5.1	0.24	8.36E-10	1.46E+02	3.88E-01	3.00E-03	6.00E-03	7.00E-03	1.00E-06	1.44E-08	3.86E-07	1.91E-06	2.10E-06	8.94E-06	7.30E-05	4.11E-04	4.00E-03
BATCH-1260	4/21/34	130	13.5	0.24	1.48E-09	3.89E+02	2.33E+00	9.44E-04	8.00E-03	2.00E-03	4.39E-07	6.78E-08	7.17E-07	1.26E-06	5.78E-06	4.43E-06	1.36E-04	7.68E-04	1.00E-03
BATCH-1261	4/26/34	125	13.0	0.24	1.30E-09	3.74E+02	2.00E+00	1.00E-03	7.00E-03	2.00E-03	4.54E-07	5.87E-08	6.40E-07	1.23E-06	5.07E-06	4.48E-06	1.22E-04	6.85E-04	1.00E-03
BATCH-1262	5/4/34	125	13.0	0.24	1.30E-09	3.74E+02	2.00E+00	1.00E-03	7.00E-03	2.00E-03	4.53E-07	5.86E-08	6.39E-07	1.22E-06	5.06E-06	4.48E-06	1.21E-04	6.84E-04	1.00E-03
BATCH-1263	5/10/34	125	13.0	0.24	1.30E-09	3.74E+02	1.99E+00	1.00E-03	7.00E-03	2.00E-03	5.84E-08	6.37E-07	1.22E-06	5.05E-06	4.47E-06	1.21E-04	6.82E-04	1.00E-03	
BATCH-1264	5/18/34	36	3.7	0.24	3.98E-10	1.07E+02	6.70E-01	5.42E-05	2.00E-03	1.04E-04	7.60E-08	1.94E-08	1.89E-07	2.93E-07	1.71E-06	9.54E-07	3.73E-05	2.10E-04	1.48E-04
BATCH-1265	5/22/34	44	4.6	0.24	4.32E-10	1.32E+02	6.88E-01	2.80E-04	2.00E-03	5.90E-04	1.30E-07	2.01E-08	2.12E-07	3.74E-07	1.71E-06	1.31E-06	4.04E-05	2.27E-04	3.29E-04
BATCH-1266	5/23/34	45	4.7	0.24	4.13E-10	1.35E+02	6.34E-01	3.39E-04	2.00E-03	7.22E-04	1.44E-07	1.86E-08	2.02E-07	3.88E-07	1.60E-06	1.42E-06	3.84E-05	2.17E-04	3.89E-04
BATCH-1267	5/26/34	45	4.7	0.24	4.12E-10	1.35E+02	6.33E-01	3.39E-04	2.00E-03	7.21E-04	1.43E-07	1.85E-08	2.02E-07	3.87E-07	1.60E-06	1.42E-06	3.84E-05	2.16E-04	3.88E-04
BATCH-1268	5/28/34	13	1.4	0.24	9.43E-11	3.91E+01	1.59E-01	1.29E-05	4.75E-04	2.47E-05	1.80E-08	4.59E-09	4.49E-08	6.95E-08	4.06E-07	2.26E-07	8.83E-06	4.98E-05	3.51E-05
BATCH-1269	5/29/34	45	4.7	0.24	4.12E-10	1.34E+02	6.31E-01	3.39E-04	2.00E-03	7.21E-04	1.43E-07	1.85E-08	2.02E-07	3.87E-07	1.60E-06	1.42E-06	3.83E-05	2.16E-04	3.88E-04
BATCH-1270	5/31/34	15	1.6	0.24	1.00E-10	4.63E+01	1.60E-01	6.50E-05	5.40E-04	1.37E-04	3.02E-08	4.67E-09	4.94E-08	8.70E-08	3.98E-07	3.05E-07	9.39E-06	5.29E-05	7.65E-05
BATCH-1271	6/2/34	16	1.7	0.24	9.88E-11	4.76E+01	1.52E-01	8.11E-05	5.43E-04	1.73E-04	3.44E-08	4.44E-09	4.84E-08	9.28E-08	3.84E-07	3.40E-07	9.20E-06	5.19E-05	9.30E-05
BATCH-1272	6/3/34	16	1.7	0.24	9.86E-11	4.76E+01	1.51E-01	8.10E-05	5.42E-04	1.73E-04	3.43E-08	4.43E-09	4.83E-08	9.27E-08	3.83E-07	3.39E-07	9.18E-06	5.18E-05	9.29E-05
BATCH-1273	6/4/34	16	1.7	0.24	9.83E-11	4.76E+01	1.51E-01	8.10E-05	5.41E-04	1.72E-04	3.43E-08	4.42E-09	4.82E-08	9.25E-08	3.82E-07	3.38E-07	9.16E-06	5.16E-05	9.28E-05

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1225	9/7/33	36	3.8	0.24	1.70E-04	4.41E-05	4.00E-03	8.00E-03	4.00E-03	4.48E-01	6.00E-02	3.43E+00	9.70E-02	2.33E-30	3.58E-06	1.12E-04	1.65E-05	3.08E-04	3.35E-16
BATCH-1226	9/9/33	149	15.6	0.24	8.78E-05	4.30E-05	9.56E-04	3.00E-03	2.00E-03	1.36E-01	1.80E-02	1.03E+00	2.70E-02	1.19E-29	9.99E-07	3.70E-05	7.99E-05	1.00E-03	1.12E-15
BATCH-1227	9/11/33	129	13.4	0.24	6.42E-05	1.92E-05	1.00E-03	3.00E-03	1.00E-03	1.75E-01	2.20E-02	1.06E+00	3.30E-02	4.68E-30	1.21E-06	3.52E-05	3.12E-05	5.43E-04	3.82E-16
BATCH-1228	9/25/33	129	13.4	0.24	6.41E-05	1.92E-05	1.00E-03	3.00E-03	1.00E-03	1.74E-01	2.20E-02	1.06E+00	3.30E-02	4.67E-30	1.21E-06	3.52E-05	3.11E-05	5.42E-04	3.82E-16
BATCH-1229	9/25/33	129	13.4	0.24	6.41E-05	1.91E-05	1.00E-03	3.00E-03	1.00E-03	1.74E-01	2.20E-02	1.06E+00	3.30E-02	4.66E-30	1.21E-06	3.51E-05	3.11E-05	5.41E-04	3.81E-16
BATCH-1230	10/8/33	128	13.4	0.24	6.40E-05	1.91E-05	1.00E-03	3.00E-03	1.00E-03	1.74E-01	2.20E-02	1.06E+00	3.30E-02	4.65E-30	1.20E-06	3.51E-05	3.11E-05	5.40E-04	3.80E-16
BATCH-1231	10/8/33	128	13.4	0.24	6.38E-05	1.91E-05	1.00E-03	3.00E-03	1.00E-03	1.74E-01	2.20E-02	1.06E+00	3.30E-02	4.64E-30	1.20E-06	3.50E-05	3.09E-05	5.38E-04	3.79E-16
BATCH-1232	10/22/33	39	4.0	0.24	1.99E-05	9.75E-06	2.17E-04	5.89E-04	4.52E-04	3.10E-02	4.00E-03	2.33E-01	6.00E-03	2.71E-30	2.27E-07	8.39E-06	1.81E-05	3.13E-04	2.53E-16
BATCH-1233	10/22/33	45	4.6	0.24	1.95E-05	5.83E-06	3.40E-04	9.80E-04	4.49E-04	5.30E-02	7.00E-03	3.23E-01	1.00E-02	1.42E-30	3.67E-07	1.07E-05	9.46E-06	1.65E-04	1.16E-16
BATCH-1234	10/26/33	45	4.6	0.24	1.95E-05	5.83E-06	3.40E-04	9.79E-04	4.48E-04	5.30E-02	7.00E-03	3.23E-01	1.00E-02	1.42E-30	3.67E-07	1.07E-05	9.45E-06	1.65E-04	1.16E-16
BATCH-1235	10/27/33	45	4.6	0.24	1.95E-05	5.82E-06	3.40E-04	9.78E-04	4.48E-04	5.30E-02	7.00E-03	3.23E-01	1.00E-02	1.42E-30	3.66E-07	1.07E-05	9.43E-06	1.64E-04	1.16E-16
BATCH-1236	10/31/33	45	4.6	0.24	1.95E-05	5.81E-06	3.39E-04	9.77E-04	4.47E-04	5.30E-02	7.00E-03	3.23E-01	1.00E-02	1.42E-30	3.66E-07	1.07E-05	9.40E-06	1.64E-04	1.15E-16
BATCH-1237	10/31/33	44	4.6	0.24	1.94E-05	5.80E-06	3.39E-04	9.76E-04	4.47E-04	5.30E-02	7.00E-03	3.22E-01	1.00E-02	1.41E-30	3.66E-07	1.07E-05	9.40E-06	1.64E-04	1.15E-16
BATCH-1238	11/5/33	14	1.5	0.24	4.71E-06	2.31E-06	5.13E-05	1.39E-04	1.07E-04	7.00E-03	9.65E-04	5.50E-02	1.00E-03	6.41E-31	5.36E-08	1.98E-06	4.28E-06	7.40E-05	5.99E-17
BATCH-1239	11/5/33	16	1.6	0.24	4.57E-06	1.37E-06	7.98E-05	2.30E-04	1.05E-04	1.20E-02	2.00E-03	7.60E-02	2.00E-03	3.33E-31	8.61E-08	2.51E-06	2.22E-06	3.87E-05	2.72E-17
BATCH-1240	11/6/33	16	1.6	0.24	4.57E-06	1.37E-06	7.97E-05	2.29E-04	1.05E-04	1.20E-02	2.00E-03	7.60E-02	2.00E-03	3.33E-31	8.59E-08	2.50E-06	2.22E-06	3.86E-05	2.72E-17
BATCH-1241	11/7/33	16	1.6	0.24	4.56E-06	1.36E-06	7.96E-05	2.29E-04	1.05E-04	1.20E-02	2.00E-03	7.60E-02	2.00E-03	3.32E-31	8.58E-08	2.50E-06	2.21E-06	3.86E-05	2.71E-17
BATCH-1242	11/8/33	16	1.6	0.24	4.55E-06	1.36E-06	7.94E-05	2.29E-04	1.05E-04	1.20E-02	2.00E-03	7.60E-02	2.00E-03	3.31E-31	8.57E-08	2.50E-06	2.21E-06	3.85E-05	2.71E-17
BATCH-1243	11/9/33	16	1.6	0.24	4.54E-06	1.36E-06	7.93E-05	2.28E-04	1.05E-04	1.20E-02	2.00E-03	7.50E-02	2.00E-03	3.30E-31	8.55E-08	2.49E-06	2.20E-06	3.83E-05	2.70E-17
BATCH-1244	11/10/33	53	5.5	0.24	2.47E-04	6.42E-05	5.00E-03	1.20E-02	6.00E-03	6.52E-01	8.80E-02	4.99E+00	1.42E-01	3.38E-30	5.21E-06	1.62E-04	2.39E-05	4.47E-04	4.87E-16
BATCH-1245	11/16/33	37	3.8	0.24	1.70E-04	4.42E-05	4.00E-03	8.00E-03	4.00E-03	4.49E-01	6.10E-02	3.43E+00	9.70E-02	2.32E-30	3.58E-06	1.12E-04	1.64E-05	3.07E-04	3.35E-16
BATCH-1246	11/20/33	108	11.2	0.24	1.07E-04	2.77E-05	2.00E-03	5.00E-03	2.00E-03	2.82E-01	3.80E-02	2.16E+00	6.10E-02	1.46E-30	2.25E-06	7.02E-05	1.03E-05	1.93E-04	2.10E-16
BATCH-1247	12/2/33	48	5.0	0.24	4.25E-05	1.11E-05	9.18E-04	2.00E-03	9.81E-04	1.12E-01	1.50E-02	8.59E-01	2.40E-02	5.82E-31	8.97E-07	2.80E-05	4.12E-06	7.69E-05	8.39E-17
BATCH-1248	12/7/33	18	1.9	0.24	1.17E-05	3.04E-06	2.52E-04	5.79E-04	2.70E-04	3.10E-02	4.00E-03	2.36E-01	7.00E-03	1.60E-31	2.47E-07	7.69E-06	1.13E-06	2.12E-05	2.31E-17
BATCH-1249	3/25/34	34	3.6	0.24	4.40E-05	2.31E-05	9.30E-04	3.00E-03	1.00E-03	2.91E-01	3.40E-02	3.13E-01	3.60E-02	6.35E-31	1.26E-06	1.04E-05	1.05E-05	8.53E-05	6.91E-13
BATCH-1250	3/26/34	34	3.5	0.24	3.30E-05	2.11E-05	6.91E-04	3.00E-03	8.95E-04	2.75E-01	3.20E-02	4.50E-02	3.00E-02	6.43E-31	1.05E-06	1.61E-06	1.00E-05	6.67E-05	7.46E-13
BATCH-1251	3/29/34	34	3.5	0.24	3.29E-05	2.11E-05	6.90E-04	3.00E-03	8.95E-04	2.75E-01	3.20E-02	4.50E-02	3.00E-02	6.43E-31	1.05E-06	1.61E-06	1.00E-05	6.67E-05	7.46E-13
BATCH-1252	3/30/34	34	3.5	0.24	3.29E-05	2.11E-05	6.90E-04	3.00E-03	8.94E-04	2.75E-01	3.20E-02	4.50E-02	3.00E-02	6.42E-31	1.05E-06	1.61E-06	9.99E-06	6.67E-05	7.45E-13
BATCH-1253	4/1/34	34	3.5	0.24	3.29E-05	2.11E-05	6.89E-04	3.00E-03	8.93E-04	2.75E-01	3.20E-02	4.50E-02	3.00E-02	6.42E-31	1.05E-06	1.61E-06	9.99E-06	6.66E-05	7.45E-13
BATCH-1254	4/2/34	23	2.4	0.24	2.21E-05	1.42E-05	4.63E-04	2.00E-03	6.01E-04	1.85E-01	2.10E-02	3.00E-02	2.00E-02	4.31E-31	7.08E-07	1.09E-06	6.71E-06	4.48E-05	5.00E-13
BATCH-1255	4/5/34	46	4.8	0.24	1.43E-04	3.44E-05	2.00E-03	5.00E-03	3.00E-03	2.99E-01	3.70E-02	1.71E+00	5.00E-02	8.64E-31	1.92E-06	5.58E-05	8.81E-06	7.54E-05	3.47E-14
BATCH-1256	4/5/34	49	5.1	0.24	1.56E-04	3.68E-05	2.00E-03	5.00E-03	4.00E-03	3.15E-01	3.90E-02	1.88E+00	5.40E-02	9.18E-31	2.06E-06	6.13E-05	9.19E-06	7.96E-05	7.72E-16
BATCH-1257	4/10/34	49	5.1	0.24	1.56E-04	3.68E-05	2.00E-03	5.00E-03	4.00E-03	3.15E-01	3.90E-02	1.88E+00	5.40E-02	9.18E-31	2.06E-06	6.13E-05	9.19E-06	7.96E-05	7.72E-16
BATCH-1258	4/10/34	151	15.7	0.24	3.04E-05	1.40E-05	6.46E-04	2.00E-03	7.67E-04	1.72E-01	2.10E-02	3.13E-01	2.30E-02	3.54E-31	8.16E-07	1.03E-05	6.21E-06	5.75E-05	3.61E-13
BATCH-1259	4/15/34	49	5.1	0.24	1.56E-04	3.68E-05	2.00E-03	5.00E-03	4.00E-03	3.16E-01	3.90E-02	1.88E+00	5.40E-02	9.19E-31	2.06E-06	6.13E-05	9.19E-06	7.96E-05	7.72E-16
BATCH-1260	4/21/34	130	13.5	0.24	4.83E-05	1.59E-05	7.19E-04	2.00E-03	1.00E-03	1.68E-01	2.00E-02	4.64E-01	2.30E-02	4.36E-31	8.47E-07	1.52E-05	5.56E-06	4.15E-05	2.51E-13
BATCH-1261	4/26/34	125	13.0	0.24	5.36E-05	1.65E-05	7.75E-04	2.00E-03	1.00E-03	1.68E-01	2.00E-02	5.47E-01	2.40E-02	4.44E-31	8.85E-07	1.79E-05	5.46E-06	4.16E-05	2.13E-13
BATCH-1262	5/4/34	125	13.0	0.24	5.36E-05	1.64E-05	7.74E-04	2.00E-03	1.00E-03	1.68E-01	2.00E-02	5.46E-01	2.40E-02	4.44E-31	8.84E-07	1.78E-05	5.44E-06	4.16E-05	2.12E-13
BATCH-1263	5/10/34	125	13.0	0.24	5.35E-05	1.64E-05	7.73E-04	2.00E-03	1.00E-03	1.68E-01	2.00E-02	5.46E-01	2.40E-02	4.43E-31	8.83E-07	1.78E-05	5.44E-06	4.15E-05	2.12E-13
BATCH-1264	5/18/34	36	3.7	0.24	1.56E-04	2.90E-06	1.34E-04	4.18E-04	1.59E-04	3.60E-02	4.00E-03	6.50E-02	5.00E-03	7.33E-32	1.69E-07	2.13E-06	1.29E-06	1.19E-05	7.50E-14
BATCH-1265	5/22/34	44	4.6	0.24	6.31E-06	4.70E-06	2.13E-04	6.24E-04	3.43E-04	5.00E-02	6.00E-03	1.37E-01	7.00E-03	1.29E-31	2.51E-07	4.49E-06	1.65E-06	1.23E-05	7.44E-14
BATCH-1266	5/23/34	45	4.7	0.24	1.70E-05	5.20E-06	2.45E-04	6.94E-04	4.03E-04	5.30E-02	6.00E-03	1.73E-01	8.00E-03	1.41E-31	2.80E-07	5.65E-06	1.73E-06	1.32E-05	6.75E-14
BATCH-1267	5/26/34	45	4.7	0.24	1.70E-05	5.20E-06	2.45E-04	6.94E-04	4.03E-04	5.30E-02	6.00E-03	1.73E-01	8.00E-03	1.40E-31	2.80E-07	5.64E-06	1.73E-06	1.32E-05	6.74E-14
BATCH-1268	5/28/34	13	1.4	0.24	1.50E-06	6.87E-07	3.18E-05	9.91E-05	8.00E-04	5.30E-02	1.00E-03	1.50E-02	1.00E-03	1.74E-32	4.01E-08	5.06E-07	3.06E-07	2.83E-06	1.78E-14
BATCH-1269	5/29/34	45	4.7	0.24	1.69E-05	5.20E-06	2.45E-04	6.93E-04	4.03E-04	5.30E-02	6.00E-03	1.73E-01	8.00E-03	1.40E-31	2.80E-07	5.64E-06	1.72E-06	1.31E-05	6.72E-14
BATCH-1270	5/31/34	15	1.6	0.24	3.33E-06	1.09E-06	4.95E-05	1.45E-04	7.98E-05	1.20E-02	1.00E-03	3.20E-02	2.00E-03	3.00E-32	5.83E-08	1.05E-06	3.83E-07	2.86E-06	1.73E-14
BATCH-1271	6/2/34	16	1.7	0.24	4.06E-06	1.25E-06	5.87E-05	1.66E-04	9.64E-05	1.30E-02	2.00E-03	4.10E-02	2.00E-03	3.36E-32	6.70E-08	1.35E-06	4.14E-07	3.15E-06	1.61E-14
BATCH-1272	6/3/34	16	1.7	0.24	4.06E-06	1.24E-06	5.86E-05	1.66E-04	9.63E-05	1.30E-02	2.00E-03	4.10E-02	2.00E-03	3.36E-32	6.69E-08	1.35E-06	4.13E-07	3.15E-06	1.61E-14
BATCH-1273	6/4/34	16	1.7	0.24	4.05E-06	1.24E-06	5.85E-05	1.66E-04	9.62E-05	1.30E-02	2.00E-03	4.10E-02	2.00E-03	3.35E-32	6.68E-08	1.35E-06	4.12E-07	3.14E-06	1.61E-14

Appendix A Nominal ILAW Inventory

TWRS&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4-	Al+3	As+5	B+3	Ba+2	Be+2	Bi+3	Ca+2	Cd+2	Ca+3	Cl-	CO3-2	Cr(OH)4-	Cr(TOTAL)	Cs+
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1225	9/7/33	36	3.8	0.24	2.77E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	1.16E-96	2.60E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	3.86E-08	1.26E+00	4.19E-08
BATCH-1226	9/9/33	149	15.6	0.24	6.35E+02	0.00E+00	2.91E-15	2.82E-11	2.75E-15	3.93E-87	1.30E-01	1.21E+00	2.27E-14	3.00E-03	6.39E+00	0.00E+00	9.17E+00	0.00E+00	7.21E-08
BATCH-1227	9/11/33	129	13.4	0.24	5.43E+02	0.00E+00	1.41E-16	3.64E-11	7.26E-16	5.02E-87	1.68E-01	1.09E+00	5.65E-15	4.00E-03	4.58E+00	0.00E+00	6.46E+00	0.00E+00	3.94E-08
BATCH-1228	9/25/33	129	13.4	0.24	5.43E+02	0.00E+00	1.41E-16	3.64E-11	7.25E-16	1.30E-97	1.68E-01	1.09E+00	5.64E-15	4.00E-03	4.57E+00	0.00E+00	6.46E+00	0.00E+00	3.93E-08
BATCH-1229	9/25/33	129	13.4	0.24	5.42E+02	0.00E+00	1.40E-16	3.64E-11	7.24E-16	2.84E-93	1.68E-01	1.09E+00	5.64E-15	4.00E-03	4.56E+00	0.00E+00	6.45E+00	0.00E+00	3.93E-08
BATCH-1230	10/8/33	128	13.4	0.24	5.42E+02	0.00E+00	1.40E-16	3.63E-11	7.23E-16	2.08E-88	1.68E-01	1.09E+00	5.62E-15	4.00E-03	4.56E+00	0.00E+00	6.45E+00	0.00E+00	3.92E-08
BATCH-1231	10/8/33	128	13.4	0.24	5.41E+02	0.00E+00	1.40E-16	3.63E-11	7.20E-16	6.40E-94	1.68E-01	1.09E+00	5.61E-15	4.00E-03	4.54E+00	0.00E+00	6.44E+00	0.00E+00	3.91E-08
BATCH-1232	10/22/33	39	4.0	0.24	1.44E+02	0.00E+00	6.60E-16	6.41E-12	6.23E-16	8.91E-88	3.00E-02	2.75E-01	5.15E-15	5.67E-04	1.45E+00	0.00E+00	2.08E+00	0.00E+00	1.63E-08
BATCH-1233	10/22/33	45	4.6	0.24	1.65E+02	0.00E+00	4.28E-17	1.11E-11	2.21E-16	1.53E-87	5.10E-02	3.32E-01	1.72E-15	1.00E-03	1.39E+00	0.00E+00	1.96E+00	0.00E+00	1.20E-08
BATCH-1234	10/26/33	45	4.6	0.24	1.65E+02	0.00E+00	4.28E-17	1.11E-11	2.20E-16	3.96E-98	5.10E-02	3.31E-01	1.72E-15	1.00E-03	1.39E+00	0.00E+00	1.96E+00	0.00E+00	1.19E-08
BATCH-1235	10/27/33	45	4.6	0.24	1.65E+02	0.00E+00	4.27E-17	1.11E-11	2.20E-16	8.63E-94	5.10E-02	3.31E-01	1.71E-15	1.00E-03	1.39E+00	0.00E+00	1.96E+00	0.00E+00	1.19E-08
BATCH-1236	10/31/33	45	4.6	0.24	1.65E+02	0.00E+00	4.26E-17	1.11E-11	2.20E-16	6.32E-89	5.10E-02	3.31E-01	1.71E-15	1.00E-03	1.39E+00	0.00E+00	1.96E+00	0.00E+00	1.19E-08
BATCH-1237	10/31/33	44	4.6	0.24	1.65E+02	0.00E+00	4.25E-17	1.10E-11	2.19E-16	1.95E-94	5.10E-02	3.30E-01	1.71E-15	1.00E-03	1.38E+00	0.00E+00	1.96E+00	0.00E+00	1.19E-08
BATCH-1238	11/5/33	14	1.5	0.24	3.40E+01	0.00E+00	1.56E-16	1.52E-12	1.47E-16	2.11E-88	7.00E-03	6.50E-02	1.22E-15	1.34E-04	3.43E-01	0.00E+00	4.92E-01	0.00E+00	3.86E-09
BATCH-1239	11/5/33	16	1.6	0.24	3.87E+01	0.00E+00	1.00E-17	2.60E-12	5.17E-17	3.58E-88	1.20E-02	7.80E-02	4.03E-16	2.70E-04	3.26E-01	0.00E+00	4.60E-01	0.00E+00	2.81E-09
BATCH-1240	11/6/33	16	1.6	0.24	3.87E+01	0.00E+00	1.00E-17	2.59E-12	5.17E-17	9.27E-99	1.20E-02	7.80E-02	4.02E-16	2.69E-04	3.26E-01	0.00E+00	4.60E-01	0.00E+00	2.80E-09
BATCH-1241	11/7/33	16	1.6	0.24	3.86E+01	0.00E+00	1.00E-17	2.59E-12	5.16E-17	2.02E-94	1.20E-02	7.80E-02	4.01E-16	2.68E-04	3.25E-01	0.00E+00	4.60E-01	0.00E+00	2.80E-09
BATCH-1242	11/8/33	16	1.6	0.24	3.86E+01	0.00E+00	9.98E-18	2.59E-12	5.14E-17	1.48E-89	1.20E-02	7.70E-02	4.01E-16	2.68E-04	3.24E-01	0.00E+00	4.59E-01	0.00E+00	2.79E-09
BATCH-1243	11/9/33	16	1.6	0.24	3.85E+01	0.00E+00	9.94E-18	2.58E-12	5.12E-17	4.56E-95	1.20E-02	7.70E-02	3.99E-16	2.67E-04	3.23E-01	0.00E+00	4.58E-01	0.00E+00	2.78E-09
BATCH-1244	11/10/33	53	5.5	0.24	4.00E-03	6.73E+00	2.28E-16	1.85E-10	7.94E-16	2.34E-92	3.79E-01	1.11E+00	7.91E-15	9.00E-03	9.06E+00	0.00E+00	5.47E-05	1.83E+00	6.08E-08
BATCH-1245	11/16/33	37	3.8	0.24	1.97E-06	4.63E+00	1.57E-16	1.27E-10	5.47E-16	1.22E-95	2.61E-01	7.60E-01	5.44E-15	6.00E-03	6.23E+00	0.00E+00	2.84E-08	1.26E+00	4.19E-08
BATCH-1246	11/20/33	108	11.2	0.24	3.40E+02	0.00E+00	9.87E-17	7.98E-11	3.43E-16	6.00E-93	3.03E-01	1.11E+00	3.42E-15	4.00E-03	3.91E+00	0.00E+00	6.83E+00	0.00E+00	2.63E-08
BATCH-1247	12/2/33	48	5.0	0.24	1.36E+02	0.00E+00	3.94E-17	3.18E-11	1.37E-16	2.39E-93	1.21E-01	4.44E-01	1.36E-15	2.00E-03	1.56E+00	0.00E+00	2.72E+00	0.00E+00	1.05E-08
BATCH-1248	12/7/33	18	1.9	0.24	3.73E+01	0.00E+00	1.08E-17	8.75E-12	3.76E-17	6.58E-94	3.30E-02	1.22E-01	3.75E-16	4.15E-04	4.29E-01	0.00E+00	7.49E-01	0.00E+00	2.88E-09
BATCH-1249	3/25/34	34	3.6	0.24	3.00E-03	3.15E+01	1.46E-12	2.12E-10	6.88E-13	2.43E-92	2.20E-02	2.04E-01	4.17E-13	1.00E-03	1.21E+01	0.00E+00	3.12E-05	9.86E-01	1.16E-06
BATCH-1250	3/26/34	34	3.5	0.24	4.00E-03	3.36E+01	1.57E-12	2.18E-10	7.43E-13	1.06E-102	1.00E-03	1.56E-01	4.50E-13	5.98E-04	1.25E+01	0.00E+00	5.24E-05	9.57E-01	1.25E-06
BATCH-1251	3/29/34	34	3.5	0.24	4.00E-03	3.36E+01	1.57E-12	2.18E-10	7.42E-13	2.30E-98	1.00E-03	1.56E-01	4.49E-13	5.98E-04	1.25E+01	0.00E+00	5.24E-05	9.57E-01	1.25E-06
BATCH-1252	3/30/34	34	3.5	0.24	4.00E-03	3.36E+01	1.57E-12	2.18E-10	7.42E-13	1.68E-93	1.00E-03	1.55E-01	4.49E-13	5.98E-04	1.25E+01	0.00E+00	5.23E-05	9.56E-01	1.25E-06
BATCH-1253	4/1/34	34	3.5	0.24	4.00E-03	3.35E+01	1.57E-12	2.18E-10	7.41E-13	5.18E-99	1.00E-03	1.55E-01	4.49E-13	5.97E-04	1.25E+01	0.00E+00	5.21E-05	9.55E-01	1.25E-06
BATCH-1254	4/2/34	23	2.4	0.24	1.39E-06	2.25E+01	1.06E-12	1.47E-10	4.98E-13	1.29E-95	7.61E-04	1.04E-01	3.02E-13	4.02E-04	8.37E+00	0.00E+00	1.66E-08	6.42E-01	8.38E-07
BATCH-1255	4/5/34	46	4.8	0.24	1.37E-06	3.46E+00	7.41E-14	1.34E-11	3.49E-14	3.29E-106	9.50E-02	3.62E+00	2.31E-14	5.84E-04	7.12E+00	0.00E+00	1.63E-08	6.61E-01	1.20E-07
BATCH-1256	4/5/34	49	5.1	0.24	2.29E-06	2.12E+00	2.68E-15	3.83E-12	1.14E-15	1.20E-101	1.04E-01	3.98E+00	2.86E-15	6.13E-04	7.21E+00	0.00E+00	2.73E-08	6.79E-01	6.98E-08
BATCH-1257	4/10/34	49	5.1	0.24	2.29E-06	2.13E+00	2.68E-15	3.83E-12	1.14E-15	8.77E-97	1.04E-01	3.98E+00	2.86E-15	6.13E-04	7.21E+00	0.00E+00	2.72E-08	6.79E-01	6.98E-08
BATCH-1258	4/10/34	151	15.7	0.24	7.82E+02	0.00E+00	7.62E-13	1.17E-10	3.60E-13	2.61E-92	6.90E-02	8.96E-01	2.18E-13	8.03E-04	6.57E+00	0.00E+00	1.06E+01	0.00E+00	6.08E-07
BATCH-1259	4/15/34	49	5.1	0.24	2.28E-06	2.13E+00	2.68E-15	3.83E-12	1.14E-15	2.70E-102	1.04E-01	3.98E+00	2.86E-15	6.13E-04	7.21E+00	0.00E+00	2.71E-08	6.79E-01	6.98E-08
BATCH-1260	4/21/34	130	13.5	0.24	5.09E+02	0.00E+00	5.30E-13	7.44E-11	2.50E-13	3.09E-103	9.30E-02	1.86E+00	1.52E-13	3.48E-04	5.92E+00	0.00E+00	9.48E+00	0.00E+00	4.37E-07
BATCH-1261	4/26/34	125	13.0	0.24	4.68E+02	0.00E+00	4.50E-13	6.34E-11	2.12E-13	6.58E-99	1.01E-01	2.03E+00	1.29E-13	3.45E-04	5.61E+00	0.00E+00	9.22E+00	0.00E+00	3.77E-07
BATCH-1262	5/4/34	125	13.0	0.24	4.68E+02	0.00E+00	4.49E-13	6.33E-11	2.12E-13	4.81E-94	1.01E-01	2.03E+00	1.29E-13	3.44E-04	5.60E+00	0.00E+00	9.22E+00	0.00E+00	3.76E-07
BATCH-1263	5/10/34	125	13.0	0.24	4.67E+02	0.00E+00	4.48E-13	6.31E-11	2.11E-13	1.48E-99	1.01E-01	2.03E+00	1.29E-13	3.44E-04	5.59E+00	0.00E+00	9.21E+00	0.00E+00	3.75E-07
BATCH-1264	5/18/34	36	3.7	0.24	1.62E+02	0.00E+00	1.58E-13	2.42E-11	7.47E-14	5.40E-93	1.40E-02	1.86E-01	4.53E-14	1.67E-04	1.36E+00	0.00E+00	2.20E+00	0.00E+00	1.26E-07
BATCH-1265	5/22/34	44	4.6	0.24	1.51E+02	0.00E+00	1.57E-13	2.20E-11	7.41E-14	9.15E-104	2.80E-02	5.50E-01	4.50E-14	1.03E-04	1.75E+00	0.00E+00	2.81E+00	0.00E+00	1.29E-07
BATCH-1266	5/23/34	45	4.7	0.24	1.48E+02	0.00E+00	1.42E-13	2.01E-11	6.72E-14	2.08E-99	3.20E-02	6.43E-01	4.09E-14	1.09E-04	1.77E+00	0.00E+00	2.92E+00	0.00E+00	1.19E-07
BATCH-1267	5/26/34	45	4.7	0.24	1.48E+02	0.00E+00	1.42E-13	2.00E-11	6.71E-14	1.52E-94	3.20E-02	6.43E-01	4.08E-14	1.09E-04	1.77E+00	0.00E+00	2.92E+00	0.00E+00	1.19E-07
BATCH-1268	5/28/34	13	1.4	0.24	3.85E+01	0.00E+00	3.75E-14	5.73E-12	1.77E-14	1.28E-93	3.00E-03	4.40E-02	1.07E-14	3.95E-05	3.23E-01	0.00E+00	5.22E-01	0.00E+00	2.99E-08
BATCH-1269	5/29/34	45	4.7	0.24	1.48E+02	0.00E+00	1.42E-13	2.00E-11	6.69E-14	4.68E-100	3.20E-02	6.42E-01	4.07E-14	1.09E-04	1.77E+00	0.00E+00	2.92E+00	0.00E+00	1.19E-07
BATCH-1270	5/31/34	15	1.6	0.24	3.51E+01	0.00E+00	3.65E-14	5.13E-12	1.72E-14	2.13E-104	6.00E-03	1.28E-01	1.05E-14	2.40E-05	4.08E-01	0.00E+00	6.53E-01	0.00E+00	3.01E-08
BATCH-1271	6/2/34	16	1.7	0.24	3.55E+01	0.00E+00	3.40E-14	4.80E-12	1.61E-14	4.98E-100	8.00E-03	1.54E-01	9.78E-15	2.61E-05	4.24E-01	0.00E+00	6.98E-01	0.00E+00	2.85E-08
BATCH-1272	6/3/34	16	1.7	0.24	3.54E+01	0.00E+00	3.40E-14	4.79E-12	1.61E-14	3.64E-95	8.00E-03	1.54E-01	9.76E-15	2.61E-05	4.24E-01	0.00E+00	6.98E-01	0.00E+00	2.85E-08
BATCH-1273	6/4/34	16	1.7	0.24	3.54E+01	0.00E+00	3.39E-14	4.78E-12	1.60E-14	1.12E-100	8.00E-03	1.54E-01	9.73E-15	2.60E-05	4.23E-01	0.00E+00	6.97E-01	0.00E+00	2.83E-08

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1225	9/7/33	36	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.63E+00	6.00E-03	6.32E-15	8.04E-15	2.78E-01	2.51E-15	6.23E+02	0.00E+00	3.00E-03
BATCH-1226	9/9/33	149	15.6	0.24	4.94E-16	9.27E+00	6.49E-01	0.00E+00	0.00E+00	2.00E-04	1.86E+00	1.00E-03	2.48E-14	8.59E-14	6.30E-02	2.00E-15	2.55E+03	0.00E+00	3.10E-02
BATCH-1227	9/11/33	129	13.4	0.24	3.93E-16	1.22E+01	7.77E-01	0.00E+00	0.00E+00	2.00E-04	1.82E+00	2.00E-03	7.40E-15	4.77E-15	8.20E-02	3.31E-15	2.20E+03	0.00E+00	3.40E-02
BATCH-1228	9/25/33	129	13.4	0.24	3.93E-16	1.21E+01	7.76E-01	0.00E+00	0.00E+00	2.00E-04	1.81E+00	2.00E-03	7.39E-15	4.77E-15	8.20E-02	3.31E-15	2.20E+03	0.00E+00	3.40E-02
BATCH-1229	9/25/33	129	13.4	0.24	3.92E-16	1.21E+01	7.76E-01	0.00E+00	0.00E+00	2.00E-04	1.81E+00	2.00E-03	7.38E-15	4.76E-15	8.20E-02	3.30E-15	2.20E+03	0.00E+00	3.40E-02
BATCH-1230	10/8/33	128	13.4	0.24	3.91E-16	1.21E+01	7.75E-01	0.00E+00	0.00E+00	2.00E-04	1.81E+00	2.00E-03	7.36E-15	4.75E-15	8.20E-02	3.30E-15	2.19E+03	0.00E+00	3.30E-02
BATCH-1231	10/8/33	128	13.4	0.24	3.90E-16	1.21E+01	7.74E-01	0.00E+00	0.00E+00	2.00E-04	1.81E+00	2.00E-03	7.34E-15	4.74E-15	8.20E-02	3.29E-15	2.19E+03	0.00E+00	3.30E-02
BATCH-1232	10/22/33	39	4.0	0.24	1.12E-16	2.10E+00	1.47E-01	0.00E+00	0.00E+00	4.91E-05	4.21E-01	2.90E-04	5.62E-15	1.95E-14	1.40E-02	4.52E-16	6.62E+02	0.00E+00	7.00E-03
BATCH-1233	10/22/33	45	4.6	0.24	1.19E-16	3.69E+00	2.36E-01	0.00E+00	0.00E+00	8.56E-05	5.52E-01	5.16E-04	2.25E-15	1.45E-15	2.50E-02	1.01E-15	7.61E+02	0.00E+00	1.00E-02
BATCH-1234	10/26/33	45	4.6	0.24	1.19E-16	3.69E+00	2.36E-01	0.00E+00	0.00E+00	8.56E-05	5.51E-01	5.16E-04	2.25E-15	1.45E-15	2.50E-02	1.01E-15	7.61E+02	0.00E+00	1.00E-02
BATCH-1235	10/27/33	45	4.6	0.24	1.19E-16	3.69E+00	2.36E-01	0.00E+00	0.00E+00	8.55E-05	5.51E-01	5.15E-04	2.24E-15	1.45E-15	2.50E-02	1.01E-15	7.61E+02	0.00E+00	1.00E-02
BATCH-1236	10/31/33	45	4.6	0.24	1.19E-16	3.68E+00	2.36E-01	0.00E+00	0.00E+00	8.53E-05	5.50E-01	5.15E-04	2.24E-15	1.45E-15	2.50E-02	1.00E-15	7.60E+02	0.00E+00	1.00E-02
BATCH-1237	10/31/33	44	4.6	0.24	1.19E-16	3.68E+00	2.36E-01	0.00E+00	0.00E+00	8.51E-05	5.50E-01	5.15E-04	2.23E-15	1.44E-15	2.50E-02	1.00E-15	7.60E+02	0.00E+00	1.00E-02
BATCH-1238	11/5/33	14	1.5	0.24	2.65E-17	4.97E-01	3.50E-02	0.00E+00	0.00E+00	1.16E-05	9.90E-02	6.87E-05	1.33E-15	4.61E-15	3.00E-03	1.07E-16	2.44E+02	0.00E+00	2.00E-03
BATCH-1239	11/5/33	16	1.6	0.24	2.80E-17	8.68E-01	5.50E-02	0.00E+00	0.00E+00	2.01E-05	1.29E-01	1.21E-04	5.27E-16	3.40E-16	6.00E-03	2.36E-16	2.68E+02	0.00E+00	2.00E-03
BATCH-1240	11/6/33	16	1.6	0.24	2.80E-17	8.65E-01	5.50E-02	0.00E+00	0.00E+00	2.01E-05	1.29E-01	1.21E-04	5.27E-16	3.40E-16	6.00E-03	2.36E-16	2.68E+02	0.00E+00	2.00E-03
BATCH-1241	11/7/33	16	1.6	0.24	2.79E-17	8.64E-01	5.50E-02	0.00E+00	0.00E+00	2.00E-05	1.29E-01	1.21E-04	5.26E-16	3.39E-16	6.00E-03	2.35E-16	2.67E+02	0.00E+00	2.00E-03
BATCH-1242	11/8/33	16	1.6	0.24	2.79E-17	8.62E-01	5.50E-02	0.00E+00	0.00E+00	2.00E-05	1.29E-01	1.21E-04	5.24E-16	3.38E-16	6.00E-03	2.35E-16	2.67E+02	0.00E+00	2.00E-03
BATCH-1243	11/9/33	16	1.6	0.24	2.77E-17	8.59E-01	5.50E-02	0.00E+00	0.00E+00	1.99E-05	1.29E-01	1.20E-04	5.22E-16	3.37E-16	6.00E-03	2.34E-16	2.67E+02	0.00E+00	2.00E-03
BATCH-1244	11/10/33	53	5.5	0.24	4.49E-16	3.51E+01	3.02E-01	0.00E+00	0.00E+00	6.00E-04	6.74E+00	8.00E-03	9.19E-15	1.17E-14	4.05E-01	3.64E-15	9.06E+02	0.00E+00	4.00E-03
BATCH-1245	11/16/33	37	3.8	0.24	3.09E-16	2.42E+01	2.08E-01	0.00E+00	0.00E+00	4.00E-04	4.64E+00	6.00E-03	6.32E-15	8.05E-15	2.78E-01	2.51E-15	6.24E+02	0.00E+00	3.00E-03
BATCH-1246	11/20/33	108	11.2	0.24	1.94E-16	1.52E+01	9.16E-01	0.00E+00	0.00E+00	2.00E-04	2.91E+00	4.00E-03	3.97E-15	5.06E-15	1.75E-01	1.57E-15	1.84E+03	0.00E+00	2.00E-03
BATCH-1247	12/2/33	48	5.0	0.24	7.73E-17	6.05E+00	3.65E-01	0.00E+00	0.00E+00	1.08E-04	1.16E+00	1.00E-03	1.58E-15	2.02E-15	7.00E-02	6.28E-16	8.16E+02	0.00E+00	6.99E-04
BATCH-1248	12/7/33	18	1.9	0.24	2.13E-17	1.67E+00	1.00E-01	0.00E+00	0.00E+00	2.98E-05	3.19E-01	3.91E-04	4.35E-16	5.54E-16	1.90E-02	1.73E-16	3.04E+02	0.00E+00	1.92E-04
BATCH-1249	3/25/34	34	3.6	0.24	5.93E-15	1.20E+01	5.30E-02	0.00E+00	0.00E+00	1.35E-04	4.12E+00	5.00E-03	4.74E-13	3.90E-11	1.19E-01	1.26E-13	5.85E+02	0.00E+00	3.00E-03
BATCH-1250	3/26/34	34	3.5	0.24	6.37E-15	1.09E+01	3.90E-02	0.00E+00	0.00E+00	1.09E-04	4.05E+00	5.00E-03	5.11E-13	4.21E-11	1.04E-01	1.36E-13	5.78E+02	0.00E+00	3.00E-03
BATCH-1251	3/29/34	34	3.5	0.24	6.37E-15	1.09E+01	3.90E-02	0.00E+00	0.00E+00	1.09E-04	4.05E+00	5.00E-03	5.10E-13	4.21E-11	1.04E-01	1.36E-13	5.78E+02	0.00E+00	3.00E-03
BATCH-1252	3/30/34	34	3.5	0.24	6.37E-15	1.09E+01	3.90E-02	0.00E+00	0.00E+00	1.09E-04	4.05E+00	5.00E-03	5.10E-13	4.21E-11	1.04E-01	1.36E-13	5.78E+02	0.00E+00	3.00E-03
BATCH-1253	4/1/34	34	3.5	0.24	6.36E-15	1.09E+01	3.90E-02	0.00E+00	0.00E+00	1.09E-04	4.05E+00	5.00E-03	5.10E-13	4.21E-11	1.04E-01	1.36E-13	5.78E+02	0.00E+00	3.00E-03
BATCH-1254	4/2/34	23	2.4	0.24	4.28E-15	7.29E+00	2.60E-02	0.00E+00	0.00E+00	7.32E-05	2.72E+00	3.00E-03	3.43E-13	2.83E-11	7.00E-02	9.13E-14	3.88E+02	0.00E+00	2.00E-03
BATCH-1255	4/5/34	46	4.8	0.24	2.96E-16	1.09E+01	3.01E-01	0.00E+00	0.00E+00	3.53E-05	2.77E+00	7.00E-03	3.26E-14	2.04E-12	5.90E-02	6.27E-15	7.84E+02	0.00E+00	5.00E-03
BATCH-1256	4/5/34	49	5.1	0.24	6.40E-18	1.15E+01	3.30E-01	0.00E+00	0.00E+00	3.33E-05	2.85E+00	7.00E-03	1.03E-14	1.27E-13	6.00E-02	7.08E-17	8.33E+02	0.00E+00	5.00E-03
BATCH-1257	4/10/34	49	5.1	0.24	6.40E-18	1.15E+01	3.30E-01	0.00E+00	0.00E+00	3.33E-05	2.85E+00	7.00E-03	1.03E-14	1.27E-13	6.00E-02	7.08E-17	8.33E+02	0.00E+00	5.00E-03
BATCH-1258	4/10/34	151	15.7	0.24	3.11E-15	7.32E+00	2.20E-01	0.00E+00	0.00E+00	8.96E-05	2.36E+00	3.00E-03	2.48E-13	2.04E-11	7.40E-02	6.61E-14	2.58E+03	0.00E+00	2.00E-03
BATCH-1259	4/15/34	49	5.1	0.24	6.39E-18	1.15E+01	3.30E-01	0.00E+00	0.00E+00	3.34E-05	2.85E+00	7.00E-03	1.03E-14	1.27E-13	6.00E-02	7.07E-17	8.33E+02	0.00E+00	5.00E-03
BATCH-1260	4/21/34	130	13.5	0.24	2.15E-15	6.40E+00	7.49E-01	0.00E+00	0.00E+00	4.47E-05	2.05E+00	3.00E-03	1.75E-13	1.42E-11	4.90E-02	4.59E-14	2.22E+03	0.00E+00	2.00E-03
BATCH-1261	4/26/34	125	13.0	0.24	1.82E-15	6.35E+00	8.16E-01	0.00E+00	0.00E+00	4.05E-05	1.97E+00	3.00E-03	1.49E-13	1.21E-11	4.70E-02	3.89E-14	2.13E+03	0.00E+00	2.00E-03
BATCH-1262	5/4/34	125	13.0	0.24	1.82E-15	6.34E+00	8.16E-01	0.00E+00	0.00E+00	4.05E-05	1.96E+00	3.00E-03	1.49E-13	1.21E-11	4.70E-02	3.88E-14	2.13E+03	0.00E+00	2.00E-03
BATCH-1263	5/10/34	125	13.0	0.24	1.81E-15	6.33E+00	8.15E-01	0.00E+00	0.00E+00	4.04E-05	1.96E+00	3.00E-03	1.48E-13	1.20E-11	4.70E-02	3.87E-14	2.13E+03	0.00E+00	2.00E-03
BATCH-1264	5/18/34	36	3.7	0.24	6.46E-16	1.52E+00	4.60E-02	0.00E+00	0.00E+00	1.86E-05	4.89E-01	6.04E-04	5.15E-14	4.24E-12	1.50E-02	1.37E-14	6.10E+02	0.00E+00	3.43E-04
BATCH-1265	5/22/34	44	4.6	0.24	6.36E-16	1.89E+00	2.22E-01	0.00E+00	0.00E+00	1.32E-05	6.05E-01	9.95E-04	5.17E-14	4.21E-12	1.50E-02	1.36E-14	7.50E+02	0.00E+00	6.68E-04
BATCH-1266	5/23/34	45	4.7	0.24	5.76E-16	2.01E+00	2.58E-01	0.00E+00	0.00E+00	1.28E-05	6.22E-01	1.00E-03	4.71E-14	3.82E-12	1.50E-02	1.23E-14	7.67E+02	0.00E+00	7.42E-04
BATCH-1267	5/26/34	45	4.7	0.24	5.76E-16	2.01E+00	2.58E-01	0.00E+00	0.00E+00	1.28E-05	6.21E-01	1.00E-03	4.70E-14	3.81E-12	1.50E-02	1.23E-14	7.67E+02	0.00E+00	7.42E-04
BATCH-1268	5/28/34	13	1.4	0.24	1.53E-16	3.60E-01	1.10E-02	0.00E+00	0.00E+00	4.41E-06	1.16E-01	1.43E-04	1.22E-14	1.00E-12	4.00E-03	3.25E-15	2.23E+02	0.00E+00	8.13E-05
BATCH-1269	5/29/34	45	4.7	0.24	5.74E-16	2.01E+00	2.58E-01	0.00E+00	0.00E+00	1.28E-05	6.20E-01	1.00E-03	4.69E-14	3.80E-12	1.50E-02	1.23E-14	7.66E+02	0.00E+00	7.41E-04
BATCH-1270	5/31/34	15	1.6	0.24	1.48E-16	4.41E-01	5.20E-02	0.00E+00	0.00E+00	3.08E-06	1.41E-01	2.32E-04	1.20E-14	9.14E-13	4.00E-03	3.16E-15	2.64E+02	0.00E+00	1.55E-04
BATCH-1271	6/2/34	16	1.7	0.24	1.38E-16	4.81E-01	6.20E-02	0.00E+00	0.00E+00	3.07E-06	1.49E-01	2.59E-04	1.13E-14	9.12E-13	4.00E-03	2.94E-15	2.71E+02	0.00E+00	1.78E-04
BATCH-1272	6/3/34	16	1.7	0.24	1.38E-16	4.80E-01	6.20E-02	0.00E+00	0.00E+00	3.07E-06	1.49E-01	2.59E-04	1.12E-14	9.12E-13	4.00E-03	2.94E-15	2.71E+02	0.00E+00	1.77E-04
BATCH-1273	6/4/34	16	1.7	0.24	1.37E-16	4.79E-01	6.20E-02	0.00E+00	0.00E+00	3.06E-06	1.48E-01	2.58E-04	1.12E-14	9.09E-13	4.00E-03	2.93E-15	2.71E+02	0.00E+00	1.77E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-		NO3-		OH-(BOUN		OH-		Pb+2		PO4-3		Se+6		Si+4		SO4-2		Sr+2		Ti+4		TOC		U(TOTAL)		Zn+2		Zr+4	
					kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol		kg-mol	
Fraction Remaining After Volatization Losses					0.00		0.00		0.00		0.00		1.00		1.00		0.90		1.00		0.90		1.00		1.00		0.00		1.00		1.00		1.00
BATCH-1225	9/7/33	36	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.50E-02	4.29E+01	4.29E+01	9.69E-18	9.69E-18	4.71E+00	4.71E+00	1.19E+01	1.19E+01	9.00E-03	9.00E-03	2.55E-16	2.55E-16	0.00E+00	0.00E+00	2.55E-05	2.55E-05	1.86E-12	2.00E-03
BATCH-1226	9/9/33	149	15.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	9.00E-03	6.69E+01	6.69E+01	3.19E-16	3.19E-16	3.36E+01	3.36E+01	6.02E+00	6.02E+00	9.00E-03	9.00E-03	2.05E-16	2.05E-16	0.00E+00	0.00E+00	1.12E-04	1.12E-04	4.16E-12	1.00E-03
BATCH-1227	9/11/33	129	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.00E-02	8.81E+01	8.81E+01	8.97E-18	8.97E-18	4.21E+01	4.21E+01	6.74E+00	6.74E+00	6.00E-03	6.00E-03	3.46E-16	3.46E-16	0.00E+00	0.00E+00	4.43E-05	4.43E-05	6.37E-13	1.00E-03
BATCH-1228	9/25/33	129	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.00E-02	8.81E+01	8.81E+01	8.96E-18	8.96E-18	4.21E+01	4.21E+01	6.73E+00	6.73E+00	6.00E-03	6.00E-03	3.46E-16	3.46E-16	0.00E+00	0.00E+00	4.43E-05	4.43E-05	6.37E-13	1.00E-03
BATCH-1229	9/25/33	129	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.00E-02	8.80E+01	8.95E+01	8.95E-18	8.93E-18	4.20E+01	4.20E+01	6.72E+00	6.71E+00	6.00E-03	6.00E-03	3.45E-16	3.45E-16	0.00E+00	0.00E+00	4.42E-05	4.41E-05	6.36E-13	1.00E-03
BATCH-1230	10/6/33	128	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.00E-02	8.79E+01	8.78E+01	8.90E-18	8.90E-18	4.20E+01	4.20E+01	6.71E+00	6.70E+00	6.00E-03	6.00E-03	3.45E-16	3.43E-16	0.00E+00	0.00E+00	4.41E-05	4.40E-05	6.35E-13	1.00E-03
BATCH-1231	10/6/33	128	13.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.00E-02	8.78E+01	8.78E+01	8.90E-18	8.90E-18	4.20E+01	4.20E+01	6.70E+00	6.70E+00	6.00E-03	6.00E-03	3.43E-16	3.43E-16	0.00E+00	0.00E+00	4.40E-05	4.40E-05	6.34E-13	1.00E-03
BATCH-1232	10/22/33	39	4.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	1.52E+01	1.52E+01	7.24E-17	7.24E-17	7.63E+00	7.63E+00	1.37E+00	1.37E+00	2.00E-03	2.00E-03	4.65E-17	4.65E-17	0.00E+00	0.00E+00	9.44E-06	2.54E-05	9.44E-13	2.76E-04
BATCH-1233	10/22/33	45	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.68E+01	2.68E+01	2.73E-18	2.73E-18	1.28E+01	1.28E+01	2.05E+00	2.05E+00	2.00E-03	2.00E-03	1.05E-16	1.05E-16	0.00E+00	0.00E+00	1.35E-05	1.35E-05	1.94E-13	4.39E-04
BATCH-1234	10/26/33	45	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.68E+01	2.68E+01	2.72E-18	2.72E-18	1.28E+01	1.28E+01	2.04E+00	2.04E+00	2.00E-03	2.00E-03	1.05E-16	1.05E-16	0.00E+00	0.00E+00	1.35E-05	1.34E-05	1.94E-13	4.39E-04
BATCH-1235	10/27/33	45	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.67E+01	2.67E+01	2.72E-18	2.72E-18	1.28E+01	1.28E+01	2.04E+00	2.04E+00	2.00E-03	2.00E-03	1.05E-16	1.05E-16	0.00E+00	0.00E+00	1.34E-05	1.34E-05	1.93E-13	4.38E-04
BATCH-1236	10/31/33	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	2.67E+01	2.67E+01	2.71E-18	2.71E-18	1.28E+01	1.28E+01	2.04E+00	2.04E+00	2.00E-03	2.00E-03	1.05E-16	1.05E-16	0.00E+00	0.00E+00	1.34E-05	1.34E-05	1.93E-13	4.38E-04
BATCH-1237	10/31/33	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-04	4.58E-04	3.59E+00	3.59E+00	1.71E-17	1.71E-17	1.80E+00	1.80E+00	3.23E-01	3.23E-01	4.83E-04	4.83E-04	1.10E-17	1.10E-17	0.00E+00	0.00E+00	6.02E-06	6.02E-06	2.23E-13	6.53E-05
BATCH-1238	11/5/33	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.94E-04	6.94E-04	6.28E+00	6.28E+00	6.40E-19	6.40E-19	3.00E+00	3.00E+00	4.81E-01	4.81E-01	4.05E-04	4.05E-04	2.47E-17	2.47E-17	0.00E+00	0.00E+00	3.16E-06	4.54E-14	1.03E-04
BATCH-1239	11/5/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.94E-04	6.93E-04	6.28E+00	6.27E+00	6.38E-19	6.37E-19	3.00E+00	2.99E+00	4.80E-01	4.79E-01	4.04E-04	4.04E-04	2.46E-17	2.46E-17	0.00E+00	0.00E+00	3.15E-06	3.15E-06	4.54E-14	1.03E-04
BATCH-1240	11/6/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.92E-04	6.92E-04	6.27E+00	6.27E+00	6.37E-19	6.37E-19	2.99E+00	2.99E+00	4.79E-01	4.79E-01	4.04E-04	4.04E-04	2.46E-17	2.46E-17	0.00E+00	0.00E+00	3.15E-06	3.15E-06	4.53E-14	1.03E-04
BATCH-1241	11/7/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-04	6.90E-04	6.26E+00	6.26E+00	6.36E-19	6.36E-19	2.99E+00	2.99E+00	4.78E-01	4.78E-01	4.03E-04	4.03E-04	2.45E-17	2.45E-17	0.00E+00	0.00E+00	3.14E-06	3.14E-06	4.52E-14	1.02E-04
BATCH-1242	11/8/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.88E-04	6.88E-04	6.25E+00	6.25E+00	6.33E-19	6.33E-19	2.99E+00	2.99E+00	4.76E-01	4.76E-01	4.01E-04	4.01E-04	2.44E-17	2.44E-17	0.00E+00	0.00E+00	3.13E-06	3.13E-06	4.51E-14	1.02E-04
BATCH-1243	11/9/33	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-02	2.10E-02	6.24E+01	6.24E+01	1.41E-17	1.41E-17	6.86E+00	6.86E+00	1.73E+01	1.73E+01	1.20E-02	1.20E-02	3.71E-16	3.71E-16	0.00E+00	0.00E+00	3.70E-05	3.70E-05	2.71E-12	3.00E-03
BATCH-1244	11/10/33	53	5.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.50E-02	4.29E+01	4.29E+01	9.69E-18	9.69E-18	4.72E+00	4.72E+00	1.19E+01	1.19E+01	9.00E-03	9.00E-03	2.55E-16	2.55E-16	0.00E+00	0.00E+00	2.54E-05	2.54E-05	1.86E-12	2.00E-03
BATCH-1245	11/16/33	37	3.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	9.00E-03	1.07E+02	6.09E-03	5.45E+01	8.08E+00	5.00E-03	2.19E-05												
BATCH-1246	11/20/33	108	11.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-03	4.00E-03	4.26E+01	4.26E+01	2.43E-18	2.17E+01	3.22E+00	2.00E-03	6.39E-17	8.72E-06	4.67E-13	5.63E-04								
BATCH-1247	12/2/33	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.00E-03	1.17E+01	6.68E-19	5.97E+00	8.87E-01	5.87E-04	1.76E-17	0.00E+00	2.40E-06	1.28E-13	1.55E-04								
BATCH-1248	12/7/33	18	1.9	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	7.04E+00	5.54E-15	4.15E+00	5.21E+00	3.00E-03	1.25E-15	0.00E+00	2.39E-06	1.73E-11	2.00E-03								
BATCH-1249	3/25/34	34	3.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	3.92E+00	5.98E-15	4.08E+00	4.61E+00	2.00E-03	1.33E-15	0.00E+00	3.99E-07	1.86E-11	2.00E-03								
BATCH-1250	3/26/34	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	3.92E+00	5.98E-15	4.08E+00	4.61E+00	2.00E-03	1.33E-15	0.00E+00	3.99E-07	1.86E-11	2.00E-03								
BATCH-1251	3/29/34	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	3.92E+00	5.97E-15	4.08E+00	4.60E+00	2.00E-03	1.33E-15	0.00E+00	3.99E-07	1.85E-11	2.00E-03								
BATCH-1252	3/30/34	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	3.92E+00	5.97E-15	4.07E+00	4.60E+00	2.00E-03	1.32E-15	0.00E+00	3.98E-07	1.85E-11	2.00E-03								
BATCH-1253	4/1/34	34	3.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	1.00E-03	2.63E+00	4.01E-15	2.74E+00	3.09E+00	2.00E-03	8.90E-16	0.00E+00	2.69E-07	1.25E-11	1.00E-03								
BATCH-1254	4/2/34	23	2.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	7.00E-03	3.71E+01	2.75E-16	3.45E+00	1.33E+01	4.00E-03	6.11E-17	0.00E+00	9.16E-05	9.16E-13	7.75E-04								
BATCH-1255	4/5/34	46	4.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	7.00E-03	4.07E+01	3.11E-18	3.59E+00	1.44E+01	5.00E-03	6.90E-19	0.00E+00	1.79E-05	7.75E-14	7.46E-04								
BATCH-1256	4/5/34	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	7.00E-03	4.07E+01	3.11E-18	3.59E+00	1.44E+01	5.00E-03	6.90E-19	0.00E+00	1.79E-05	7.75E-14	7.46E-04								
BATCH-1257	4/10/34	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	7.00E-03	4.07E+01	3.11E-18	3.59E+00	1.44E+01	5.00E-03	6.90E-19	0.00E+00	1.79E-05	7.75E-14	7.46E-04								
BATCH-1258	4/10/34	151	15.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	1.64E+01	2.90E-15	4.04E+01	3.34E+00	2.00E-03	6.64E-16	0.00E+00	5.92E-05	9.15E-12	1.00E-03								
BATCH-1259	4/15/34	49	5.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	7.00E-03	4.07E+01	3.11E-18	3.59E+00	1.44E+01	5.00E-03	6.89E-19	0.00E+00	1.79E-05	7.75E-14	7.47E-04								
BATCH-1260	4/21/34	130	13.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.00E-03	1.01E+02	2.01E-15	3.71E+01	5.27E+00	2.00E-03	4.47E-16	0.00E+00	4.18E-05	6.27E-12	8.94E-04								
BATCH-1261	4/26/34	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	1.12E+02	1.71E-15	3.65E+01	5.71E+00	2.00E-03	3.79E-16	0.00E+00	3.95E-05	5.32E-12	8.19E-04								
BATCH-1262	5/4/34	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	1.12E+02	1.71E-15	3.64E+01	5.70E+00	2.00E-03	3.78E-16	0.00E+00	3.95E-05	5.31E-12	8.18E-04								
BATCH-1263	5/10/34	125	13.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	3.00E-03	1.12E+02	1.70E-15	3.64E+01	5.70E+00	2.00E-03	3.77E-16	0.00E+00	3.95E-05	5.30E-12	8.16E-04								
BATCH-1264	5/18/34	36	3.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.29E-04	4.29E-04	3.41E+00	6.01E-16	8.39E+00	6.94E-01	3.93E-04	1.38E-16	0.00E+00	1.23E-05	2.53E-04	2.53E-04								
BATCH-1265	5/22/34	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.91E-04	6.91E-04	3.00E+01	5.96E-16	1.10E+01	1.56E+00	5.62E-04	1.32E-16	0.00E+00	1.24E-05	1.86E-12	2.65E-04								
BATCH-1266	5/23/34	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E-04	3.54E-01	5.41E-16	1.15E+01	1.81E+00	6.26E-04	1.20E-16	0.00E+00	1.25E-05	1.68E-12	2.59E-04									
BATCH-1267	5/26/34	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.16E-04	3.54E+01	5.40E-16	1.15E+01	1.81E+00	6.26E-04	1.20E-16	0.00E+00	1.25E-05	1.68E-12	2.59E-04									
BATCH-1268	5/28/34	13	1.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-04	8.07E-01	1.42E-16	1.99E+00	1.65E-01	9.31E-05	3.27E-17	0.00E+00	2.91E-06	4.50E-13	6.01E-05									
BATCH-1269	5/29/34	45	4.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.16E-04	3.54E-01	5.38E-16	1.15E+01	1.80E+00	6.25E-04	1.19E-16	0.00E+00	1.25E-05	1.68E-12	2.58E-04									
BATCH-1270	5/31/34	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-04	6.98E-02	1.39E-16	2.56E+00	3.64E-01	1.31E-04	3.08E-17	0.00E+00	2.88E-06	4.32E-13	6.16E-05									
BATCH-1271	6/2/34	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-04	8.47E+00	1.29E-16	2.76E+00	4.32E-01	1.50E-04	2.87E-17	0.00E+00	2.99E-06	4.03E-13	6.20E-05									
BATCH-1272	6/3/34	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-04	8.46E+00	1.29E-16	2.76E+00	4.32E-01	1.50E-04	2.86E-17	0.00E+00	2.99E-06	4.02E-13	6.19E-05									
BATCH-1273	6/4/34	16	1.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-04	8.46E+00	1.29E-16	2.76E+00	4.31E-01	1.49E-04	2.85E-17	0.00E+00	2.99E-06	4.01E-13	6.17E-05									

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1274	11/2/34	71	7.4	0.24	0.00E+00	0.00E+00	5.12E-04	7.14E-05	3.70E-02	5.22E-01	1.42E+03	2.40E-02	3.00E-03	7.07E+00	1.08E-17	7.00E-02	1.06E-05	1.00E-03	5.00E-03
BATCH-1275	11/3/34	71	7.4	0.24	0.00E+00	0.00E+00	5.11E-04	7.13E-05	3.70E-02	5.21E-01	1.42E+03	2.40E-02	3.00E-03	7.07E+00	1.08E-17	7.00E-02	1.06E-05	1.00E-03	5.00E-03
BATCH-1276	11/10/34	71	7.4	0.24	0.00E+00	0.00E+00	5.10E-04	7.12E-05	3.70E-02	5.20E-01	1.42E+03	2.40E-02	3.00E-03	7.06E+00	1.08E-17	7.00E-02	1.06E-05	1.00E-03	5.00E-03
BATCH-1277	11/11/34	64	6.6	0.24	0.00E+00	0.00E+00	4.50E-02	1.00E-03	3.30E+00	3.53E-01	1.27E+03	5.90E-02	2.30E-02	6.33E+00	1.47E-17	4.56E-01	1.23E-04	1.73E-01	1.00E-03
BATCH-1278	11/17/34	64	6.7	0.24	0.00E+00	0.00E+00	4.80E-02	1.00E-03	3.52E+00	3.50E-01	1.15E+03	6.20E-02	2.40E-02	6.40E+00	1.51E-17	4.82E-01	1.30E-04	1.84E-01	1.00E-03
BATCH-1279	11/18/34	64	6.7	0.24	0.00E+00	0.00E+00	4.80E-02	1.00E-03	3.52E+00	3.50E-01	1.15E+03	6.20E-02	2.40E-02	6.40E+00	1.51E-17	4.82E-01	1.30E-04	1.84E-01	1.00E-03
BATCH-1280	11/24/34	44	4.6	0.24	0.00E+00	0.00E+00	3.30E-02	8.68E-04	2.42E+00	2.41E-01	7.94E+02	4.20E-02	1.70E-02	4.40E+00	1.04E-17	3.31E-01	8.95E-05	1.27E-01	5.00E-04
BATCH-1281	11/25/34	44	4.6	0.24	0.00E+00	0.00E+00	3.30E-02	8.68E-04	2.42E+00	2.41E-01	7.94E+02	4.20E-02	1.70E-02	4.40E+00	1.04E-17	3.31E-01	8.95E-05	1.27E-01	5.00E-04
BATCH-1282	11/29/34	44	4.6	0.24	0.00E+00	0.00E+00	3.30E-02	8.68E-04	2.42E+00	2.41E-01	7.94E+02	4.20E-02	1.70E-02	4.54E+00	1.07E-17	3.42E-01	9.24E-05	1.31E-01	7.50E-04
BATCH-1283	11/29/34	46	4.8	0.24	0.00E+00	0.00E+00	3.40E-02	8.96E-04	2.50E+00	2.48E-01	8.17E+02	4.40E-02	1.70E-02	4.54E+00	1.02E-17	1.11E+00	2.70E-04	4.24E-01	2.50E-04
BATCH-1284	12/4/34	86	9.0	0.24	0.00E+00	0.00E+00	1.14E-01	3.00E-03	8.27E+00	3.43E-01	2.11E+02	1.42E-01	5.20E-02	8.57E+00	2.08E-17	1.15E+00	2.80E-04	4.41E-01	2.50E-04
BATCH-1285	12/4/34	89	9.2	0.24	0.00E+00	0.00E+00	1.18E-01	3.00E-03	8.60E+00	3.51E-01	1.89E+02	1.48E-01	5.40E-02	8.83E+00	2.08E-17	1.15E+00	2.80E-04	4.41E-01	2.50E-04
BATCH-1286	12/13/34	103	10.7	0.24	0.00E+00	0.00E+00	7.00E-03	2.02E-04	5.23E-01	1.84E-01	1.24E+03	1.50E-02	4.00E-03	4.06E+00	4.94E-18	8.80E-02	2.17E-05	2.70E-02	1.50E-03
BATCH-1287	12/14/34	103	10.7	0.24	0.00E+00	0.00E+00	7.00E-03	2.02E-04	5.22E-01	1.84E-01	1.23E+03	1.50E-02	4.00E-03	4.04E+00	4.92E-18	8.80E-02	2.16E-05	2.70E-02	1.50E-03
BATCH-1288	12/24/34	103	10.7	0.24	0.00E+00	0.00E+00	7.00E-03	2.02E-04	5.20E-01	1.83E-01	1.23E+03	1.50E-02	4.00E-03	4.30E+00	6.40E-18	1.93E-01	5.17E-05	7.30E-02	5.00E-04
BATCH-1289	12/25/34	131	13.6	0.24	0.00E+00	0.00E+00	1.90E-02	5.00E-04	1.39E+00	1.60E-01	6.34E+02	2.50E-02	1.00E-02	4.30E+00	6.40E-18	1.93E-01	5.17E-05	7.30E-02	5.00E-04
BATCH-1290	1/4/35	102	10.6	0.24	0.00E+00	0.00E+00	2.80E-02	6.36E-04	2.01E+00	1.32E-01	2.96E+02	3.50E-02	1.30E-02	4.68E+00	3.27E-18	2.61E-01	5.44E-05	1.05E-01	2.50E-04
BATCH-1291	1/8/35	99	10.3	0.24	0.00E+00	0.00E+00	2.80E-02	6.46E-04	2.05E+00	1.30E-01	2.77E+02	3.60E-02	1.30E-02	4.68E+00	3.24E-18	2.65E-01	5.50E-05	1.06E-01	2.49E-04
BATCH-1292	1/14/35	48	5.0	0.24	0.00E+00	0.00E+00	3.00E-03	7.46E-05	2.18E-01	7.74E-02	5.07E+02	6.00E-03	2.00E-03	1.71E+00	1.05E-18	3.50E-02	7.10E-06	1.10E-02	5.00E-04
BATCH-1293	1/18/35	48	5.0	0.24	0.00E+00	0.00E+00	3.00E-03	7.45E-05	2.18E-01	7.74E-02	5.06E+02	6.00E-03	2.00E-03	1.70E+00	1.05E-18	3.50E-02	7.09E-06	1.10E-02	5.00E-04
BATCH-1294	1/20/35	48	5.0	0.24	0.00E+00	0.00E+00	3.00E-03	7.43E-05	2.17E-01	7.65E-02	5.04E+02	6.00E-03	2.00E-03	1.70E+00	1.04E-18	3.50E-02	7.07E-06	1.10E-02	5.00E-04
BATCH-1295	1/24/35	39	4.1	0.24	0.00E+00	0.00E+00	5.00E-03	1.16E-04	3.65E-01	4.23E-02	1.64E+02	7.00E-03	2.00E-03	1.14E+00	8.54E-19	4.90E-02	1.07E-05	1.50E-02	1.50E-04
BATCH-1296	1/25/35	43	4.5	0.24	0.00E+00	0.00E+00	1.00E-02	2.38E-04	7.53E-01	4.95E-02	1.11E+02	1.30E-02	5.00E-03	1.75E+00	1.22E-18	9.80E-02	2.03E-05	3.90E-02	9.80E-05
BATCH-1297	1/28/35	44	4.5	0.24	0.00E+00	0.00E+00	1.10E-02	2.51E-04	7.95E-01	5.04E-02	1.07E+02	1.40E-02	5.00E-03	1.82E+00	1.26E-18	1.03E-01	2.14E-05	4.10E-02	9.68E-05
BATCH-1298	1/30/35	18	1.8	0.24	0.00E+00	0.00E+00	8.01E-04	1.98E-05	5.80E-02	2.07E-02	1.35E+02	2.00E-03	4.51E-04	4.54E-01	2.78E-19	9.00E-03	1.89E-06	3.00E-03	1.55E-04
BATCH-1299	2/1/35	18	1.8	0.24	0.00E+00	0.00E+00	7.99E-04	1.98E-05	5.80E-02	2.07E-02	1.34E+02	2.00E-03	4.50E-04	4.52E-01	2.77E-19	9.00E-03	1.88E-06	3.00E-03	1.54E-04
BATCH-1300	2/2/35	18	1.8	0.24	0.00E+00	0.00E+00	7.96E-04	1.97E-05	5.80E-02	2.07E-02	1.34E+02	2.00E-03	4.48E-04	4.50E-01	2.76E-19	9.00E-03	1.87E-06	3.00E-03	1.54E-04
BATCH-1301	2/3/35	14	1.5	0.24	0.00E+00	0.00E+00	1.00E-03	2.76E-05	8.60E-02	9.90E-03	3.89E+01	2.00E-03	5.78E-04	2.70E-01	2.02E-19	1.20E-02	2.53E-06	5.00E-03	3.55E-05
BATCH-1302	2/4/35	15	1.6	0.24	0.00E+00	0.00E+00	2.00E-03	5.64E-05	1.78E-01	1.17E-02	2.62E+01	3.00E-03	1.00E-03	4.14E-01	2.89E-19	2.30E-02	4.82E-06	9.00E-03	2.32E-05
BATCH-1303	2/4/35	16	1.6	0.24	0.00E+00	0.00E+00	3.00E-03	5.95E-05	1.88E-01	1.17E-02	2.55E+01	3.00E-03	1.00E-03	4.31E-01	2.98E-19	2.40E-02	5.06E-06	1.00E-02	2.29E-05
BATCH-1304	5/11/35	122	12.7	0.24	0.00E+00	0.00E+00	1.63E-01	4.00E-03	1.18E+01	4.83E-01	2.53E+02	2.03E-01	7.00E-02	1.22E+01	1.44E-17	1.51E+00	3.01E-04	6.07E-01	5.00E-04
BATCH-1305	5/12/35	122	12.7	0.24	0.00E+00	0.00E+00	1.62E-01	4.00E-03	1.18E+01	4.83E-01	2.53E+02	2.03E-01	7.00E-02	1.22E+01	1.44E-17	1.51E+00	3.00E-04	6.06E-01	5.00E-04
BATCH-1306	5/24/35	122	12.7	0.24	0.00E+00	0.00E+00	1.62E-01	4.00E-03	1.17E+01	4.82E-01	2.53E+02	2.03E-01	7.00E-02	1.21E+01	1.44E-17	1.51E+00	3.00E-04	6.05E-01	5.00E-04
BATCH-1307	5/25/35	122	12.7	0.24	0.00E+00	0.00E+00	1.62E-01	4.00E-03	1.17E+01	4.82E-01	2.53E+02	2.03E-01	7.00E-02	1.21E+01	1.44E-17	1.51E+00	3.00E-04	6.05E-01	5.00E-04
BATCH-1308	6/6/35	167	17.4	0.24	0.00E+00	0.00E+00	3.16E-01	8.10E-02	2.28E+01	2.31E+00	3.34E+03	2.66E+00	3.02E-01	1.66E+01	6.88E-13	1.85E+00	3.30E-02	1.00E+00	9.30E-02
BATCH-1309	6/24/35	80	8.3	0.24	0.00E+00	0.00E+00	4.10E-02	5.00E-03	2.98E+00	3.09E-01	1.59E+03	4.09E-01	3.40E-02	4.84E+00	9.18E-14	2.28E-01	6.34E-04	1.36E-01	1.00E-02
BATCH-1310	6/24/35	31	3.3	0.24	0.00E+00	0.00E+00	1.70E-02	3.98E-04	1.26E+00	5.22E-02	2.72E+01	2.20E-02	8.00E-03	2.50E+00	1.55E-18	1.62E-01	3.23E-05	6.50E-02	5.02E-05
BATCH-1311	6/27/35	60	6.3	0.24	0.00E+00	0.00E+00	6.70E-02	3.00E-03	4.80E+00	3.09E-01	1.21E+03	3.55E-01	6.50E-02	6.02E+00	2.13E-14	4.86E-01	3.29E-04	2.26E-01	2.25E-03
BATCH-1312	7/2/35	31	3.2	0.24	0.00E+00	0.00E+00	1.70E-02	3.95E-04	1.25E+00	5.13E-02	2.70E+01	2.20E-02	8.00E-03	2.48E+00	1.54E-18	1.61E-01	3.21E-05	6.50E-02	4.98E-05
BATCH-1313	7/4/35	31	3.2	0.24	0.00E+00	0.00E+00	1.70E-02	3.97E-04	1.26E+00	5.22E-02	2.72E+01	2.20E-02	8.00E-03	2.49E+00	1.55E-18	1.62E-01	3.22E-05	6.50E-02	5.01E-05
BATCH-1314	7/5/35	31	3.2	0.24	0.00E+00	0.00E+00	1.70E-02	3.97E-04	1.26E+00	5.13E-02	2.71E+01	2.20E-02	8.00E-03	2.49E+00	1.54E-18	1.61E-01	3.22E-05	6.50E-02	5.00E-05
BATCH-1315	7/7/35	29	3.1	0.24	0.00E+00	0.00E+00	1.50E-02	3.33E-04	1.06E+00	4.32E-02	2.27E+01	1.80E-02	6.00E-03	2.09E+00	1.30E-18	1.35E-01	2.70E-05	5.50E-02	4.20E-05
BATCH-1316	7/9/35	22	2.3	0.24	0.00E+00	0.00E+00	1.00E-02	1.00E-03	7.19E-01	7.47E-02	4.36E+02	9.90E-02	8.00E-03	1.17E+00	2.22E-14	5.50E-02	1.53E-04	3.30E-02	2.50E-03
BATCH-1317	7/10/35	77	8.0	0.24	0.00E+00	0.00E+00	2.40E-02	5.41E-04	1.71E+00	1.21E-01	1.53E+03	5.40E-02	1.90E-02	3.86E+00	1.43E-16	2.12E-01	1.01E-04	9.00E-02	2.49E-04
BATCH-1318	7/11/35	29	3.1	0.24	0.00E+00	0.00E+00	1.40E-02	3.30E-04	1.05E+00	4.32E-02	2.26E+01	1.80E-02	6.00E-03	2.07E+00	1.29E-18	1.34E-01	2.68E-05	5.40E-02	4.17E-05
BATCH-1319	7/14/35	29	3.1	0.24	0.00E+00	0.00E+00	1.50E-02	3.32E-04	1.05E+00	4.32E-02	2.27E+01	1.80E-02	6.00E-03	2.09E+00	1.29E-18	1.35E-01	2.70E-05	5.40E-02	4.19E-05
BATCH-1320	7/18/35	29	3.1	0.24	0.00E+00	0.00E+00	1.50E-02	3.32E-04	1.05E+00	4.32E-02	2.27E+01	1.80E-02	6.00E-03	2.08E+00	1.29E-18	1.35E-01	2.69E-05	5.40E-02	4.18E-05
BATCH-1321	7/18/35	10	1.1	0.24	0.00E+00	0.00E+00	3.00E-03	7.88E-05	2.50E-01	9.90E-03	5.38E+00	4.00E-03	1.00E-03	4.94E-01	3.06E-19	3.20E-02	6.39E-06	1.30E-02	9.93E-06
BATCH-1322	7/20/35	8	0.8	0.24	0.00E+00	0.00E+00	2.00E-03	2.87E-04	1.71E-01	1.80E-02	1.18E+02	2.30E-02	2.00E-03	2.78E-01	5.27E-15	1.30E-02	3.64E-05	8.00E-03	5.00E-04

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00	Ci 1.00
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1274	11/2/34	71	7.4	0.24	1.21E-09	2.13E+02	5.60E-01	5.00E-03	9.00E-03	1.10E-02	1.46E-06	2.08E-08	5.60E-07	2.78E-06	3.05E-06	1.30E-05	1.06E-04	5.98E-04	5.00E-03
BATCH-1275	11/3/34	71	7.4	0.24	1.21E-09	2.13E+02	5.60E-01	5.00E-03	9.00E-03	1.10E-02	1.46E-06	2.08E-08	5.60E-07	2.77E-06	3.04E-06	1.30E-05	1.06E-04	5.97E-04	5.00E-03
BATCH-1276	11/10/34	71	7.4	0.24	1.21E-09	2.13E+02	5.59E-01	5.00E-03	9.00E-03	1.10E-02	1.46E-06	2.07E-08	5.59E-07	2.77E-06	3.04E-06	1.30E-05	1.06E-04	5.97E-04	5.00E-03
BATCH-1277	11/11/34	64	6.6	0.24	8.88E-09	1.91E+02	1.08E+00	1.00E-03	7.00E-03	2.00E-03	1.22E-06	3.27E-08	2.03E-05	2.92E-06	1.35E-05	1.28E-05	2.91E-04	2.00E-03	1.00E-03
BATCH-1278	11/17/34	64	6.7	0.24	9.42E-09	1.93E+02	1.12E+00	9.88E-04	7.00E-03	2.00E-03	1.22E-06	3.39E-08	2.16E-05	2.98E-06	1.42E-05	1.30E-05	3.05E-04	2.00E-03	1.00E-03
BATCH-1279	11/18/34	64	6.7	0.24	9.41E-09	1.93E+02	1.12E+00	9.88E-04	7.00E-03	2.00E-03	1.22E-06	3.39E-08	2.16E-05	2.98E-06	1.42E-05	1.30E-05	3.05E-04	2.00E-03	1.00E-03
BATCH-1280	11/24/34	44	4.6	0.24	6.46E-09	1.33E+02	7.72E-01	6.81E-04	5.00E-03	1.00E-03	8.41E-07	2.33E-08	1.49E-05	2.05E-06	9.75E-06	8.93E-06	2.09E-04	1.00E-03	7.91E-04
BATCH-1281	11/25/34	44	4.6	0.24	6.46E-09	1.33E+02	7.72E-01	6.81E-04	5.00E-03	1.00E-03	8.41E-07	2.33E-08	1.49E-05	2.05E-06	9.75E-06	8.93E-06	2.09E-04	1.00E-03	7.91E-04
BATCH-1282	11/29/34	44	4.6	0.24	6.46E-09	1.33E+02	7.72E-01	7.00E-04	5.00E-03	1.00E-03	8.67E-07	2.40E-08	1.53E-05	2.11E-06	1.01E-05	9.21E-06	2.16E-04	1.00E-03	8.13E-04
BATCH-1283	11/29/34	46	4.8	0.24	6.67E-09	1.37E+02	7.97E-01	7.00E-04	5.00E-03	1.00E-03	8.67E-07	2.40E-08	1.53E-05	2.11E-06	1.01E-05	9.21E-06	2.16E-04	1.00E-03	8.13E-04
BATCH-1284	12/4/34	86	9.0	0.24	1.59E-08	2.58E+02	3.86E-01	3.75E-04	2.10E-02	9.20E-04	1.69E-06	1.20E-08	4.86E-05	5.99E-06	3.21E-05	2.90E-05	5.94E-04	4.00E-03	9.54E-04
BATCH-1285	12/4/34	89	9.2	0.24	1.64E-08	2.66E+02	3.74E-01	3.66E-04	2.20E-02	9.07E-04	1.74E-06	1.16E-08	5.05E-05	6.21E-06	3.33E-05	3.01E-05	6.16E-04	4.00E-03	9.71E-04
BATCH-1286	12/13/34	103	10.7	0.24	1.68E-09	3.09E+02	3.06E-01	1.00E-03	3.00E-03	3.00E-03	5.50E-07	1.02E-08	3.30E-06	1.14E-06	2.84E-06	5.20E-06	7.14E-05	4.02E-04	1.00E-03
BATCH-1287	12/14/34	103	10.7	0.24	1.68E-09	3.08E+02	3.05E-01	1.00E-03	3.00E-03	3.00E-03	5.49E-07	1.02E-08	3.29E-06	1.14E-06	2.84E-06	5.19E-06	7.12E-05	4.01E-04	1.00E-03
BATCH-1288	12/24/34	103	10.7	0.24	1.67E-09	3.08E+02	3.04E-01	1.00E-03	3.00E-03	3.00E-03	5.47E-07	1.02E-08	3.28E-06	1.13E-06	2.83E-06	5.17E-06	7.10E-05	4.00E-04	1.00E-03
BATCH-1289	12/25/34	131	13.6	0.24	3.75E-09	3.92E+02	4.66E-01	5.98E-04	3.00E-03	1.00E-03	5.44E-07	1.42E-08	8.53E-06	1.29E-06	5.71E-06	5.67E-06	1.24E-04	6.99E-04	6.72E-04
BATCH-1290	1/4/35	102	10.6	0.24	3.23E-09	3.05E+02	3.19E-01	2.74E-04	4.00E-03	5.47E-04	5.34E-07	9.44E-09	1.10E-05	1.57E-06	8.00E-06	7.26E-06	1.56E-04	9.32E-04	4.09E-04
BATCH-1291	1/8/35	99	10.3	0.24	3.24E-09	2.97E+02	3.02E-01	2.60E-04	4.00E-03	5.21E-04	5.30E-07	8.94E-09	1.11E-05	1.59E-06	8.11E-06	7.36E-06	1.58E-04	9.43E-04	3.99E-04
BATCH-1292	1/14/35	48	5.0	0.24	5.05E-10	1.45E+02	1.28E-01	5.52E-04	1.00E-03	1.00E-03	2.31E-07	4.16E-09	1.25E-06	4.79E-07	1.20E-06	2.19E-06	2.97E-05	1.69E-04	6.20E-04
BATCH-1293	1/18/35	48	5.0	0.24	5.04E-10	1.45E+02	1.27E-01	5.51E-04	1.00E-03	1.00E-03	2.31E-07	4.15E-09	1.25E-06	4.78E-07	1.19E-06	2.18E-06	2.97E-05	1.69E-04	6.18E-04
BATCH-1294	1/20/35	48	5.0	0.24	5.03E-10	1.44E+02	1.27E-01	5.48E-04	1.00E-03	1.00E-03	2.30E-07	4.14E-09	1.25E-06	4.76E-07	1.19E-06	2.18E-06	2.96E-05	1.68E-04	6.16E-04
BATCH-1295	1/24/35	39	4.1	0.24	7.11E-10	1.18E+02	1.23E-01	1.51E-04	7.71E-04	2.96E-04	1.44E-07	3.65E-09	2.04E-06	3.42E-07	1.51E-06	1.50E-06	3.26E-05	1.85E-04	1.78E-04
BATCH-1296	1/25/35	43	4.5	0.24	1.21E-09	1.29E+02	1.19E-01	1.02E-04	2.00E-03	2.05E-04	1.99E-07	3.53E-09	4.10E-06	5.87E-07	2.99E-06	2.72E-06	5.85E-05	3.49E-04	1.53E-04
BATCH-1297	1/28/35	44	4.5	0.24	1.26E-09	1.30E+02	1.17E-01	1.01E-04	2.00E-03	2.03E-04	2.06E-07	3.47E-09	4.32E-06	6.16E-07	3.15E-06	2.86E-06	6.13E-05	3.67E-04	1.55E-04
BATCH-1298	1/30/35	18	1.8	0.24	1.34E-10	5.27E+01	3.40E-02	1.47E-04	3.51E-04	2.92E-04	6.14E-08	1.11E-09	3.32E-07	1.27E-07	3.17E-07	5.79E-07	7.89E-06	4.48E-05	1.65E-04
BATCH-1299	2/1/35	18	1.8	0.24	1.34E-10	5.26E+01	3.40E-02	1.46E-04	3.49E-04	2.91E-04	6.12E-08	1.10E-09	3.31E-07	1.27E-07	3.17E-07	5.77E-07	7.87E-06	4.47E-05	1.64E-04
BATCH-1300	2/2/35	18	1.8	0.24	1.33E-10	5.25E+01	3.40E-02	1.45E-04	3.48E-04	2.89E-04	6.09E-08	1.10E-09	3.30E-07	1.26E-07	3.15E-07	5.56E-07	7.83E-06	4.45E-05	1.63E-04
BATCH-1301	2/3/35	14	1.5	0.24	1.69E-10	4.23E+01	2.90E-02	3.57E-05	1.83E-04	7.01E-05	3.42E-08	8.65E-10	4.83E-07	8.11E-08	3.59E-07	7.74E-06	1.39E-05	8.26E-05	4.23E-05
BATCH-1302	2/4/35	15	1.6	0.24	2.86E-10	4.63E+01	2.80E-02	2.42E-05	3.87E-04	4.84E-05	4.72E-08	8.36E-10	9.70E-07	1.39E-07	7.47E-07	6.78E-07	1.45E-05	8.68E-05	3.63E-05
BATCH-1303	2/4/35	16	1.6	0.24	2.98E-10	4.67E+01	2.80E-02	2.39E-05	4.13E-04	4.80E-05	4.88E-08	8.23E-10	1.02E-06	8.56E-06	4.60E-05	4.15E-05	8.40E-04	5.00E-03	3.67E-05
BATCH-1304	5/11/35	122	12.7	0.24	1.62E-08	3.66E+02	5.10E-01	4.79E-04	2.80E-02	1.00E-03	2.40E-06	1.55E-08	6.28E-05	8.56E-06	4.59E-05	4.15E-05	8.40E-04	5.00E-03	1.00E-03
BATCH-1305	5/12/35	122	12.7	0.24	1.62E-08	3.66E+02	5.10E-01	4.79E-04	2.80E-02	1.00E-03	2.40E-06	1.55E-08	6.27E-05	8.56E-06	4.59E-05	4.14E-05	8.39E-04	5.00E-03	1.00E-03
BATCH-1306	5/24/35	122	12.7	0.24	1.62E-08	3.66E+02	5.10E-01	4.78E-04	2.80E-02	1.00E-03	2.40E-06	1.55E-08	6.27E-05	8.55E-06	4.59E-05	4.14E-05	8.38E-04	5.00E-03	1.00E-03
BATCH-1307	5/25/35	122	12.7	0.24	1.61E-08	3.65E+02	5.09E-01	4.77E-04	2.80E-02	1.00E-03	2.39E-06	1.54E-08	6.26E-05	8.54E-06	4.58E-05	4.14E-05	8.38E-04	5.00E-03	1.00E-03
BATCH-1308	6/6/35	167	17.4	0.24	5.39E-05	5.01E+02	1.31E+03	9.20E-02	3.18E+00	2.44E-01	1.24E+00	3.70E-05	4.55E-04	7.09E-04	7.03E-04	3.00E-03	4.90E-02	2.76E-01	1.04E-01
BATCH-1309	6/24/35	80	8.3	0.24	5.98E-07	2.39E+02	1.59E+02	1.00E-02	2.55E-01	2.60E-02	1.89E-01	4.51E-06	6.68E-05	1.02E-04	1.05E-04	4.05E-04	5.00E-03	2.60E-02	1.10E-02
BATCH-1310	6/24/35	31	3.3	0.24	1.74E-09	9.35E+01	5.50E-02	5.14E-05	3.00E-03	1.17E-04	2.58E-07	1.66E-09	6.74E-06	9.19E-07	4.93E-06	4.45E-06	9.02E-05	5.60E-04	1.44E-04
BATCH-1311	6/27/35	60	6.3	0.24	6.27E-09	1.81E+02	1.25E+02	8.00E-03	3.68E-01	1.30E-02	5.40E-02	3.55E-06	4.15E-05	4.79E-05	7.88E-05	1.48E-04	7.00E-03	3.90E-02	1.30E-02
BATCH-1312	7/2/35	31	3.2	0.24	1.72E-09	9.31E+01	5.40E-02	5.10E-05	3.00E-03	1.16E-04	2.56E-07	1.65E-09	6.69E-06	9.12E-07	4.90E-06	4.42E-06	8.96E-05	5.56E-04	1.43E-04
BATCH-1313	7/4/35	31	3.2	0.24	1.73E-09	9.34E+01	5.50E-02	5.13E-05	3.00E-03	1.16E-04	2.57E-07	1.66E-09	6.73E-06	9.18E-07	4.93E-06	4.44E-06	9.01E-05	5.59E-04	1.43E-04
BATCH-1314	7/5/35	31	3.2	0.24	1.73E-09	9.33E+01	5.50E-02	5.12E-05	3.00E-03	1.16E-04	2.57E-07	1.66E-09	6.71E-06	9.16E-07	4.92E-06	4.44E-06	8.99E-05	5.58E-04	1.43E-04
BATCH-1315	7/7/35	29	3.1	0.24	1.45E-09	8.83E+01	4.60E-02	4.30E-05	3.00E-03	9.75E-05	2.15E-07	1.39E-09	5.64E-06	7.69E-07	4.13E-06	3.72E-06	7.55E-05	4.68E-04	1.20E-04
BATCH-1316	7/9/35	22	2.3	0.24	1.44E-07	6.55E+01	3.85E+01	2.00E-03	6.20E-02	6.00E-03	4.60E-02	1.09E-06	1.62E-05	2.47E-05	2.53E-05	9.78E-05	8.29E-06	1.93E-04	1.00E-03
BATCH-1317	7/10/35	77	8.0	0.24	2.42E-09	2.30E+02	1.30E+00	3.19E-04	2.00E-02	7.12E-04	3.58E-04	3.78E-08	9.18E-06	1.80E-06	1.00E-05	8.29E-06	1.93E-04	1.00E-03	6.71E-04
BATCH-1318	7/11/35	29	3.1	0.24	1.44E-09	8.79E+01	4.50E-02	4.27E-05	3.00E-03	9.68E-05	2.14E-07	1.38E-09	5.60E-06	7.63E-07	4.10E-06	3.70E-06	7.49E-05	4.65E-04	1.19E-04
BATCH-1319	7/14/35	29	3.1	0.24	1.45E-09	8.82E+01	4.60E-02	4.29E-05	3.00E-03	9.74E-05	2.15E-07	1.39E-09	5.63E-06	7.68E-07	4.12E-06	3.72E-06	7.54E-05	4.68E-04	1.20E-04
BATCH-1320	7/18/35	29	3.1	0.24	1.45E-09	8.81E+01	4.60E-02	4.28E-05	3.00E-03	9.72E-05	2.15E-07	1.39E-09	5.62E-06	7.66E-07	4.11E-06	3.71E-06	7.52E-05	4.67E-04	1.20E-04
BATCH-1321	7/18/35	10	1.1	0.24	3.44E-10	3.14E+01	1.10E-02	1.02E-05	6.00E-04	2.31E-05	5.10E-08	3.29E-10	1.33E-06	1.82E-07	9.76E-07	8.81E-07	1.79E-05	1.11E-04	2.84E-05
BATCH-1322	7/20/35	8	0.8	0.24	3.43E-08	2.36E+01	9.14E+00	5.79E-04	1.50E-02	1.00E-03	1.10E-02	2.59E-07	3.84E-06	5.86E-06	6.00E-06	2.32E-05	2.65E-04	2.00E-03	6.31E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1274	11/2/34	71	7.4	0.24	2.27E-04	5.36E-05	3.00E-03	7.00E-03	5.00E-03	4.60E-01	5.70E-02	2.74E+00	7.80E-02	1.34E-30	3.00E-06	8.94E-05	1.34E-05	1.16E-04	5.60E-16
BATCH-1275	11/3/34	71	7.4	0.24	2.27E-04	5.35E-05	3.00E-03	7.00E-03	5.00E-03	4.59E-01	5.70E-02	2.74E+00	7.80E-02	1.34E-30	3.00E-06	8.93E-05	1.34E-05	1.16E-04	5.61E-16
BATCH-1276	11/10/34	71	7.4	0.24	2.27E-04	5.34E-05	3.00E-03	7.00E-03	5.00E-03	4.59E-01	5.70E-02	2.74E+00	7.80E-02	1.34E-30	2.99E-06	8.92E-05	1.34E-05	1.16E-04	5.60E-16
BATCH-1277	11/11/34	64	6.6	0.24	5.71E-05	1.82E-05	5.07E-04	5.70E-02	1.00E-03	2.69E+00	4.54E-01	1.94E+00	7.95E-01	1.87E-29	2.97E-05	7.30E-05	5.31E-04	2.00E-03	6.63E-14
BATCH-1278	11/17/34	64	6.7	0.24	4.98E-05	1.67E-05	3.95E-04	6.10E-02	1.00E-03	2.84E+00	4.82E-01	1.94E+00	8.44E-01	1.98E-29	3.15E-05	7.34E-05	5.65E-04	3.00E-03	7.07E-14
BATCH-1279	11/18/34	64	6.7	0.24	4.97E-05	1.67E-05	3.95E-04	6.10E-02	1.00E-03	2.84E+00	4.82E-01	1.94E+00	8.44E-01	1.98E-29	3.15E-05	7.34E-05	5.65E-04	3.00E-03	7.06E-14
BATCH-1280	11/24/34	44	4.6	0.24	3.43E-05	1.15E-05	2.73E-04	4.20E-02	7.95E-04	1.95E+00	3.31E-01	1.33E+00	5.80E-01	1.36E-29	2.16E-05	5.05E-05	3.88E-04	2.00E-03	4.85E-14
BATCH-1281	11/25/34	44	4.6	0.24	3.43E-05	1.15E-05	2.73E-04	4.20E-02	7.95E-04	1.95E+00	3.31E-01	1.33E+00	5.79E-01	1.36E-29	2.16E-05	5.05E-05	3.88E-04	2.00E-03	4.85E-14
BATCH-1282	11/29/34	44	4.6	0.24	3.43E-05	1.15E-05	2.73E-04	4.20E-02	7.95E-04	1.95E+00	3.31E-01	1.33E+00	5.98E-01	1.41E-29	2.23E-05	5.20E-05	4.01E-04	2.00E-03	5.01E-14
BATCH-1283	11/29/34	46	4.8	0.24	3.53E-05	1.19E-05	2.80E-04	4.30E-02	8.17E-04	2.01E+00	3.41E-01	1.37E+00	5.98E-01	1.41E-29	2.23E-05	5.20E-05	4.01E-04	2.00E-03	5.01E-14
BATCH-1284	12/4/34	86	9.0	0.24	3.94E-05	2.85E-05	1.00E-03	1.52E-01	8.79E-04	6.48E+00	1.14E+00	5.81E+00	1.93E+00	4.62E-29	1.00E-04	1.69E-04	3.00E-03	2.00E-02	2.34E-05
BATCH-1285	12/4/34	89	9.2	0.24	4.00E-05	2.95E-05	1.00E-03	1.58E-01	8.91E-04	6.73E+00	1.19E+00	6.06E+00	2.01E+00	4.80E-29	1.05E-04	1.75E-04	3.00E-03	2.10E-02	2.46E-05
BATCH-1286	12/13/34	103	10.7	0.24	6.50E-05	1.61E-05	8.12E-04	1.10E-02	1.00E-03	5.31E-01	8.50E-02	9.79E-01	1.43E-01	3.23E-30	5.35E-06	3.34E-05	8.58E-05	4.09E-04	1.04E-14
BATCH-1287	12/14/34	103	10.7	0.24	6.48E-05	1.60E-05	8.10E-04	1.10E-02	1.00E-03	5.30E-01	8.50E-02	9.77E-01	1.43E-01	3.22E-30	5.34E-06	3.33E-05	8.56E-05	4.08E-04	1.04E-14
BATCH-1288	12/24/34	103	10.7	0.24	6.46E-05	1.59E-05	8.07E-04	1.10E-02	1.00E-03	5.28E-01	8.40E-02	9.73E-01	1.42E-01	3.21E-30	5.33E-06	3.32E-05	8.54E-05	4.07E-04	1.04E-14
BATCH-1289	12/25/34	131	13.6	0.24	2.93E-05	8.88E-06	2.83E-04	2.40E-02	6.78E-04	1.14E+00	1.92E-01	8.79E-01	3.35E-01	7.85E-30	1.25E-05	3.27E-05	2.23E-04	1.00E-03	2.78E-14
BATCH-1290	1/4/35	102	10.6	0.24	1.75E-05	8.08E-06	2.39E-04	3.60E-02	4.00E-04	1.61E+00	2.79E-01	1.30E+00	4.57E-01	2.41E-30	2.20E-05	4.17E-05	4.93E-04	3.00E-03	3.38E-06
BATCH-1291	1/8/35	99	10.3	0.24	1.70E-05	8.10E-06	2.43E-04	3.70E-02	3.88E-04	1.63E+00	2.83E-01	1.33E+00	4.63E-01	2.45E-30	2.26E-05	4.23E-05	5.13E-04	4.00E-03	3.67E-06
BATCH-1292	1/14/35	48	5.0	0.24	2.73E-05	6.74E-06	3.41E-04	4.00E-03	6.30E-04	2.23E-01	3.60E-02	4.11E-01	5.70E-02	2.88E-31	2.25E-06	1.40E-05	3.52E-05	4.39E-15	
BATCH-1293	1/18/35	48	5.0	0.24	2.73E-05	6.73E-06	3.41E-04	4.00E-03	6.28E-04	2.23E-01	3.60E-02	4.10E-01	5.70E-02	2.88E-31	2.25E-06	1.40E-05	3.51E-05	1.65E-04	4.38E-15
BATCH-1294	1/20/35	48	5.0	0.24	2.72E-05	6.71E-06	3.39E-04	4.00E-03	6.26E-04	2.22E-01	3.50E-02	4.09E-01	5.70E-02	2.87E-31	2.24E-06	1.40E-05	3.51E-05	1.65E-04	4.37E-15
BATCH-1295	1/24/35	39	4.1	0.24	7.78E-06	2.35E-06	7.50E-05	6.00E-03	1.80E-04	3.01E-01	5.10E-02	2.33E-01	8.50E-02	4.42E-31	3.32E-06	8.67E-06	5.76E-05	2.63E-04	7.37E-15
BATCH-1296	1/25/35	43	4.5	0.24	6.53E-06	3.02E-06	8.93E-05	1.30E-02	1.49E-04	6.01E-01	1.04E-01	4.85E-01	1.71E-01	9.02E-31	8.21E-06	1.56E-05	1.84E-04	1.00E-03	1.26E-06
BATCH-1297	1/28/35	44	4.5	0.24	6.60E-06	3.15E-06	9.46E-05	1.40E-02	1.51E-04	6.34E-01	1.10E-01	5.17E-01	1.80E-01	9.52E-31	8.77E-06	1.65E-05	1.99E-04	1.00E-03	1.43E-06
BATCH-1298	1/30/35	18	1.8	0.24	7.26E-06	1.79E-06	9.07E-05	1.00E-03	1.67E-04	5.90E-02	9.00E-03	1.09E-01	1.50E-02	7.66E-32	5.98E-07	3.73E-06	9.35E-06	4.40E-05	1.17E-15
BATCH-1299	2/1/35	18	1.8	0.24	7.23E-06	1.79E-06	9.04E-05	1.00E-03	1.67E-04	5.90E-02	9.00E-03	1.09E-01	1.50E-02	7.64E-32	5.96E-07	3.72E-06	9.32E-06	4.39E-05	1.16E-15
BATCH-1300	2/2/35	18	1.8	0.24	7.19E-06	1.78E-06	8.99E-05	1.00E-03	1.66E-04	5.90E-02	9.00E-03	1.08E-01	1.50E-02	7.61E-32	5.94E-07	3.70E-06	9.29E-06	4.37E-05	1.16E-15
BATCH-1301	2/3/35	14	1.5	0.24	5.58E-07	7.15E-07	1.78E-05	2.00E-03	4.27E-05	7.10E-02	1.20E-02	5.50E-02	2.00E-02	1.05E-31	7.86E-07	2.06E-06	1.37E-05	6.22E-05	1.75E-15
BATCH-1302	2/4/35	15	1.6	0.24	1.55E-06	7.15E-07	2.12E-05	3.00E-03	3.54E-05	1.42E-01	2.50E-02	1.15E-01	4.00E-02	2.14E-31	1.95E-06	3.70E-06	4.37E-05	3.03E-04	2.99E-07
BATCH-1303	2/4/35	16	1.6	0.24	1.56E-06	7.45E-07	2.24E-05	3.00E-03	3.57E-05	1.50E-01	2.60E-02	1.22E-01	4.30E-02	2.26E-31	2.08E-06	3.90E-06	4.72E-05	3.32E-04	3.38E-07
BATCH-1304	5/11/35	122	12.7	0.24	5.51E-05	4.06E-05	1.00E-03	2.16E-01	1.00E-03	9.28E+00	1.64E+00	8.33E+00	2.64E+00	1.40E-29	1.44E-04	2.41E-04	4.00E-03	2.80E-02	3.39E-05
BATCH-1305	5/12/35	122	12.7	0.24	5.51E-05	4.06E-05	1.00E-03	2.16E-01	1.00E-03	9.27E+00	1.63E+00	8.33E+00	2.64E+00	1.40E-29	1.44E-04	2.41E-04	4.00E-03	2.80E-02	3.39E-05
BATCH-1306	5/24/35	122	12.7	0.24	5.50E-05	4.06E-05	1.00E-03	2.15E-01	1.00E-03	9.27E+00	1.63E+00	8.32E+00	2.64E+00	1.40E-29	1.44E-04	2.41E-04	4.00E-03	2.80E-02	3.38E-05
BATCH-1307	5/25/35	122	12.7	0.24	5.50E-05	4.05E-05	1.00E-03	2.15E-01	1.00E-03	9.25E+00	1.63E+00	8.31E+00	2.63E+00	1.40E-29	1.44E-04	2.41E-04	4.00E-03	2.80E-02	3.38E-05
BATCH-1308	6/6/35	167	17.4	0.24	4.00E-03	4.00E-03	1.33E-01	3.24E-01	1.07E-01	4.97E+00	1.39E+00	1.25E+01	4.50E+00	3.04E-29	1.97E-04	1.50E-02	1.40E-02	1.49E-04	
BATCH-1309	6/24/35	80	8.3	0.24	4.35E-04	5.00E-04	1.60E-02	2.80E-02	1.10E-02	5.10E-01	1.37E-01	1.96E+00	4.60E-01	2.25E-30	1.77E-05	3.45E-04	2.00E-03	2.27E-05	
BATCH-1310	6/24/35	31	3.3	0.24	5.92E-06	4.36E-06	1.55E-04	2.30E-02	1.32E-04	9.96E-01	1.75E-01	8.95E-01	2.83E-01	1.51E-30	1.55E-05	2.59E-05	3.88E-04	2.00E-02	2.27E-05
BATCH-1311	6/27/35	60	6.3	0.24	5.27E-04	3.96E-04	1.40E-02	9.10E-02	1.50E-02	2.99E+00	5.79E-01	5.87E+00	7.65E-01	5.41E-30	1.02E-04	9.06E-05	4.00E-03	3.64E-06	
BATCH-1312	7/2/35	31	3.2	0.24	5.87E-06	4.33E-06	1.54E-04	2.30E-02	1.31E-04	9.89E-01	1.74E-01	8.88E-01	2.81E-01	1.50E-30	1.54E-05	2.57E-05	3.85E-04	3.00E-03	3.61E-06
BATCH-1313	7/4/35	31	3.2	0.24	5.91E-06	4.35E-06	1.55E-04	2.30E-02	1.32E-04	9.95E-01	1.75E-01	8.93E-01	2.83E-01	1.51E-30	1.55E-05	2.59E-05	3.87E-04	3.00E-03	3.63E-06
BATCH-1314	7/5/35	31	3.2	0.24	5.89E-06	4.35E-06	1.54E-04	2.30E-02	1.31E-04	9.92E-01	1.75E-01	8.91E-01	2.82E-01	1.50E-30	1.54E-05	2.58E-05	3.87E-04	3.00E-03	3.63E-06
BATCH-1315	7/7/35	29	3.1	0.24	4.95E-06	3.65E-06	1.30E-04	1.90E-02	1.10E-04	8.33E-01	1.47E-01	7.48E-01	2.37E-01	1.26E-30	1.30E-05	2.17E-05	3.24E-04	3.00E-03	3.04E-06
BATCH-1316	7/9/35	22	2.3	0.24	1.05E-04	1.21E-04	4.00E-03	7.00E-03	3.00E-03	1.23E-01	3.30E-02	4.72E-01	1.11E-01	5.43E-31	4.27E-06	8.33E-05	3.75E-04	5.00E-03	5.48E-06
BATCH-1317	7/10/35	77	8.0	0.24	2.85E-05	1.54E-05	5.43E-04	4.00E-02	6.68E-04	1.44E+00	2.71E-01	2.23E+00	3.83E-01	2.61E-30	4.06E-05	3.80E-05	1.00E-03	1.50E-02	4.75E-06
BATCH-1318	7/11/35	29	3.1	0.24	4.91E-06	3.62E-06	1.29E-04	1.90E-02	1.09E-04	8.27E-01	1.46E-01	7.43E-01	2.35E-01	1.25E-30	1.29E-05	2.15E-05	3.22E-04	3.00E-03	3.02E-06
BATCH-1319	7/14/35	29	3.1	0.24	4.94E-06	3.64E-06	1.29E-04	1.90E-02	1.10E-04	8.32E-01	1.47E-01	7.47E-01	2.37E-01	1.26E-30	1.29E-05	2.16E-05	3.24E-04	3.00E-03	3.04E-06
BATCH-1320	7/18/35	29	3.1	0.24	4.92E-06	3.64E-06	1.29E-04	1.90E-02	1.10E-04	8.30E-01	1.46E-01	7.46E-01	2.36E-01	1.26E-30	1.29E-05	2.16E-05	3.23E-04	3.00E-03	3.03E-06
BATCH-1321	7/18/35	10	1.1	0.24	1.17E-06	8.63E-07	3.06E-05	5.00E-03	2.61E-05	1.97E-01	3.50E-02	1.77E-01	5.60E-02	2.98E-31	3.06E-06	5.13E-06	7.68E-05	5.99E-04	7.20E-07
BATCH-1322	7/20/35	8	0.8	0.24	2.50E-05	2.87E-05	9.27E-04	2.00E-03	6.21E-04	2.90E-02	8.00E-03	1.12E-01	2.60E-02	1.29E-31	1.01E-06	1.98E-05	8.92E-05	1.00E-03	1.30E-06

Appendix A Nominal ILAW Inventory
TWRS&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1274	11/2/34	71	7.4	0.24	5.00E-03	3.07E+00	2.72E-15	5.41E-12	1.09E-15	9.41E-98	1.52E-01	5.80E+00	3.82E-15	8.93E-04	1.05E+01	0.00E+00	1.07E-04	9.89E-01	1.01E-07
BATCH-1275	11/3/34	71	7.4	0.24	5.00E-03	3.07E+00	2.72E-15	5.41E-12	1.10E-15	1.58E-97	1.52E-01	5.79E+00	3.82E-15	8.92E-04	1.05E+01	0.00E+00	6.44E-05	9.88E-01	1.01E-07
BATCH-1276	11/10/34	71	7.4	0.24	4.00E-03	3.06E+00	2.72E-15	5.40E-12	1.09E-15	2.41E-108	1.52E-01	5.79E+00	3.82E-15	8.91E-04	1.05E+01	0.00E+00	7.40E-05	9.86E-01	1.01E-07
BATCH-1277	11/11/34	64	6.6	0.24	3.00E-03	5.72E+01	6.78E-15	1.15E-11	7.15E-15	3.63E-104	3.70E-02	1.53E+00	8.06E-14	5.14E-04	1.88E+01	0.00E+00	5.09E-05	4.29E-01	2.02E-07
BATCH-1278	11/17/34	64	6.7	0.24	4.00E-03	6.08E+01	7.10E-15	1.20E-11	7.58E-15	4.49E-99	3.20E-02	1.35E+00	8.58E-14	5.04E-04	1.95E+01	0.00E+00	4.09E-05	8.60E-01	2.10E-07
BATCH-1279	11/18/34	64	6.7	0.24	4.00E-03	6.08E+01	7.10E-15	1.20E-11	7.58E-15	1.38E-104	3.20E-02	1.35E+00	8.58E-14	5.04E-04	1.95E+01	0.00E+00	8.59E-05	4.08E-01	2.10E-07
BATCH-1280	11/24/34	44	4.6	0.24	2.91E-06	4.18E+01	4.87E-15	8.24E-12	5.20E-15	5.14E-101	2.20E-02	9.28E-01	5.89E-14	3.47E-04	1.34E+01	0.00E+00	5.84E-08	2.81E-01	1.45E-07
BATCH-1281	11/25/34	44	4.6	0.24	2.59E-06	4.18E+01	4.87E-15	8.24E-12	5.20E-15	8.63E-101	2.20E-02	9.27E-01	5.89E-14	3.47E-04	1.34E+01	0.00E+00	3.51E-08	2.81E-01	1.45E-07
BATCH-1282	11/29/34	44	4.6	0.24	2.17E-06	4.18E+01	4.87E-15	8.24E-12	5.20E-15	1.32E-111	2.20E-02	9.27E-01	6.08E-14	3.47E-04	1.34E+01	0.00E+00	4.03E-08	2.81E-01	1.45E-07
BATCH-1283	11/29/34	46	4.8	0.24	1.37E-06	4.31E+01	5.03E-15	8.50E-12	5.37E-15	1.92E-107	2.30E-02	9.54E-01	6.08E-14	3.57E-04	1.38E+01	0.00E+00	2.69E-08	2.90E-01	1.49E-07
BATCH-1284	12/4/34	86	9.0	0.24	1.61E-06	8.62E+01	1.96E-16	1.30E-02	2.10E-16	1.66E-102	8.50E-02	7.63E-01	4.77E-06	4.48E-04	2.38E+01	0.00E+00	3.17E-08	7.51E-01	8.67E-02
BATCH-1285	12/4/34	89	9.2	0.24	2.46E-06	8.89E+01	4.06E-18	1.40E-02	4.48E-18	7.76E-108	8.90E-02	7.64E-01	5.01E-06	4.56E-04	2.45E+01	0.00E+00	4.84E-08	7.78E-01	9.12E-02
BATCH-1286	12/13/34	103	10.7	0.24	2.45E+02	0.00E+00	1.72E-15	3.12E-12	1.38E-15	2.39E-98	1.15E-01	2.55E+00	1.35E-14	3.00E-04	5.51E+00	0.00E+00	7.70E+00	0.00E+00	5.63E-08
BATCH-1287	12/14/34	103	10.7	0.24	2.45E+02	0.00E+00	1.72E-15	3.12E-12	1.38E-15	4.01E-98	1.14E-01	2.55E+00	1.35E-14	3.00E-04	5.50E+00	0.00E+00	7.69E+00	0.00E+00	5.62E-08
BATCH-1288	12/24/34	103	10.7	0.24	2.45E+02	0.00E+00	1.72E-15	3.11E-12	1.38E-15	6.10E-109	1.14E-01	2.54E+00	1.34E-14	2.99E-04	5.48E+00	0.00E+00	7.68E+00	0.00E+00	5.60E-08
BATCH-1289	12/25/34	131	13.6	0.24	5.55E+02	0.00E+00	2.91E-15	4.95E-12	3.02E-15	3.39E-104	4.10E-02	1.63E+00	3.39E-14	2.37E-04	8.12E+00	0.00E+00	9.18E+00	0.00E+00	8.70E-08
BATCH-1290	1/4/35	102	10.6	0.24	3.72E+02	0.00E+00	1.71E-15	2.00E-03	1.82E-15	1.01E-99	4.90E-02	1.21E+00	6.89E-07	1.84E-04	8.06E+00	0.00E+00	1.01E+01	0.00E+00	1.25E-02
BATCH-1291	1/8/35	99	10.3	0.24	3.59E+02	0.00E+00	1.57E-15	2.00E-03	1.68E-15	3.05E-105	5.00E-02	1.18E+00	7.47E-07	1.80E-04	7.97E+00	0.00E+00	1.01E+01	0.00E+00	1.36E-02
BATCH-1292	1/14/35	48	5.0	0.24	1.03E+02	0.00E+00	7.25E-16	1.31E-12	5.81E-16	1.01E-98	4.80E-02	1.07E+00	5.66E-15	1.26E-04	2.32E+00	0.00E+00	3.24E+00	0.00E+00	2.36E-08
BATCH-1293	1/18/35	48	5.0	0.24	1.03E+02	0.00E+00	7.24E-16	1.31E-12	5.80E-16	1.69E-98	4.80E-02	1.07E+00	5.65E-15	1.26E-04	2.31E+00	0.00E+00	3.23E+00	0.00E+00	2.36E-08
BATCH-1294	1/20/35	48	5.0	0.24	1.03E+02	0.00E+00	7.22E-16	1.31E-12	5.79E-16	2.57E-109	4.80E-02	1.07E+00	5.64E-15	1.26E-04	2.31E+00	0.00E+00	3.23E+00	0.00E+00	2.35E-08
BATCH-1295	1/24/35	39	4.1	0.24	1.47E+02	0.00E+00	7.71E-16	1.31E-12	8.02E-16	9.00E-105	1.10E-02	4.33E-01	8.98E-15	6.27E-05	2.15E+00	0.00E+00	2.44E+00	0.00E+00	2.31E-08
BATCH-1296	1/25/35	43	4.5	0.24	1.39E+02	0.00E+00	6.38E-16	7.14E-04	6.81E-16	3.77E-100	1.80E-02	4.52E-01	2.58E-07	6.88E-05	3.01E+00	0.00E+00	3.77E+00	0.00E+00	4.69E-03
BATCH-1297	1/28/35	44	4.5	0.24	1.40E+02	0.00E+00	6.10E-16	8.05E-04	6.52E-16	1.19E-105	2.00E-02	4.60E-01	2.91E-07	6.98E-05	3.10E+00	0.00E+00	3.92E+00	0.00E+00	5.29E-03
BATCH-1298	1/30/35	18	1.8	0.24	2.74E+01	0.00E+00	1.93E-16	3.49E-13	1.54E-16	2.67E-99	1.30E-02	2.85E-01	1.50E-15	3.36E-05	6.15E-01	0.00E+00	8.59E-01	0.00E+00	6.28E-09
BATCH-1299	2/1/35	18	1.8	0.24	2.74E+01	0.00E+00	1.92E-16	3.48E-13	1.54E-16	4.48E-99	1.30E-02	2.84E-01	1.50E-15	3.34E-05	6.14E-01	0.00E+00	8.58E-01	0.00E+00	6.27E-09
BATCH-1300	2/2/35	18	1.8	0.24	2.73E+01	0.00E+00	1.91E-16	3.46E-13	1.53E-16	6.80E-110	1.30E-02	2.83E-01	1.50E-15	3.33E-05	6.11E-01	0.00E+00	8.55E-01	0.00E+00	6.24E-09
BATCH-1301	2/3/35	14	1.5	0.24	3.49E+01	0.00E+00	1.83E-16	3.11E-13	1.90E-16	2.13E-105	4.00E-03	1.03E-01	2.13E-15	1.49E-05	5.10E-01	0.00E+00	5.77E-01	0.00E+00	5.47E-09
BATCH-1302	2/4/35	15	1.6	0.24	3.30E+01	0.00E+00	1.51E-16	1.69E-04	1.61E-16	8.93E-101	4.00E-03	1.07E-01	6.10E-08	1.63E-05	7.14E-01	0.00E+00	8.94E-01	0.00E+00	1.11E-03
BATCH-1303	2/4/35	16	1.6	0.24	3.31E+01	0.00E+00	1.45E-16	1.91E-04	1.54E-16	2.81E-106	5.00E-03	1.09E-01	6.88E-08	1.65E-05	7.33E-01	0.00E+00	9.28E-01	0.00E+00	1.24E-03
BATCH-1304	5/11/35	122	12.7	0.24	4.00E-03	1.23E+02	1.21E-19	1.90E-02	3.21E-19	4.16E-103	1.23E-01	1.05E+00	6.91E-06	6.29E-04	3.37E+01	0.00E+00	1.34E-04	1.07E+00	1.26E-01
BATCH-1305	5/12/35	122	12.7	0.24	4.00E-03	1.22E+02	1.21E-19	1.90E-02	3.21E-19	6.95E-103	1.22E-01	1.05E+00	6.91E-06	6.28E-04	3.37E+01	0.00E+00	1.33E-04	1.07E+00	1.26E-01
BATCH-1306	5/24/35	122	12.7	0.24	4.00E-03	1.22E+02	1.20E-19	1.90E-02	3.21E-19	1.05E-113	1.22E-01	1.05E+00	6.90E-06	6.28E-04	3.37E+01	0.00E+00	1.33E-04	1.07E+00	1.26E-01
BATCH-1307	5/25/35	122	12.7	0.24	5.00E-03	1.22E+02	1.15E-19	1.90E-02	3.22E-19	2.88E-109	1.22E-01	1.05E+00	6.89E-06	6.27E-04	3.36E+01	0.00E+00	7.78E-05	1.07E+00	1.25E-01
BATCH-1308	6/6/35	167	17.4	0.24	3.26E+01	2.08E+02	1.99E-04	2.00E-02	1.85E-04	1.20E-110	1.50E-02	7.20E-01	1.00E-03	6.00E-03	3.05E+01	0.00E+00	7.76E-01	9.78E+00	5.52E-02
BATCH-1309	6/24/35	80	8.3	0.24	2.51E+02	0.00E+00	3.46E-05	3.00E-03	2.50E-05	2.31E-110	1.30E-02	6.64E-01	1.40E-04	8.99E-04	5.62E+00	0.00E+00	7.99E+00	0.00E+00	8.44E-03
BATCH-1310	6/24/35	31	3.3	0.24	5.68E+01	0.00E+00	1.30E-20	2.00E-03	3.45E-20	4.46E-104	3.40E-02	4.44E-01	7.42E-07	6.75E-05	3.62E+00	0.00E+00	5.23E+00	0.00E+00	1.35E-02
BATCH-1311	6/27/35	60	6.3	0.24	2.00E-03	4.65E+01	2.24E-06	2.80E-02	1.30E-05	6.75E-105	1.80E-01	1.02E+00	9.48E-05	1.00E-03	1.37E+01	0.00E+00	6.75E-05	2.51E+00	2.22E-01
BATCH-1312	7/2/35	31	3.2	0.24	5.66E+01	0.00E+00	1.23E-20	2.00E-03	3.44E-20	3.07E-110	3.40E-02	4.42E-01	7.36E-07	6.70E-05	3.60E+00	0.00E+00	5.21E+00	0.00E+00	1.34E-02
BATCH-1313	7/4/35	31	3.2	0.24	5.67E+01	0.00E+00	1.29E-20	2.00E-03	3.44E-20	7.46E-104	3.40E-02	4.43E-01	7.41E-07	6.74E-05	3.62E+00	0.00E+00	5.23E+00	0.00E+00	1.35E-02
BATCH-1314	7/5/35	31	3.2	0.24	5.67E+01	0.00E+00	1.29E-20	2.00E-03	3.43E-20	1.13E-114	3.40E-02	4.43E-01	7.39E-07	6.72E-05	3.61E+00	0.00E+00	5.22E+00	0.00E+00	1.35E-02
BATCH-1315	7/7/35	29	3.1	0.24	4.75E+01	0.00E+00	1.08E-20	2.00E-03	2.88E-20	3.73E-104	2.90E-02	3.71E-01	6.20E-07	5.64E-05	3.03E+00	0.00E+00	4.38E+00	0.00E+00	1.13E-02
BATCH-1316	7/9/35	22	2.3	0.24	6.06E+01	0.00E+00	8.36E-06	8.00E-04	6.04E-06	5.57E-111	3.00E-03	1.61E-01	3.38E-05	2.17E-04	1.36E+00	0.00E+00	1.93E+00	0.00E+00	2.05E-03
BATCH-1317	7/10/35	77	8.0	0.24	1.36E+02	0.00E+00	1.48E-08	1.00E-02	8.54E-08	4.69E-105	1.32E-01	9.47E-01	1.58E-06	2.26E-04	6.13E+00	0.00E+00	9.62E+00	0.00E+00	7.86E-02
BATCH-1318	7/11/35	29	3.1	0.24	4.73E+01	0.00E+00	1.03E-20	2.00E-03	2.88E-20	2.57E-110	2.80E-02	3.69E-01	6.16E-07	5.60E-05	3.01E+00	0.00E+00	4.36E+00	0.00E+00	1.12E-02
BATCH-1319	7/14/35	29	3.1	0.24	4.75E+01	0.00E+00	1.08E-20	2.00E-03	2.88E-20	6.24E-104	2.90E-02	3.71E-01	6.20E-07	5.64E-05	3.03E+00	0.00E+00	4.38E+00	0.00E+00	1.13E-02
BATCH-1320	7/18/35	29	3.1	0.24	4.74E+01	0.00E+00	1.08E-20	2.00E-03	2.87E-20	9.44E-115	2.90E-02	3.70E-01	6.18E-07	5.62E-05	3.02E+00	0.00E+00	4.37E+00	0.00E+00	1.12E-02
BATCH-1321	7/18/35	10	1.1	0.24	1.12E+01	0.00E+00	2.57E-21	4.07E-04	6.83E-21	8.83E-105	7.00E-03	8.80E-02	1.47E-07	1.34E-05	7.17E-01	0.00E+00	1.04E+00	0.00E+00	2.67E-03
BATCH-1322	7/20/35	8	0.8	0.24	1.44E+01	0.00E+00	1.99E-06	1.90E-04	1.44E-06	1.32E-111	7.29E-04	3.80E-02	8.03E-06	5.16E-05	3.23E-01	0.00E+00	4.59E-01	0.00E+00	4.85E-04

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1274	11/2/34	71	7.4	0.24	4.49E-18	1.67E+01	4.80E-01	0.00E+00	0.00E+00	4.85E-05	4.15E+00	1.00E-02	1.46E-14	1.53E-13	8.70E-02	2.47E-20	1.21E+03	0.00E+00	8.00E-03
BATCH-1275	11/3/34	71	7.4	0.24	4.51E-18	1.67E+01	4.80E-01	0.00E+00	0.00E+00	4.85E-05	4.15E+00	1.00E-02	1.46E-14	1.53E-13	8.70E-02	4.02E-19	1.21E+03	0.00E+00	8.00E-03
BATCH-1276	11/10/34	71	7.4	0.24	4.50E-18	1.66E+01	4.79E-01	0.00E+00	0.00E+00	4.84E-05	4.14E+00	1.00E-02	1.45E-14	1.53E-13	8.70E-02	3.58E-19	1.21E+03	0.00E+00	8.00E-03
BATCH-1277	11/11/34	64	6.6	0.24	1.58E-15	6.73E+00	1.10E-01	0.00E+00	0.00E+00	8.59E-05	5.05E+00	2.00E-03	2.56E-13	4.01E-12	5.50E-02	1.44E-12	1.09E+03	0.00E+00	5.40E-02
BATCH-1278	11/17/34	64	6.7	0.24	1.58E-15	6.36E+00	9.40E-02	0.00E+00	0.00E+00	8.92E-05	5.18E+00	2.00E-03	2.73E-13	4.27E-12	5.50E-02	1.53E-12	1.10E+03	0.00E+00	5.70E-02
BATCH-1279	11/18/34	64	6.7	0.24	1.58E-15	6.36E+00	9.40E-02	0.00E+00	0.00E+00	8.92E-05	5.18E+00	2.00E-03	2.73E-13	4.26E-12	5.50E-02	1.53E-12	1.10E+03	0.00E+00	5.70E-02
BATCH-1280	11/24/34	44	4.6	0.24	1.16E-15	4.38E+00	6.50E-02	0.00E+00	0.00E+00	6.13E-05	3.56E+00	1.00E-03	1.87E-13	2.93E-12	3.80E-02	1.05E-12	7.55E+02	0.00E+00	3.90E-02
BATCH-1281	11/25/34	44	4.6	0.24	1.16E-15	4.37E+00	6.50E-02	0.00E+00	0.00E+00	6.13E-05	3.56E+00	1.00E-03	1.87E-13	2.93E-12	3.80E-02	1.05E-12	7.55E+02	0.00E+00	3.90E-02
BATCH-1282	11/29/34	44	4.6	0.24	1.16E-15	4.37E+00	6.50E-02	0.00E+00	0.00E+00	6.13E-05	3.56E+00	1.00E-03	1.87E-13	2.93E-12	3.80E-02	1.05E-12	7.55E+02	0.00E+00	3.90E-02
BATCH-1283	11/29/34	46	4.8	0.24	1.19E-15	4.51E+00	6.60E-02	0.00E+00	0.00E+00	6.32E-05	3.67E+00	1.00E-03	1.93E-13	3.02E-12	3.90E-02	1.09E-12	7.79E+02	0.00E+00	4.10E-02
BATCH-1284	12/4/34	86	9.0	0.24	2.16E-05	1.26E+01	2.04E-01	0.00E+00	0.00E+00	1.19E-04	1.08E+01	5.00E-03	1.00E-03	1.21E-13	1.13E-01	4.24E-14	1.47E+03	0.00E+00	1.29E-01
BATCH-1285	12/4/34	89	9.2	0.24	2.27E-05	1.31E+01	2.11E-01	0.00E+00	0.00E+00	1.22E-04	1.12E+01	6.00E-03	1.00E-03	5.16E-15	1.17E-01	8.64E-16	1.51E+03	0.00E+00	1.34E-01
BATCH-1286	12/13/34	103	10.7	0.24	2.47E-16	5.17E+00	1.07E+00	0.00E+00	0.00E+00	2.53E-05	1.81E+00	3.00E-03	4.34E-14	6.61E-13	3.00E-02	2.23E-13	1.76E+03	0.00E+00	1.00E-02
BATCH-1287	12/14/34	103	10.7	0.24	2.46E-16	5.16E+00	1.07E+00	0.00E+00	0.00E+00	2.53E-05	1.81E+00	3.00E-03	4.34E-14	6.59E-13	3.00E-02	2.22E-13	1.75E+03	0.00E+00	1.00E-02
BATCH-1288	12/24/34	103	10.7	0.24	2.46E-16	5.13E+00	1.07E+00	0.00E+00	0.00E+00	2.52E-05	1.80E+00	3.00E-03	4.33E-14	6.58E-13	3.00E-02	2.22E-13	1.75E+03	0.00E+00	1.00E-02
BATCH-1289	12/25/34	131	13.6	0.24	6.62E-16	3.22E+00	4.14E-01	0.00E+00	0.00E+00	3.71E-05	2.21E+00	1.00E-03	1.08E-13	1.68E-12	2.50E-02	6.02E-13	2.23E+03	0.00E+00	2.30E-02
BATCH-1290	1/4/35	102	10.6	0.24	3.12E-06	3.33E+00	4.28E-01	0.00E+00	0.00E+00	3.82E-05	2.79E+00	1.00E-03	1.46E-04	1.03E-12	2.90E-02	3.69E-13	1.74E+03	0.00E+00	3.20E-02
BATCH-1291	1/8/35	99	10.3	0.24	3.38E-06	3.36E+00	4.30E-01	0.00E+00	0.00E+00	3.79E-05	2.82E+00	1.00E-03	1.58E-04	9.44E-13	3.00E-02	3.39E-13	1.69E+03	0.00E+00	3.30E-02
BATCH-1292	1/14/35	48	5.0	0.24	1.04E-16	2.17E+00	4.51E-01	0.00E+00	0.00E+00	1.06E-05	7.60E-01	1.00E-03	1.83E-14	2.78E-13	1.30E-02	9.38E-14	8.24E+02	0.00E+00	4.00E-03
BATCH-1293	1/18/35	48	5.0	0.24	1.04E-16	2.17E+00	4.50E-01	0.00E+00	0.00E+00	1.06E-05	7.59E-01	1.00E-03	1.82E-14	2.77E-13	1.30E-02	9.37E-14	8.24E+02	0.00E+00	4.00E-03
BATCH-1294	1/20/35	48	5.0	0.24	1.03E-16	2.16E+00	4.49E-01	0.00E+00	0.00E+00	1.06E-05	7.56E-01	1.00E-03	1.82E-14	2.77E-13	1.30E-02	9.35E-14	8.23E+02	0.00E+00	4.00E-03
BATCH-1295	1/24/35	39	4.1	0.24	1.76E-16	8.53E-01	1.10E-01	0.00E+00	0.00E+00	9.85E-06	5.87E-01	3.12E-04	2.86E-14	4.46E-13	7.00E-03	1.60E-13	6.71E+02	0.00E+00	6.00E-03
BATCH-1296	1/25/35	43	4.5	0.24	1.16E-06	1.25E+00	1.60E-01	0.00E+00	0.00E+00	1.43E-05	1.04E+00	4.54E-04	5.44E-05	3.84E-13	1.10E-02	1.38E-13	7.35E+02	0.00E+00	1.20E-02
BATCH-1297	1/28/35	44	4.5	0.24	1.31E-06	1.31E+00	1.67E-01	0.00E+00	0.00E+00	1.47E-05	1.10E+00	4.83E-04	6.13E-05	3.67E-13	1.20E-02	1.32E-13	7.44E+02	0.00E+00	1.30E-02
BATCH-1298	1/30/35	18	1.8	0.24	2.75E-17	5.77E-01	1.20E-01	0.00E+00	0.00E+00	2.83E-06	2.02E-01	3.21E-04	4.85E-15	7.38E-14	3.00E-03	2.49E-14	3.00E+02	0.00E+00	1.00E-03
BATCH-1299	2/1/35	18	1.8	0.24	2.75E-17	5.75E-01	1.19E-01	0.00E+00	0.00E+00	2.82E-06	2.01E-01	3.20E-04	4.84E-15	7.36E-14	3.00E-03	2.49E-14	3.00E+02	0.00E+00	1.00E-03
BATCH-1300	2/2/35	18	1.8	0.24	2.74E-17	5.72E-01	1.19E-01	0.00E+00	0.00E+00	2.81E-06	2.00E-01	3.18E-04	4.82E-15	7.33E-14	3.00E-03	2.48E-14	2.99E+02	0.00E+00	1.00E-03
BATCH-1301	2/3/35	14	1.5	0.24	4.16E-17	2.02E-01	2.60E-02	0.00E+00	0.00E+00	2.33E-06	1.39E-01	7.40E-05	6.78E-15	1.06E-13	2.00E-03	3.78E-14	2.41E+02	0.00E+00	3.00E-03
BATCH-1302	2/4/35	15	1.6	0.24	2.76E-07	2.95E-01	3.80E-02	0.00E+00	0.00E+00	3.39E-06	2.47E-01	1.08E-04	1.29E-05	9.09E-14	3.00E-03	3.26E-14	2.64E+02	0.00E+00	3.00E-03
BATCH-1303	2/4/35	16	1.6	0.24	3.11E-07	3.09E-01	4.00E-02	0.00E+00	0.00E+00	3.49E-06	2.60E-01	1.14E-04	1.45E-05	8.69E-14	3.00E-03	3.12E-14	2.66E+02	0.00E+00	3.00E-03
BATCH-1304	5/11/35	122	12.7	0.24	3.12E-05	1.81E+01	2.91E-01	0.00E+00	0.00E+00	1.68E-04	1.55E+01	8.00E-03	1.00E-03	3.81E-15	1.62E-01	4.92E-18	2.09E+03	0.00E+00	1.85E-01
BATCH-1305	5/12/35	122	12.7	0.24	3.12E-05	1.80E+01	2.91E-01	0.00E+00	0.00E+00	1.68E-04	1.55E+01	8.00E-03	1.00E-03	3.80E-15	1.61E-01	4.90E-18	2.09E+03	0.00E+00	1.85E-01
BATCH-1306	5/24/35	122	12.7	0.24	3.12E-05	1.80E+01	2.91E-01	0.00E+00	0.00E+00	1.68E-04	1.55E+01	8.00E-03	1.00E-03	3.80E-15	1.61E-01	4.88E-18	2.08E+03	0.00E+00	1.85E-01
BATCH-1307	5/25/35	122	12.7	0.24	3.11E-05	1.80E+01	2.90E-01	0.00E+00	0.00E+00	1.68E-04	1.55E+01	8.00E-03	1.00E-03	3.80E-15	1.61E-01	6.14E-18	2.08E+03	0.00E+00	1.84E-01
BATCH-1308	6/6/35	167	17.4	0.24	3.17E-05	6.31E+01	2.57E-01	0.00E+00	0.00E+00	2.20E-03	8.91E+01	2.00E-03	9.59E-04	8.80E-02	5.91E-01	2.30E-02	2.86E+03	0.00E+00	2.32E-01
BATCH-1309	6/24/35	80	8.3	0.24	1.23E-06	1.04E+01	3.98E-01	0.00E+00	0.00E+00	6.00E-04	1.28E+01	2.54E-04	9.08E-05	1.60E-02	4.80E-02	4.00E-03	1.36E+03	0.00E+00	3.40E-02
BATCH-1310	6/24/35	31	3.3	0.24	3.35E-06	1.94E+00	2.52E-01	0.00E+00	0.00E+00	1.81E-05	1.66E+00	8.21E-04	1.57E-04	4.09E-16	1.70E-02	5.28E-19	5.33E+02	0.00E+00	2.00E-02
BATCH-1311	6/27/35	60	6.3	0.24	1.32E-05	2.56E+01	4.38E-01	0.00E+00	0.00E+00	4.00E-04	8.45E+00	1.30E-02	4.21E-04	5.85E-05	1.94E-01	5.89E-05	1.03E+03	0.00E+00	8.00E-02
BATCH-1312	7/2/35	31	3.2	0.24	3.33E-06	1.92E+00	2.51E-01	0.00E+00	0.00E+00	1.79E-05	1.65E+00	8.15E-04	1.56E-04	4.06E-16	1.70E-02	6.56E-19	5.30E+02	0.00E+00	2.00E-02
BATCH-1313	7/4/35	31	3.2	0.24	3.35E-06	1.94E+00	2.52E-01	0.00E+00	0.00E+00	1.80E-05	1.66E+00	8.20E-04	1.56E-04	4.08E-16	1.70E-02	5.26E-19	5.33E+02	0.00E+00	2.00E-02
BATCH-1314	7/5/35	31	3.2	0.24	3.34E-06	1.93E+00	2.52E-01	0.00E+00	0.00E+00	1.80E-05	1.66E+00	8.18E-04	1.56E-04	4.07E-16	1.70E-02	5.23E-19	5.32E+02	0.00E+00	2.00E-02
BATCH-1315	7/7/35	29	3.1	0.24	2.80E-06	1.62E+00	2.11E-01	0.00E+00	0.00E+00	1.51E-05	1.39E+00	6.87E-04	1.31E-04	3.42E-16	1.50E-02	4.42E-19	5.03E+02	0.00E+00	1.70E-02
BATCH-1316	7/9/35	22	2.3	0.24	2.98E-07	2.53E+00	9.60E-02	0.00E+00	0.00E+00	1.51E-04	3.08E+00	6.13E-05	2.19E-05	4.00E-03	1.20E-02	1.00E-03	3.73E+02	0.00E+00	8.00E-03
BATCH-1317	7/10/35	77	8.0	0.24	4.38E-06	9.11E+00	7.17E-01	0.00E+00	0.00E+00	8.03E-05	3.35E+00	5.00E-03	2.03E-04	3.86E-07	4.50E-02	3.88E-07	1.31E+03	0.00E+00	3.10E-02
BATCH-1318	7/11/35	29	3.1	0.24	2.78E-06	1.61E+00	2.10E-01	0.00E+00	0.00E+00	1.50E-05	1.38E+00	6.82E-04	1.30E-04	3.40E-16	1.40E-02	5.49E-19	5.01E+02	0.00E+00	1.60E-02
BATCH-1319	7/14/35	29	3.1	0.24	2.80E-06	1.62E+00	2.11E-01	0.00E+00	0.00E+00	1.51E-05	1.39E+00	6.86E-04	1.31E-04	3.41E-16	1.40E-02	4.40E-19	5.03E+02	0.00E+00	1.70E-02
BATCH-1320	7/18/35	29	3.1	0.24	2.79E-06	1.62E+00	2.11E-01	0.00E+00	0.00E+00	1.51E-05	1.39E+00	6.85E-04	1.31E-04	3.41E-16	1.40E-02	4.37E-19	5.02E+02	0.00E+00	1.70E-02
BATCH-1321	7/18/35	10	1.1	0.24	6.63E-07	3.84E-01	5.00E-02	0.00E+00	0.00E+00	3.58E-06	3.29E-01	1.63E-04	3.10E-05	8.09E-17	3.00E-03	1.05E-19	1.79E+02	0.00E+00	4.00E-03
BATCH-1322	7/20/35	8	0.8	0.24	7.09E-08	6.00E-01	2.30E-02	0.00E+00	0.00E+00	3.59E-05	7.32E-01	1.46E-05	5.22E-06	9.44E-04	3.00E-03	2.50E-04	1.34E+02	0.00E+00	2.00E-03

Appendix A Nominal ILAW Inventory
TWRS0&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date.
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2-	NO3-	OH-(BOUN	OH-	Pb+2	PO4-3	Se+6	Si+4	SO4-2	Sr+2	Ti+4	TOC	U(TOTAL)	Zn+2	Zr+4
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1274	11/2/34	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	5.93E+01	9.55E-23	5.23E+00	2.10E+01	7.00E-03	2.51E-21	0.00E+00	2.60E-05	9.89E-14	1.00E-03
BATCH-1275	11/3/34	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	5.92E+01	1.76E-20	5.23E+00	2.10E+01	7.00E-03	4.03E-21	0.00E+00	2.60E-05	9.88E-14	1.00E-03
BATCH-1276	11/10/34	71	7.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-02	5.91E+01	1.57E-20	5.22E+00	2.10E+01	7.00E-03	3.49E-21	0.00E+00	2.60E-05	9.87E-14	1.00E-03
BATCH-1277	11/11/34	64	6.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-02	1.43E+01	1.39E-15	3.57E+00	1.44E+01	2.00E-03	1.76E-13	0.00E+00	2.66E-05	9.57E-12	8.67E-04
BATCH-1278	11/17/34	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	1.24E+01	1.49E-15	3.55E+00	1.44E+01	2.00E-03	1.88E-13	0.00E+00	2.71E-05	1.02E-11	8.71E-04
BATCH-1279	11/18/34	64	6.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-02	1.23E+01	1.48E-15	3.54E+00	1.44E+01	2.00E-03	1.88E-13	0.00E+00	2.71E-05	1.02E-11	8.71E-04
BATCH-1280	11/24/34	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	8.51E+00	1.02E-15	2.44E+00	9.88E+00	1.00E-03	1.29E-13	0.00E+00	1.87E-05	7.01E-12	5.99E-04
BATCH-1281	11/25/34	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	8.51E+00	1.02E-15	2.44E+00	9.87E+00	1.00E-03	1.29E-13	0.00E+00	1.86E-05	7.01E-12	5.99E-04
BATCH-1282	11/29/34	44	4.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02	8.51E+00	1.02E-15	2.44E+00	9.87E+00	1.00E-03	1.33E-13	0.00E+00	1.86E-05	7.00E-12	5.99E-04
BATCH-1283	11/29/34	46	4.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-02	8.75E+00	1.05E-15	2.51E+00	1.02E+01	1.00E-03	1.33E-13	0.00E+00	1.92E-05	7.23E-12	6.18E-04
BATCH-1284	12/4/34	86	9.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-02	2.27E+01	4.11E-17	4.11E+00	2.61E+01	3.00E-03	5.20E-15	0.00E+00	6.80E-04	2.36E-05	3.56E-04
BATCH-1285	12/4/34	89	9.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-02	2.35E+01	8.38E-19	4.22E+00	2.70E+01	3.00E-03	1.06E-16	0.00E+00	7.15E-04	2.48E-05	3.50E-04
BATCH-1286	12/13/34	103	10.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.56E+02	2.16E-16	2.78E+01	7.87E+00	2.00E-03	2.74E-14	0.00E+00	1.86E-05	1.51E-12	4.03E-04
BATCH-1287	12/14/34	103	10.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.56E+02	2.16E-16	2.78E+01	7.85E+00	2.00E-03	2.73E-14	0.00E+00	1.85E-05	1.51E-12	4.01E-04
BATCH-1288	12/24/34	103	10.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.56E+02	2.16E-16	2.77E+01	7.82E+00	2.00E-03	2.73E-14	0.00E+00	1.85E-05	1.51E-12	3.89E-04
BATCH-1289	12/25/34	131	13.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	5.62E+01	5.83E-16	2.23E+01	6.79E+00	1.00E-03	7.38E-14	0.00E+00	4.01E-05	2.61E-12	2.58E-04
BATCH-1290	1/4/35	102	10.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.75E+01	3.57E-16	3.65E+01	7.49E+00	8.17E-04	4.52E-14	0.00E+00	1.15E-04	3.41E-06	2.45E-04
BATCH-1291	1/8/35	99	10.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	3.68E+01	3.29E-16	3.71E+01	7.53E+00	8.11E-04	4.16E-14	0.00E+00	1.22E-04	3.69E-06	2.45E-04
BATCH-1292	1/14/35	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.57E+01	9.09E-17	1.17E+01	3.31E+00	8.23E-04	1.15E-14	0.00E+00	7.80E-06	6.35E-13	1.69E-04
BATCH-1293	1/18/35	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.57E+01	9.08E-17	1.17E+01	3.30E+00	8.21E-04	1.15E-14	0.00E+00	7.78E-06	6.34E-13	1.69E-04
BATCH-1294	1/20/35	48	5.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	6.55E+01	9.06E-17	1.17E+01	3.29E+00	8.18E-04	1.15E-14	0.00E+00	6.93E-06	1.06E-12	1.03E-04
BATCH-1295	1/24/35	39	4.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.49E+01	1.55E-16	5.92E+00	1.80E+00	2.71E-04	1.96E-14	0.00E+00	4.29E-05	1.27E-06	9.63E-05
BATCH-1296	1/25/35	43	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.40E+01	1.33E-16	1.37E+01	2.80E+00	3.05E-04	1.69E-14	0.00E+00	4.75E-05	1.44E-06	9.52E-05
BATCH-1297	1/28/35	44	4.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	1.43E+01	1.28E-16	1.44E+01	2.93E+00	3.15E-04	1.62E-14	0.00E+00	2.07E-06	1.69E-13	4.50E-05
BATCH-1298	1/30/35	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.21E-04	1.75E+01	2.42E-17	3.10E+00	8.78E-01	2.19E-04	3.06E-15	0.00E+00	2.07E-06	1.68E-13	4.49E-05
BATCH-1299	2/1/35	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.18E-04	1.74E+01	2.41E-17	3.10E+00	8.76E-01	2.18E-04	3.05E-15	0.00E+00	2.06E-06	1.68E-13	4.46E-05
BATCH-1300	2/2/35	18	1.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.15E-04	1.74E+01	2.40E-17	3.09E+00	8.71E-01	2.17E-04	3.04E-15	0.00E+00	2.06E-06	2.52E-13	2.45E-05
BATCH-1301	2/3/35	14	1.5	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.58E-04	3.54E+00	3.67E-17	1.40E+00	4.27E-01	6.41E-05	4.64E-15	0.00E+00	1.64E-06	1.02E-05	2.28E-05
BATCH-1302	2/4/35	15	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.32E+00	3.16E-17	3.24E+00	6.93E-01	7.23E-05	4.00E-15	0.00E+00	1.02E-05	3.02E-07	2.28E-05
BATCH-1303	2/4/35	16	1.6	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.39E+00	3.02E-17	3.41E+00	6.93E-01	7.47E-05	3.83E-15	0.00E+00	1.13E-05	3.40E-07	2.25E-05
BATCH-1304	5/11/35	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	3.24E+01	6.24E-21	5.82E+00	3.72E+01	4.00E-03	5.85E-19	0.00E+00	9.85E-04	3.42E-05	4.81E-04
BATCH-1305	5/12/35	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	3.24E+01	6.23E-21	5.82E+00	3.72E+01	4.00E-03	5.83E-19	0.00E+00	9.85E-04	3.41E-05	4.81E-04
BATCH-1306	5/24/35	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	3.24E+01	6.20E-21	5.81E+00	3.72E+01	4.00E-03	5.80E-19	0.00E+00	9.84E-04	3.41E-05	4.81E-04
BATCH-1307	5/25/35	122	12.7	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-02	3.23E+01	7.42E-21	5.80E+00	3.71E+01	4.00E-03	7.35E-19	0.00E+00	9.82E-04	3.41E-05	4.80E-04
BATCH-1308	6/6/35	167	17.4	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.40E-02	2.03E+01	2.52E-05	1.09E+01	5.04E+01	8.00E-03	4.00E-03	0.00E+00	5.92E-01	1.98E-01	3.93E-01
BATCH-1309	6/24/35	80	8.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.15E+01	4.57E-06	1.34E+01	5.32E+00	5.00E-03	7.18E-04	0.00E+00	1.00E-02	3.70E-02	7.00E-02
BATCH-1310	6/24/35	31	3.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.33E+01	6.70E-22	2.43E+01	4.20E+00	3.95E-04	6.28E-20	0.00E+00	1.08E-04	3.67E-06	5.17E-05
BATCH-1311	6/27/35	60	6.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-02	3.90E+01	1.48E-07	6.92E+00	2.39E+01	1.40E-02	6.19E-06	0.00E+00	2.00E-03	8.93E-04	4.00E-03
BATCH-1312	7/2/35	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.32E+01	7.93E-22	2.42E+01	4.17E+00	3.92E-04	7.85E-20	0.00E+00	1.07E-04	3.64E-06	5.13E-05
BATCH-1313	7/4/35	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	1.33E+01	6.68E-22	2.43E+01	4.20E+00	3.94E-04	6.25E-20	0.00E+00	1.08E-04	3.66E-06	5.16E-05
BATCH-1314	7/5/35	31	3.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	1.32E+01	6.64E-22	2.43E+01	4.19E+00	3.93E-04	6.22E-20	0.00E+00	1.07E-04	3.65E-06	5.15E-05
BATCH-1315	7/7/35	29	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.11E+01	5.61E-22	2.03E+01	3.52E+00	3.30E-04	5.25E-20	0.00E+00	9.01E-05	3.07E-06	4.32E-05
BATCH-1316	7/9/35	22	2.3	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	2.78E+00	1.10E-06	3.23E+00	1.29E+00	1.00E-03	1.74E-04	0.00E+00	2.00E-03	9.00E-03	1.70E-02
BATCH-1317	7/10/35	77	8.0	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-02	4.53E+01	9.77E-10	3.84E+01	9.97E+00	5.00E-03	4.08E-08	0.00E+00	2.22E-04	1.06E-05	2.65E-04
BATCH-1318	7/11/35	29	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.10E+01	6.63E-22	2.03E+01	3.49E+00	3.28E-04	6.57E-20	0.00E+00	8.95E-05	3.04E-06	4.29E-05
BATCH-1319	7/14/35	29	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.11E+01	5.59E-22	2.03E+01	3.51E+00	3.30E-04	5.23E-20	0.00E+00	9.00E-05	3.06E-06	4.32E-05
BATCH-1320	7/18/35	29	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-03	1.11E+01	5.56E-22	2.03E+01	3.50E+00	3.29E-04	5.20E-20	0.00E+00	8.98E-05	3.06E-06	4.31E-05
BATCH-1321	7/18/35	10	1.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.63E+00	1.33E-22	4.81E+00	8.32E-01	7.81E-05	1.24E-20	0.00E+00	2.13E-05	7.25E-07	1.02E-05
BATCH-1322	7/20/35	8	0.8	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.32E-04	6.60E-01	2.62E-07	7.68E-01	3.06E-01	3.11E-04	4.13E-05	0.00E+00	5.85E-04	2.00E-03	4.00E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	3-H	14-C	59-Ni	60-Co	63-Ni	79-Se	90-Sr	93-Zr	93m-Nb	99-Tc	106-Ru	113m-Cd	125-Sb	126-Sn	129-I
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					0.00	0.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25
BATCH-1323	7/21/35	10	1.1	0.24	0.00E+00	0.00E+00	3.00E-03	7.82E-05	2.48E-01	9.90E-03	5.34E+00	4.00E-03	1.00E-03	4.91E-01	3.04E-19	3.20E-02	6.34E-06	1.30E-02	9.86E-06
BATCH-1324	7/21/35	10	1.1	0.24	0.00E+00	0.00E+00	3.00E-03	7.86E-05	2.49E-01	9.90E-03	5.37E+00	4.00E-03	1.00E-03	4.94E-01	3.06E-19	3.20E-02	6.38E-06	1.30E-02	9.92E-06
BATCH-1325	7/22/35	30	3.1	0.24	0.00E+00	0.00E+00	8.00E-03	1.86E-04	5.85E-01	4.14E-02	6.03E+02	1.90E-02	7.00E-03	1.33E+00	4.90E-17	7.30E-02	3.46E-05	3.10E-02	8.56E-05
BATCH-1326	7/22/35	10	1.1	0.24	0.00E+00	0.00E+00	3.00E-03	7.85E-05	2.49E-01	9.90E-03	5.36E+00	4.00E-03	1.00E-03	4.93E-01	3.05E-19	3.20E-02	6.37E-06	1.30E-02	9.90E-06
BATCH-1327	7/25/35	11	1.2	0.24	0.00E+00	0.00E+00	2.00E-03	4.37E-05	1.38E-01	9.90E-03	2.21E+02	4.00E-03	2.00E-03	3.12E-01	1.16E-17	1.70E-02	8.14E-06	7.00E-03	2.01E-05

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	134-Cs	137-Cs	151-Sm	152-Eu	154-Eu	155-Eu	226-Ra	227-Ac	228-Ra	229-Th	231-Pa	232-Th	232-U	233-U	234-U
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1323	7/21/35	10	1.1	0.24	3.41E-10	3.12E+01	1.10E-02	1.01E-05	5.95E-04	2.29E-05	5.06E-08	3.27E-10	1.32E-06	1.81E-07	9.69E-07	8.75E-07	1.77E-05	1.10E-04	2.82E-05
BATCH-1324	7/21/35	10	1.1	0.24	3.43E-10	3.14E+01	1.10E-02	1.02E-05	5.99E-04	2.30E-05	5.09E-08	3.29E-10	1.33E-06	1.82E-07	9.75E-07	8.80E-07	1.78E-05	1.11E-04	2.84E-05
BATCH-1325	7/22/35	30	3.1	0.24	8.31E-10	9.04E+01	4.44E-01	1.10E-04	7.00E-03	2.44E-04	1.23E-04	1.30E-08	3.15E-06	6.19E-07	3.43E-06	2.85E-06	6.62E-05	4.72E-04	2.30E-04
BATCH-1326	7/22/35	10	1.1	0.24	3.43E-10	3.13E+01	1.10E-02	1.01E-05	5.98E-04	2.30E-05	5.08E-08	3.28E-10	1.33E-06	1.81E-07	9.73E-07	8.78E-07	1.78E-05	1.10E-04	2.83E-05
BATCH-1327	7/25/35	11	1.2	0.24	1.96E-10	3.32E+01	1.05E-01	2.58E-05	2.00E-03	5.75E-05	2.89E-05	3.05E-09	7.42E-07	1.46E-07	8.08E-07	6.70E-07	1.56E-05	1.11E-04	5.42E-05

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	235-U	236-U	237-Np	238-Pu	238-U	239-Pu	240-Pu	241-Am	241-Pu	242-Cm	242-Pu	243-Am	243-Cm	244-Cm	Ag+
					Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BATCH-1323	7/21/35	10	1.1	0.24	1.16E-06	8.57E-07	3.04E-05	5.00E-03	2.59E-05	1.96E-01	3.40E-02	1.76E-01	5.60E-02	2.96E-31	3.04E-06	5.09E-06	7.62E-05	5.95E-04	7.15E-07
BATCH-1324	7/21/35	10	1.1	0.24	1.17E-06	8.62E-07	3.06E-05	5.00E-03	2.60E-05	1.97E-01	3.50E-02	1.77E-01	5.60E-02	2.98E-31	3.06E-06	5.12E-06	7.67E-05	5.98E-04	7.19E-07
BATCH-1325	7/22/35	30	3.1	0.24	9.78E-06	5.30E-06	1.86E-04	1.40E-02	2.29E-04	4.93E-01	9.30E-02	7.65E-01	1.31E-01	8.94E-31	1.39E-05	1.30E-05	4.90E-04	5.00E-03	1.63E-06
BATCH-1326	7/22/35	10	1.1	0.24	1.17E-06	8.60E-07	3.05E-05	5.00E-03	2.60E-05	1.96E-01	3.50E-02	1.76E-01	5.60E-02	2.97E-31	3.05E-06	5.11E-06	7.65E-05	5.97E-04	7.17E-07
BATCH-1327	7/25/35	11	1.2	0.24	2.30E-06	1.25E-06	4.39E-05	3.00E-03	5.40E-05	1.16E-01	2.20E-02	1.80E-01	3.10E-02	2.11E-31	3.28E-06	3.07E-06	1.15E-04	1.00E-03	3.84E-07

Appendix A Nominal ILAW Inventory
TWRS O&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Al(OH)4- kg-mol	Al+3 kg-mol	As+5 kg-mol	B+3 kg-mol	Ba+2 kg-mol	Be+2 kg-mol	Bi+3 kg-mol	Ca+2 kg-mol	Cd+2 kg-mol	Ce+3 kg-mol	Cl- kg-mol	CO3-2 kg-mol	Cr(OH)4- kg-mol	Cr(TOTAL) kg-mol	Cs+ kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1323	7/21/35	10	1.1	0.24	1.12E+01	0.00E+00	2.44E-21	4.04E-04	6.81E-21	6.08E-111	7.00E-03	8.70E-02	1.46E-07	1.33E-05	7.11E-01	0.00E+00	1.03E+00	0.00E+00	2.64E-03
BATCH-1324	7/21/35	10	1.1	0.24	1.12E+01	0.00E+00	2.56E-21	4.06E-04	6.81E-21	1.48E-104	7.00E-03	8.80E-02	1.47E-07	1.33E-05	7.16E-01	0.00E+00	1.04E+00	0.00E+00	2.67E-03
BATCH-1325	7/22/35	30	3.1	0.24	4.65E+01	0.00E+00	5.07E-09	3.00E-03	2.93E-08	1.61E-105	4.50E-02	3.25E-01	5.40E-07	7.76E-05	2.10E+00	0.00E+00	3.30E+00	0.00E+00	2.70E-02
BATCH-1326	7/22/35	10	1.1	0.24	1.12E+01	0.00E+00	2.55E-21	4.05E-04	6.80E-21	2.23E-115	7.00E-03	8.80E-02	1.46E-07	1.33E-05	7.14E-01	0.00E+00	1.03E+00	0.00E+00	2.67E-03
BATCH-1327	7/25/35	11	1.2	0.24	1.09E+01	0.00E+00	1.19E-09	8.20E-04	6.90E-09	3.79E-106	1.10E-02	7.70E-02	1.27E-07	1.83E-05	4.95E-01	0.00E+00	7.77E-01	0.00E+00	6.36E-03

Appendix A Nominal ILAW Inventory

TWRS O&UP Case 3 by LAW feed batch with offgas losses

(Components are decayed to starting date,

units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	Cu+2	F-	Fe+3	H+	H2O	Hg+2	K+	La+3	Li+	Mg+2	Mn+4	Mo+6	Na+	NH3	Ni+2
					kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol	kg-mol
Fraction Remaining After Volatization Losses					1.00	1.00	1.00	1.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
BATCH-1323	7/21/35	10	1.1	0.24	6.59E-07	3.81E-01	5.00E-02	0.00E+00	0.00E+00	3.55E-06	3.27E-01	1.61E-04	3.06E-05	8.04E-17	3.00E-03	1.30E-19	1.78E+02	0.00E+00	4.00E-03
BATCH-1324	7/21/35	10	1.1	0.24	6.62E-07	3.83E-01	5.00E-02	0.00E+00	0.00E+00	3.57E-06	3.29E-01	1.62E-04	3.10E-05	8.08E-17	3.00E-03	1.04E-19	1.79E+02	0.00E+00	4.00E-03
BATCH-1325	7/22/35	30	3.1	0.24	1.50E-06	3.13E+00	2.46E-01	0.00E+00	0.00E+00	2.76E-05	1.15E+00	2.00E-03	6.98E-05	1.32E-07	1.50E-02	1.33E-07	5.15E+02	0.00E+00	1.10E-02
BATCH-1326	7/22/35	10	1.1	0.24	6.61E-07	3.82E-01	5.00E-02	0.00E+00	0.00E+00	3.56E-06	3.28E-01	1.62E-04	3.09E-05	8.06E-17	3.00E-03	1.03E-19	1.79E+02	0.00E+00	4.00E-03
BATCH-1327	7/25/35	11	1.2	0.24	3.54E-07	7.36E-01	5.80E-02	0.00E+00	0.00E+00	6.49E-06	2.71E-01	3.85E-04	1.64E-05	3.12E-08	4.00E-03	3.13E-08	1.89E+02	0.00E+00	2.00E-03

Appendix A Nominal ILAW Inventory
TWRSO&UP Case 3 by LAW feed batch with offgas losses
(Components are decayed to starting date,
units are Ci for radionuclides and kg-mol for chemicals)

Batch	Starting Date	Total m3 glass	Processing Days	Days to fill cask	NO2- kg-mol	NO3- kg-mol	OH(BOUN kg-mol	OH- kg-mol	Pb+2 kg-mol	PO4-3 kg-mol	Se+6 kg-mol	Si+4 kg-mol	SO4-2 kg-mol	Sr+2 kg-mol	TH+4 kg-mol	TOC kg-mol	U(TOTAL) kg-mol	Zn+2 kg-mol	Zr+4 kg-mol
Fraction Remaining After Volatization Losses					0.00	0.00	0.00	0.00	1.00	1.00	0.90	1.00	0.90	1.00	1.00	0.00	1.00	1.00	1.00
BATCH-1323	7/21/35	10	1.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.61E+00	1.57E-22	4.79E+00	8.26E-01	7.76E-05	1.55E-20	0.00E+00	2.12E-05	7.20E-07	1.02E-05
BATCH-1324	7/21/35	10	1.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.63E+00	1.32E-22	4.81E+00	8.31E-01	7.80E-05	1.24E-20	0.00E+00	2.13E-05	7.24E-07	1.02E-05
BATCH-1325	7/22/35	30	3.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03	1.55E+01	3.35E-10	1.32E+01	3.42E+00	2.00E-03	1.40E-08	0.00E+00	7.61E-05	3.63E-06	9.10E-05
BATCH-1326	7/22/35	10	1.1	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	2.62E+00	1.31E-22	4.80E+00	8.29E-01	7.79E-05	1.23E-20	0.00E+00	2.13E-05	7.23E-07	1.02E-05
BATCH-1327	7/25/35	11	1.2	0.24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	3.66E+00	7.89E-11	3.10E+00	8.06E-01	3.71E-04	3.30E-09	0.00E+00	1.79E-05	8.55E-07	2.14E-05

Appendix B

Additional Information on Biases and Uncertainties for Selected Radionuclides

Discussion on Selected ILAW Inventory Components

Tritium. The global and model estimates for tritium are highly dependant on vapor/liquid partitioning assumptions that distribute tritium between airborne releases, process condensate releases to cribs and evaporator bottoms sent to the tanks. The HDW model assumes that 100 percent of tritium in fuel is routed to tank wastes. Due to losses to atmosphere and condensate, actual tank inventories are significantly less.

The best basis inventory (tank by tank summation) includes some tritium sample-based estimates for individual tanks, but nearly all values are estimated by the HDW model. Since most of the best-basis values are from the HDW model the best basis inventory is expected to be conservative relative to the actual inventory.

No tritium is expected to survive the vitrification process to end up in the ILAW packages (Kirkbride 1999). Tritium is expected to be discharged from the pretreatment and waste vitrification facilities in the process condensates as tritiated water. The excess process condensates that are not recycled are routed to Effluent Treatment Facility.

Carbon-14. The activation product ^{14}C is produced primarily from neutron activation of nitrogen impurities in the fuel and cladding. Most of the individual tank best-basis estimates and all of the global inventory are derived from HDW model results (Kupfer 1999). HDW predictions of ^{14}C production have a likely bias of 0.80. Additional uncertainty may exist, associated with losses of ^{14}C to atmospheric emissions (Harmsen 1998).

Nickel-59 and Nickel-63. These radionuclides are generated by neutron activation of nickel impurities in the fuel cladding. Nearly all the best basis inventory values are derived from the HDW model results. Beginning in 1959 the aluminum alloy fuel cladding contained 9,000 to 13000 ppm nickel. Prior to1959 the fuel cladding alloy contained no more than 100 ppm nickel. The HDW model assumes a constant 800 ppm, thus ^{59}Ni and ^{63}Ni activation products are biased high for pre-1959 wastes and biased low for post 1959 wastes. Modeling of the effect of this variation in nickel impurity in the fuel cladding resulted in higher total inventory values by a factor of 1.18 for ^{59}Ni and a factor of 1.35 for ^{63}Ni (Harmsen 1998). The best basis inventory is considered accurate although few sample results are available.

Co-60. The ORIGEN2 estimates for activation product, ^{60}Co, assume a cobalt impurity level of 10 ppm in cladding and 0 ppm in core uranium. Since the actual levels of cobalt in uranium are unknown but probably not zero, it is predictable that the HDW model results are low. Improved modeling of the cobalt impurity increased the HDW tank inventory by a factor of 2.75. The best-basis tank sum is considered to be the more accurate estimate, since almost half of the tank sum is based on sample data.

Selenium-79. Most of the best-basis (tank-by-tank summation) and all of the global inventory estimate for ^{79}Se are based on the HDW model. Recent Chinese measurements indicate the half life of ^{79}Se should be increased from 0.65×10^5 years to 8.05×10^5 years (Harmsen 1998). Curie values for ^{79}Se based on the HDW model can be reduced by about a factor of twelve by using the updated half life value. ORIGEN2 based calculations of ^{79}Se production should be reduced by a

factor of 0.85 to account for a lower fission yield. The total tank inventory is considered to be conservative, since it neglects previous removals such as cribbing.

Strontium-90 and Yttrium-90. The tank summation and global inventories for ^{90}Sr agree within 20%. These inventories account for the quantity of ^{90}Sr separated in B-Plant and routed to capsules, offsite, plant residuals, and solid waste. The majority of the tank summation inventory is based on samples.

Zirconium-93, Niobium-93m, Cadmium-113m, Tin-126, and Samarium-151. The ^{93}Sr, ^{93m}Nb, ^{113m}Cd, ^{126}Sn, and ^{151}Sm values in the best basis inventory are almost entirely derived from the HDW Rev 4 model and are subject to the model limitations. The HDW model over-estimates the distribution of these isotopes to tanks 241-AZ-101 and 241-AZ-102 based on the special ORIGEN2 run for these tanks and under-estimates the inventory of these isotopes in the rest of the tanks. The tank-by-tank summation corrects the inventory of 241-AZ-101 and 241-AZ-102 but does not adjust the inventory of the rest of the tanks (i.e., HDW values are used). The result is that the best-basis inventory slightly under-estimates the ^{93}Zr, ^{93m}Nb, ^{113m}Cd, ^{126}Sn, and ^{151}Sm inventories (Kupfer 1999).

The HDW curie value of ^{126}Sn should be reduced by a factor of 0.4 to account for a recently updated half life value, and by a factor of 0.78 to account for better fission yield value (Harmsen 1998). The HDW calculated values for ^{113m}Cd should be reduced by a factor of 0.66 to account for better fission yield and cross section values (Harmsen 1998).

Technetium-99. The best basis value for ^{99}Tc agrees reasonably well with the process knowledge based (global) estimate. The best basis value is likely the more valid since the global estimate does not account for known losses of ^{99}Tc that occurred during fuel separation operations (Kupfer 1999).

There is good evidence that 20% or more of the technetium produced was lost to the waste stream during initial fuel reprocessing, mainly co-processed with the UO_3 and sent offsite, but with minor losses to the environment as well (Schmittroth 1995).

The HDW global inventory for ^{99}Tc may be biased high by about 32% due to it's not accounting for the fractional separation of Tc to the uranium product stream in the uranium recovery, PUREX and REDOX processes (cribbing, offsite shipment, U contaminant). Approximately 60% of the tank summation inventory is based on the HDW model (Kupfer 1999).

The batchwise ILAW inventory for Case 3 from the TWRSO&UP meets the Phase 1 contract specifications for average activity, but not the 80% removal requirement.

Ruthenium-106. Ninety-nine percent of the ^{106}Ru inventory is found in tanks 241-AZ-101 and 241-AZ-102 (Kupfer 1999).

Antimony-125. Eighty-nine percent of the ^{125}Sb inventory is found in tanks 241-AZ-101 and 241-AZ-102. The best basis inventory estimates from the special ORIGEN2 run for these tanks shows about 25 percent more ^{125}Sb than does the global (HDW model) for these tanks. The

^{125}Sb best-basis inventory of the rest of the tanks is nearly all from the HDW model values (Kupfer 1999).

Iodine-129. The best-basis of ^{129}I is somewhat larger than the global estimate. The global (HDW model) estimate conservatively assumes that all of the ^{129}I in the fuel was routed to the waste tanks. Thus the reason for the higher tank sum is not inherently obvious. The difference could be due to sample error, but is likely not due to underestimated model values. Both best basis and global inventory values are likely to be significantly higher than actual values (Kupfer 1999).

The calculated ^{129}I production in the fuel could be reduced by a factor of 0.76 to account for a better fission yield value (Harmsen 1998).

Cesium-134. Then ^{134}Cs values in the best-basis inventory are primarily derived from the HDW Rev 4 model and are subject to the model limitations. The HDW model slightly under-estimates the distribution of ^{134}Cs to tanks 241-AZ-101 and 241-AZ-102. The tank-by-tank summation corrects the inventory of 241-AZ-101 and 241-AZ-102 but does not adjust the inventory of the rest of the tanks. The result is that the best-basis inventory slightly under-estimates the ^{134}Cs inventory (Kupfer 1999).

The TWRSO&UP inventory as currently configured does not remove ^{134}Cs or Cs+ from the LAW feed along with ^{137}Cs removals. Therefore the ^{134}Cs and Cs+ values were adjusted so that the ILAW to BBI ratios were the same as for ^{137}Cs. This adjustment was applied to the Appendix HA values.

Cesium-137 and Barium-137m. The ^{137}Cs inventory in the ILAW is constrained by the BNFL Inc. Phase 1 contract specifications.

The best-basis values for ^{137}Cs and ^{137m}Ba agree with the global values.

Europium-152. The ^{152}Eu values in the best-basis inventory are primarily derived from the HDW Rev 4 model and are subject to the model limitations. The HDW model overestimates the inventory of ^{152}Eu to tanks 241-AZ-101 and 241-AZ-102 based on the special ORIGEN2 run for these tanks and underestimates the ^{152}Eu inventory in the rest of the tanks. The tank-by-tank summation corrects the inventory of 241-AZ-101 and 241-AZ-102 but does not adjust the inventory of the rest of the tanks, i.e., HDW values are used. Tanks 241-AZ-101 and 241-AZ-102 contain 28 percent of the ^{152}Eu inventory. The result is that the best-basis inventory slightly underestimates the ^{152}Eu inventory (Kupfer 1999).

Europium-154. The best basis of ^{154}Eu is significantly larger than the global estimate. The global ^{154}Eu estimates for 241-AZ-101 and 241-AZ-102 from the HDW model are 30 percent lower than the best-basis ORIGEN2 estimates. Tanks 241-AZ-101 and 241-AZ-102 account for 40 percent of the best-basis inventory. The balance of the best basis inventory, which includes sample values and engineering estimates is about 25 percent higher than the balance of the global HDW model estimate (Kupfer 1999).

Europium-155. The best basis of ^{155}Eu is significantly larger than the global estimate. The ORIGEN2 estimates of ^{155}Eu in tanks 241-AZ-101 and 241-AZ-102 are about 90 percent higher than the respective global (HDW model) estimates. The best basis inventory uses an ORIGEN2 ^{155}Eu value for 241-AZ-101 and a HDW model value for 241-AZ-102. The engineering estimate for 241-AZ-102 included a sample-based heel inventory of ^{155}Eu that was determined to be ludicrous. Most of the best-basis estimates for the remaining tanks (152) are from the HDW model with only 23 tanks based on sample data or engineering estimates. The best basis inventory of the remaining tanks is about 23 percent higher than the balance of the global HDW model estimate (Kupfer 1999).

Neptunium-237. The best-basis value for ^{237}Np is about 30 percent higher than the global ^{237}Np estimate. This difference appears to be due to the ^{237}Np inventories in 241-AN-103 and 241-AN-105 which account for 30 percent of the best-basis total tank inventory. The best-basis values for these two tanks are the largest contributors to the tank-summation value and are several times larger than the values estimated by the HDW model. The best-basis values for 241-AN-103 and 241-AN-105 are based on "bounding value estimates" that are derived from analytical detection limit data (Kupfer 1999).

For most of the Hanford processing history, more than 70% of the neptunium was recovered (Schmittroth 1995).

The HDW global inventory for Np may be significantly uncertain due to the use of approximate factors, which account for extraction losses (Harmsen 1998).

Plutonium-238, -239, -240, -241, -242. Plutonium inventories in the BBI are primarily based on accountability records and samples. The tank sum ^{239}Pu and ^{240}Pu inventories are significantly higher than those estimated by the global inventories.

Americium-241 and –243, and Curium-242, -243, and –244. The tank summation inventories for this group of radionuclides are significantly higher (50 percent to 3-fold) than those estimated by the global model (HDW). Comparisons of sample based and model predicted ^{241}Am inventories for selected tanks suggests that sample results are biased high. This could be the reason for the tank summation inventory of ^{241}Am being 1.5 times greater than the global model prediction. A major reason for the discrepancy in sample versus model based inventory values for ^{243}Cm and ^{244}Cm is traced to sample results for tank 241-AW-105. Here the sample based inventory is essentially equivalent to the model based inventory for all 177 tanks. The large sample based inventory value for tank 241-AW-105 appears to be an anomaly since the other zircaloy cladding waste receiver tank (241-AW-103) contains 4000 fold less by sample determination. There is possibility of analytical errors for both Am and Cm isotopes (Kupfer 1999).

Uranium-233, -234, -235, -236, and –238. Many of the uranium isotopic inventory estimates are based on the total uranium analysis of samples. The global basis uses accountability and sample data, with the result that global inventory values closely match tank summation values. These inventories are significantly lower than those estimated from total uranium by the HDW Rev. 4 model. The HDW model assumes that significant amounts of TBP (uranium recovery

process) waste remain in the tanks while sample results and observations from Rodenhizer (1987) and MacCready (1957) confirm that recovery of uranium was more efficient (Kupfer 1999).

Thorium-232. There are no analytical data for ^{232}Th. The best-basis tank summation thus reflects HDW inventory values which are about two-fold higher than estimates based on accountability measurements made during the thorium fuel processing campaigns in 1966 and 1970 (Kupfer 1999).

Radon-226, Actinium-227, Radon-228, Thorium-229, and Protactinium-231. The tank summation inventories for these isotopes (alpha decay chain daughters of ^{232}Th, ^{233}U, ^{234}U, and ^{235}U) are based essentially on the HDW model estimates, due to lack of any direct analytical data from samples. The estimate for these daughter radionuclides is in error due to the lack of proper second-order decay functions in the HDW model. With the exception of ^{228}Ra, these daughter nuclides are expected to slowly buildup in Hanford tank wastes, not reaching peak activity levels until thousands of years in the future (Kupfer 1999).
The HDW model performs separations of uranium, plutonium, and neptunium after decaying the reactor production values to 1/1/1994, rather than at the time of fuel separation. Thus, the uranium, plutonium, and neptunium decay daughters ^{226}Ra, ^{227}Ac, ^{228}Ra, ^{229}Th, ^{231}Pa, and ^{232}Th, are overpredicted by as much as a factor of 50. Conversely, the ^{233}U that builds in from the decay of ^{237}Np is removed along with the rest of the uranium in the HDW model, resulting in a ^{233}U prediction that is low by as much as a factor of 84 for some tanks (Harmsen 1998).

Tungsten and Thorium. For the tungsten and thorium components, there were no batch inventories or Best Basis tank inventories. For these cases, the global estimate (Kupfer 1999) was the only inventory.

Appendix C

Radioisotope Half Lives

Radioisotope Half Lives

Table C-1 lists the half life values from the ORIGEN2 library. These are the half lives used in generating the input to the HDW model from the reactor production. Slightly different half lives may have been used for other steps in arriving at the ILAW inventories.

Table C-1. Half Lives from ORIGEN2 Library for Selected Radionuclides

Isotope	Half-life, years
3-H	1.23E+01
14-C	5.73E+03
59-Ni	7.60E+04
60-Co	5.27E+00
63-Ni	1.00E+02
79-Se	6.50E+04
90-Sr	2.88E+01
90-Y	7.31E-03
93-Zr	1.53E+06
93m-Nb	1.61E+01
99-Tc	2.11E+05
106-Ru	1.02E+00
113m-Cd	1.41E+01
125-Sb	2.76E+00
126-Sn	1.00E+05
129-I	1.57E+07
134-Cs	2.06E+00
137-Cs	3.01E+01
137m-Ba	4.85E-06
151-Sm	9.00E+01
152-Eu	1.35E+01
154-Eu	8.59E+00
155-Eu	4.76E+00
226-Ra	1.60E+03
227-Ac	2.18E+01
228-Ra	5.75E+00
229-Th	7.34E+03
231-Pa	3.28E+04
232-Th	1.41E+10
232-U	6.89E+01
233-U	1.59E+05
234-U	2.46E+05
235-U	7.04E+08
236-U	2.34E+07
237-Np	2.14E+06
238-Pu	8.77E+01
238-U	4.47E+09
239-Pu	2.41E+04
240-Pu	6.56E+03
241-Am	4.32E+01
241-Pu	1.44E+01
242-Cm	4.46E-01
242-Pu	3.73E+05
243-Am	7.37E+03
243-Cm	2.91E+01
244-Cm	1.81E+01

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Appendix D

Comparison with Interim PA ILAW Inventory

Comparison with Interim PA ILAW Inventory

Table D-1 compares the nominal ILAW inventory values from Table 4.2 and the bounding ILAW values from Table 4.3 with the ILAW inventories developed for the Interim PA (Schmittroth 1995). Some of the differences can be attributed to the contract controls on components such as ^{137}Cs, ^{90}Sr, ^{99}Tc, and TRU. Other differences can be attributed to different assumptions on the losses to product and removals during the fuel processing and on the fraction of the tank waste components that are incorporated into the ILAW product.

Table D-1. Comparison of Nominal and Bounding ILAW Radionuclide Inventory with Interim PA Inventory.

Component	Nominal Total Ci	Upper Bound Total Ci	Interim PA ILAW Inventory Ci
3-H	0.00E+00	2.46E+04	8.94E+04
14-C	0.00E+00	4.38E+03	7.73E+00
59-Ni	1.67E+02	8.58E+02	
60-Co	4.18E+03	1.99E+04	
63-Ni	1.62E+04	8.45E+04	
79-Se	6.00E+02	9.32E+02	1.03E+03
90-Sr	4.50E+06	5.85E+06	1.61E+06
93-Zr	1.25E+03	4.12E+03	4.87E+03
93m-Nb	8.36E+02	2.53E+03	4.20E+03
99-Tc	5.79E+03	6.65E+03	2.23E+04
106-Ru	8.94E+02	1.27E+05	
113m-Cd	7.97E+03	1.67E+04	
125-Sb	5.20E+04	2.47E+05	
126-Sn	4.23E+02	1.16E+03	1.58E+03
129-I	2.20E+01	1.01E+02	6.62E+00
134-Cs	5.89E+04	4.89E+02	
137-Cs	9.11E+05	1.18E+06	4.51E+05
151-Sm	7.80E+05	2.61E+06	3.16E+06
152-Eu	3.07E+02	1.45E+03	
154-Eu	3.77E+04	1.83E+05	
155-Eu	3.15E+04	1.76E+05	
226-Ra	1.03E+03	1.14E+03	4.70E-03
227-Ac	6.05E-02	8.75E+01	1.08E+02
228-Ra	3.32E+01	7.75E+01	2.76E+00
229-Th	3.40E-01	1.81E+00	9.79E-01
231-Pa	3.37E-01	1.53E+02	1.45E+02
232-Th	1.28E+00	4.40E+00	2.68E+00
232-U	3.46E+01	1.49E+02	
233-U	1.31E+02	5.72E+02	2.58E+01
234-U	4.41E+01	3.42E+02	1.80E+01
235-U	1.79E+00	1.46E+01	7.36E-01
236-U	1.43E+00	1.24E+01	4.47E-01
237-Np	8.10E+01	3.00E+02	3.74E+00
238-Pu	1.06E+02	3.94E+02	
238-U	4.83E+01	3.28E+02	1.78E+01
239-Pu	3.05E+03	1.13E+04	2.23E+03
240-Pu	5.25E+02	1.95E+03	4.31E+02
241-Am	1.08E+04	4.01E+04	4.25E+03
241-Pu	7.17E+03	1.66E+05	
242-Cm	5.76E+01	1.72E+02	
242-Pu	4.49E-02	1.66E-01	
243-Am	6.89E-01	2.55E+00	2.70E+00
243-Cm	6.73E+00	2.49E+01	
244-Cm	1.01E+02	3.73E+02	

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Appendix E

Quality Assurance

Quality Assurance

Quality assurance for this report is provided through the following peer review process. A peer review plan was established that identified three technical reviews to be performed on the Inventory Data Package for the Immobilized Low-Activity Tank Waste Performance Assessment. Fluor Daniel Northwest, Inc. (FDNW) was responsible for an internal review of the document. The Pacific Northwest National Laboratory (PNNL), Numatec Hanford Company (NHC), and Lockheed Martin Hanford Company (LMHC) were responsible for the Hanford technical reviews of this document. NHC is responsible for the TWRSO&UP inventory studies. LMHC is responsible for developing the BBI inventories. PNNL is responsible for the privatization regulatory DQO.

The Hanford reviewers, upon completion of their reviews, provided the author (D. Wootan) with written documentation of their comments. Acceptance of the comment resolutions was indicated by reviewer's signature on the Engineering Data Transmittal (EDT).

The peer review members were selected based on their experience and knowledge of specific subject areas. The internal peer review was provided by Donald Hammervold and R. Puigh. Bruce Higley was chosen from NHC to provide the technical review based on his knowledge of the TWRSO&UP inventory studies. Robert Watrous was chosen from LMHC for his knowledge of BBI inventory studies. Karyn Wiemers was chosen from PNNL for her knowledge of the characterization requirements for the LAW feed.

Appendix F

Peer Review Checklist

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: HNF-4921
Title: Immobilized Low Activity Waste Inventory Data Package
Author: David W. Wootan
Date: July 28, 1999
Scope of Review: Full Document

Yes	No*	NA	
[ ]	[ ]	[X]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[X]	Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[ ]	[ ]	[X]	Computer codes and data files documented.
[ ]	[ ]	[X]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[ ]	[ ]	[X]	Software input correct and consistent with document reviewed.
[ ]	[ ]	[X]	Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[X]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[X]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]		[X]**	Review calculations, comments, and/or notes are attached.
[ ]	[ ]	[X]	Traceability
[X]	[ ]	[ ]	Document approved (i.e., the reviewer affirms the technical accuracy of the document).

Donald J. Hammervold Donald J. Hammervold 7/29/99
Reviewer: (Printed and Signed) Date

* All "NO" responses must be explained below or on an additional page.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

APPENDIX I

DISPOSAL FACILITY DATA

FOR THE

HANFORD IMMOBILIZED LOW-ACTIVITY TANK WASTE

PERFORMANCE ASSESSMENT

Raymond Puigh
Fluor Federal Services
P.O. Box 1050
Richland, Washington

December 1999

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EXECUTIVE SUMMARY

The current Immobilized Low-Activity Waste (ILAW) disposal planning utilizes the existing disposal vaults from the grout program suitably modified to receive ILAW packages and new disposal facilities currently in their early design phase. The existing disposal vaults were originally constructed by the former grout program in the late 1980's and early 1990's. These vaults were designed to contain a liquid low-level waste (LLW) grout mixture during the curing and solidification period, and to serve as a disposal structure for the resulting grouted waste monolith. Five vaults were constructed. One vault was filled before termination of the program leaving four empty vaults available for use.

Each vault is 37.6 m (123.5 ft) long and 15.4 m (50.5 ft) wide, with a roof clearance of 10.4 m (34.0 ft), providing 579 m^2 (6,236 ft^2) of floor space. The vaults are constructed of reinforced concrete, and were designed and constructed in compliance with RCRA requirements for both hazardous waste surface impoundments and land disposal units. Each vault is built above a RCRA-compliant leak detection and collection system. The leak detection system consists of a sealed concrete slab sloped to a collection sump fitted with a riser pipe to the surface. The system is capable of collecting, detecting, sampling, and removing any leachate that might escape from the primary vault structure.

A conceptual design activity has been performed to modify the existing disposal vaults to accept and ultimately serve as a disposal facility for the ILAW from the Hanford waste tanks (Pickett 1998a). The existing asphalt layer and concrete "topping" layer above the precast concrete roof slabs will be removed from the four available vaults. For each vault, side wall and end wall extensions 1.8 m (6.0 ft) high will be added to the original top of the side and end walls, respectively. To support the unloading of ILAW packages from the transportation vehicles, rails for a gantry crane are to be placed on top of the side wall extensions and will run the full length of the vaults.

A conceptual design for the new ILAW disposal facilities (Pickett 1998b) utilizes a long concrete vault concept divided into cells. Each vault will be an underground, open-topped, concrete vault approximately 23 m (76 ft) wide and 207.8 m (686 ft) long. The total vault height was increased to 11.0 m to accommodate the new waste package dimensions. The top of the vault walls will extend 1 m (3.3 ft) above grade. Each vault will be divided into 11 cells, separated by concrete partition walls

Each vault is built above a RCRA-compliant leak detection and collection system. It consists of a cast-in-place reinforced concrete basin approximately 209.5 m (687.3 ft) long, 24.7 m (81 ft) wide with walls 1.07 m (3.5 ft) high. The basin floor is 0.6 m (2 ft) thick and contains steel reinforcing bars within. The catch basin is lined with two flexible membrane liners, and on top of these lie a layer of gravel with perforated collection pipe routed to sumps, one at each end of a vault. Liquids entering the sump can be removed by use of a portable pump lowered down a riser pipe.

Interim closure for each filled cell in the new disposal facility will consist of using inert backfill material followed by a "controlled density fill," unreinforced concrete. A waterproof membrane will be placed above the "controlled density fill." After all cells in the vault have been filled and interim closed, a closure cap consisting of a capillary break followed by a modified RCRA C cap will be placed over the entire vault. A similar closure is assumed for the existing disposal vaults. Each vault will be interim closed using the process used for the cell closure for the new disposal facility. After all vaults have been filled and interim closed, a similar closure cap will be placed over all four vaults.

The design for the ILAW disposal facilities has not yet been finalized. Facility uncertainty cases have been identified that may impact disposal performance. Alternate concepts for disposal of the ILAW waste are still being considered. Alternate trench concepts are provided to explore the sensitivity of the proposed ILAW disposal performance to different disposal concepts. In December, 1999 the Department of Energy has identified the remote handled trench as the baseline concept for ILAW disposal at Hanford.

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1.0 INTRODUCTION

Based on the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) (Ecology 1996) the U.S. Department of Energy (DOE) and River Protection Project (RPP) team are proceeding with engineering activities to support the eventual disposal of low-activity waste from the Hanford underground storage tanks. The Tank Waste Remediation System (TWRS) Environmental Impact Statement (EIS) (DOE 1996) and the subsequent Record of Decision (ROD) (DOE 1997) stipulate that the low-activity portion of the tank waste shall be vitrified.

The DOE Order 5820.2A (DOE 1988) provided early guidance and requirements for the disposal of radioactive waste on a DOE site. This Order has been superceded by DOE Order 435.1 (DOE 1998a). One requirement in both Orders is the need to develop and maintain a site-specific performance assessment for the proposed disposal facility. This performance assessment must provide reasonable assurance that public health and environmental resources will be protected consistent with local, state, and federal regulations.

The Hanford Immobilized Low-Activity Tank Waste Performance Assessment (DOE 1998b) was issued in 1998 to provide the first formal performance assessment in support of the eventual disposal of low-activity tank waste at Hanford. The analyses within this report used two conceptual facility models (Eiholzer 1995) based on early project planning. Since that time there has been an evolution in the planning for this proposed disposal action. Specifically, the DOE has entered into a contract with BNFL, Inc. that will ultimately lead to the vitrification of approximately 8.6% (6000 packages of 70,000 [Kirkbride 1999]) of the current low-activity waste from the underground tanks. The DOE has proposed that four existing grout vaults be modified and ultimately used for the disposal of the low-activity tank waste (Burbank 1999). Finally, a conceptual design has been developed for new disposal facilities for the low-activity tank waste [Pickett 1998b].

The purpose of this report is to provide a description of the waste package and disposal facilities based on the latest information. This information will be used in the next performance assessment to support the development of models used to assess the overall system performance in meeting established performance objectives (DOE 1998b). This performance assessment is currently scheduled to be issued in 2001. Data on the waste form will be taken from the current BNFL, Inc. planning and contract requirements (BNFL 1998, Taylor 1999). Data on the facility design will be taken from the planned modification to the existing grout vaults (Pickett 1998a) and the conceptual design developed for the new disposal facility (Pickett 1998b). Data on the engineered barriers will be taken from the current draft version of the disposal facility closure plan (Hohl 1998).

2.0 LOW-LEVEL WASTE PACKAGE

The DOE has entered into a contract with BNFL, Inc. to design and ultimately process approximately 9% of the ILAW from the Hanford tanks. (The contract identifies a minimum of 6,000 packages and Kirkbride (1999) estimates approximately 70,000 ILAW packages are

needed for all the ILAW). The product description and specifications defined in this section are based on the current DOE contract (DOE 1998b) and the BNFL, Inc. reports submitted to the DOE as part of the contract negotiations. The definition of the product form and specification for the remaining 91% of the Hanford tank waste is not defined at this time. For the purposes of the ILAW Performance Assessment activities, all the ILAW waste products are assumed equivalent to the BNFL, Inc. descriptions and DOE specifications identified in this first contract.

The ILAW product for the first phase to be provided by BNFL, Inc. consists of a silicate glass monolith sealed in a stainless-steel package. The headspace above the silicate glass in the package is filled with silicate sand (BNFL 1998). The stainless steel package has external dimensions of 1.4 m x 1.4 m x 1.4 m, -0 m/+0.05 m (tolerances). The stainless steel wall thickness of the package is 6 mm. The package top is 12 mm plate and the bottom is 8 mm plate. BNFL, Inc. plans to load each ILAW package to within 85% capacity (by volume) and fill the void space with silicate sand such that the remaining free fill space is less than 5% (by volume). (BNFL , Inc. is also considering an alternative inert filling material that may be introduced in liquid form, such as grout.) The top lid will be welded using the tungsten-inert gas (TIG) process. The waste package data are summarized in Table 1. Other canister geometries for the waste package are currently being considered (see section 6.1).

The current contract with BNFL, Inc. (DOE 1998b) also places the following restrictions on the waste packages. The accessible external surface temperatures of the waste package shall not exceed 50° C. The packages shall contain no detectable free liquid. The compressive strength of representative samples shall be equal to or greater than 3.45E6 Pa. At least 75% of the initial compressive strength shall be retained after samples are subjected to thermal degradation, radiation degradation, biodegradation, and immersion degradation. Each fully loaded package shall be able to withstand a compression load of 100,000 kg force.

3.0 DISPOSAL FACILITY DESIGNS

Two disposal facility designs have been developed for the disposal of ILAW product. The first ILAW disposal facilities are currently planned to be the four existing Grout Vaults that will be modified to accept the ILAW waste packages (Pickett 1998a). The Grout Vaults will hereafter be referred to as the existing disposal vaults. The new ILAW disposal facilities are currently designed to consist of rows of concrete cells located below grade. These two facility designs will be used to hold ILAW waste packages generated under the current contract between DOE and BNFL, Inc. (DOE 1998b). Future disposal facility designs may include trench disposal, the reuse of processing canyon facilities, and the reuse of the storage tanks. The analyses of any of these options will be performed in future performance assessments, once plans are developed. A limited examination of trench disposal will be considered as part of the uncertainty cases for the next ILAW Performance Assessment.

In this section, a description of the current facility design concepts for the disposal of ILAW waste packages is provided. For the purposes of the 2001 PA there are the only two design concepts. Therefore, sufficient new disposal facility trenches having the current design

(Pickett 1998b) are assumed to be available for the disposal of ILAW from the Hanford waste tanks.

Table 1: Waste Form and Canister Data for the 2001 PA

Silicate Glass Monolith Dimensions: 1.4 m x 1.4 m x 1.2 m (85% waste fill fraction) Minimum Surface Area: 10.6 m^2 (degree of cracking an uncertainty parameter) Glass composition : to be determined Glass corrosion rate: to be determined
Canister Data Material: stainless steel Shape: rectangular prism (1.4 m x 1.4 m x 1.4 m) Wall Thickness: side walls 6mm bottom 8mm top 12mm Number of canisters: 68741*
Canister Fill Data (by free volume) Void space: <5% Glass Monolith: 85% Silicate Sand: 10 - 15% (depends on void space)

*Reference (Kirkbride 1999)

3.1 Existing Disposal Facility

The major components of the existing disposal facility design are the below-grade disposal vaults, the under-vault catch basin, the asphalt diffusion barrier, and the leachate detection, collection, and removal system. The vault and catch basin structures constitute a double-liner composite system. An elastomeric asphalt urethane coating on the vault interior and the concrete vault structure were initially installed to provide the primary composite liner. The secondary composite liner, located below the vault, is the concrete catch basin covered with a high-density polyethylene (HDPE) flexible membrane liner. An asphalt diffusion barrier surrounds each vault. The leachate detection, collection, and removal system allow monitoring of the system's performance during operations prior to closure.

Construction of the original Grout Vaults was completed in 1995. Specifications for these vaults and their construction are documented in (Koci 1994). A conceptual design study was completed in 1998 that described how the vaults could be modified to accommodate currently planned ILAW waste packages (Pickett 1998a). Materials used in the original construction are specified in Koci 1994.

3.1.1 Location

The existing disposal facility lies east of AP tank farm and Canton Avenue, north of Hanford grid coordinate N40000, west of W45000, and south of N41500 (see Figures 1 and 2). The existing disposal facility is at the western edge of the Tank Waste Vitrification Area.

3.1.2 Design

The dimensional data for the existing disposal facility are summarized in Table 2.

Table 2: Dimension Data Summary for Existing Disposal Facility

Concrete Structures			
Basin:			
	Bottom footprint (edge):		20.3 m x 41.3 m
	Bottom edge elevation:		185.6 m (609 ft) [maximum]
	Bottom thickness:		0.6 m (minimum)
	Height:		1.7 m (bottom edge to top of basin side wall)
Vault:			
	Bottom:	outside	39.6 m x 18.6 m
		Inside	15.4 m x 37.7 m
	Bottom edge elevation:		186.5 m (612 ft)
	Thickness:		1.4 m
	Sidewalls:		11.7 m high (measured from bottom of vault)
	Thickness:	N/S walls	0.8 m
		E/W walls	1.4 m bottom
			0.5 m top
Diffusion Barrier			
	Bottom thickness:		0.9 m
	Sidewall:		
		Height:3-sides	11.1 m (measured from bottom of vault)
		East side	10.3 m
		Thickness:	1.0 m

3.1.2.1 Concrete Catch Basin

The foundation for the four concrete catch basins consists of an 46 cm (18-in.) asphalt pavement laid on top of an 46 cm (18-in.) base of asphalt-coated gravel. The diffusion barrier material is placed in 15 cm (6-in.) layers over the subgrade. See Koci 1994 for specifications of the lower diffusion barrier materials.

The concrete catch basin is constructed of reinforced concrete. Its major components are concrete, having a compressive strength of 316 kg/ cm^2 (4,500 lb/in^2), Grade 60 reinforcing steel, having an ultimate tensile strength of 4218 kg/ cm^2 (60,000 lb/in^2), and ASTM A36 steel-plate water stops. See Figure 3 for the detailed design of the concrete catch basin.

The concrete catch basin is the foundation for the lower flexible membrane liner (FML). This liner is a 0.15 cm (60-mil) thick HDPE sheet placed directly on the concrete surface of the catch basin. The catch basin is cleaned of dirt and debris prior to liner placement. The basin is formed to provide a 20 cm (8-in.) radius on inside corners and a 5 cm (2-in.) radius on outside corners. The radiused corners keep the basin stress concentrations to a minimum. The basin surface in contact with the flexible membrane liner is given a steel trowel finish. The HDPE liner was fabricated from large pieces of sheeting to proper size and shape, keeping field joints to minimum. Corner pieces were preformed to proper size and shape at the factory. The seam welding technique was qualified for both shop and field work.

The HDPE liner is compatible with the radiation field intensity at the catch basin (DOE-RL 1988). It was installed by qualified personnel experienced in liner installation. Particular care was taken to ensure that liner sections were correctly seamed.

3.1.2.2 Leachate Detection, Collection, and Removal System (LDCRS)

A 10 cm (4-in.) perforated steel leachate collection pipe is laid in the catch basin trough, on top of the HDPE liner. The pipe is covered with a geotextile fabric that will prevent gravel infiltration, but allow liquids to drain from the liner into the perforated pipe and leachate collection system. A layer of small gravel then is placed in the catch basin to a thickness of 0.3 m (1 ft) near the edges of the basin and 1.2 m (4 ft) at the low point of the trough. The gravel is washed and sieved before placement to remove fines and large rocks. Care is taken in handling and placing drainage gravel to prevent contamination that could be caused by blowing sand and debris. Contamination by fine material could cause a reduction in permeability that would slow the leachate movement and lengthen detection time. A geotextile is laid over the gravel to prevent seepage of concrete into the drainage gravel during the vault floor construction. A temporary plastic sheet was placed over each catch basin to protect the catch basin geotextile and gravel prior to vault construction. The perforated collection pipe leads to an embedded pipe and sump. The pipe and sump liner are carbon steel. Sump access is through a 66 cm (26-in.) access riser. See Figures 3 for details.

3.1.2.3 Concrete Vault

The below-grade concrete disposal vaults are of rectangular design and are constructed to the American Concrete Institute (ACI), *Concrete Sanitary Engineering Structures*, ACI 350R-83 (ACI 1983c) requirements.

The vault is built on top of the gravel layer of the LDCRS. The vault is constructed of reinforced concrete having a compressive strength of 316 kg/ cm^2 (4,500 lb/in^2) Grade 60 reinforcing steel, having an ultimate tensile strength of 4218 kg/ cm^2 (60,000 lb/in^2), and ASTM A36 steel plate water stops. The original vault roof was constructed of concrete plates laid on top of the vault. See Figure 4 for details.

The following construction techniques were used to ensure that the vault concrete cracks are minimized:

- Replacing 15% of the cement with pozzolan (fly ash). The reduced cement helps reduce the heat of hydration and the pozzolan densifies the concrete.

- Using ice when necessary to ensure that the plastic concrete has a maximum temperature of 70° F at time of placement .

Using insulated forms or curing blankets to minimize thermal gradients during the curing period.

- Using a low water to cement ratio.

The exterior sides of the vault are covered by the exterior drainage system. This system is formed by a drainage net (HDPE geogrid) and a nominal 0.15 cm (60-mil) HDPE flexible membrane liner. A 5 cm (2-in.) thickness of insulation and geotextile were placed against the exterior drainage system of the catch basin before placing the asphalt paving diffusion barrier. Liquids entering this system from the vault are drained to the LDCRS.

3.1.2.4 Diffusion Barrier

The diffusion barrier was placed under each catch basin and vault as part of the foundation, and around the sides and top of each vault with a minimum thickness of 1 m (40-in.). The diffusion barrier controls the diffusion of moisture into the vault, and the diffusion of radio-active and hazardous contaminants from the vault.

The bottom portion of the diffusion barrier under the first four vaults is made of a 46 cm (18-in.) thick layer of asphalt-coated gravel placed on compacted soil, then an 46 cm (18-in.) thick layer of asphalt pavement.

3.1.2.5 Soil Backfill

Backfill material around the vaults is withdrawn from stockpiled excavated soils and will be compacted to 90% maximum dry density in accordance with ASTM D1557.

3.1.2.6 Modifications to the Exiting Disposal Vaults

The modifications to the existing disposal vaults to support waste package emplacement will include demolition of the roof portions of each original grout vault and modifications to the vault side walls and LDCRS.

To uncover the four existing grout vaults (218-E-16-102 through 218-E-16-105), an approximate area of 107 by 137 m (350 by 450 ft) from the existing grade elevation of 200 m

(656 ft) to a 198 m (649.5 ft) elevation will be excavated. A slope of 1-½:1 from the 200 m (656 ft) elevation to new grade will be maintained around this area. In addition to removing compacted backfill around the vaults, the excavation consists of removing and hauling the following materials to the Richland Landfill:

1. The 1.0 m (3-ft 4-in.) deep asphalt and concrete topping (diffusion break) above the vaults, 0.6 m (2-ft) deep by 1.0 m (3-ft 4-in.) wide asphalt covering around three sides of the vaults, and 1.4 m (4-ft 6-in.) deep by 1.0 m (3-ft 4-in.) wide asphalt covering on the east side of each vault will be excavated. The existing concrete vault pits and pump pits located on the top of each vault will be removed. Existing piping and conduits embedded within the asphalt topping and HVAC inlet on each vault will be removed before hauling the asphalt. The HVAC exhauster and ductwork located between Vaults 102 and 103 and above their roofs will also be removed.

2. The precast concrete cover blocks (1.2 m (4-ft) wide by 16.6 m (54-ft 6-in) long by 0.7 m (2-ft 2-in) thick) that make up each vault roof will be removed.

3. Leachate concrete pump pit, located on the east side of each vault, will be removed. Existing 66 cm (26 in.) pipe to leachate collection sump and 21 cm (8 in.) pipe for leak detection will be cut to the new grade level to maintain the functionality of the leak detection system. Both of these pipes will be provided with new blind flanges.

4. Existing electrical concrete duct banks and manholes with existing cables will be removed.

5. The interior floor and wall surfaces of vaults are coated with an asphaltic coating. Because the coating contributes to the fire loading in the vaults, it must be removed. Removal of the coating will be done by mechanically scraping it from the concrete surfaces or by sandblasting.

The existing walls of each vault will be extended 1.8 m (6 ft) high to provide shielding. Extended concrete walls will taper in thickness from 0.6 m (2 ft) at the base of the existing wall to 0.5 m (1-ft 6-in.) at the top for north and south sides of vaults (Figure 5). The extended concrete walls will remain 0.8 m (2.5 ft) thick for east and west sides of vaults. The vertical rebar of the existing concrete walls will be exposed to splice them mechanically with the new rebar of the wall extension.

Figure 5 shows the waste package loading for package dimensions of 1.2 m x 1.2 m x 1.8 m.

Given the current ILAW waste package dimensions (1.4 m x 1.4 m x 1.4 m), each existing vault will be capable of holding 25 x 10 packages in a given layer and a total of 7 layers in a given vault. Therefore, each existing disposal vault will hold 1750 packages.

Eighty pound (80-lb) American Society of Civil Engineers (ASCE) rated rails will be provided on top of the north and south walls for each vault for a 15-ton gantry crane. These rails will be extended for approximately 14.6 m (48 ft) into the waste package delivery/crane maintenance area. The rails in this area will be supported by W14 steel beams and 46 cm (18-in.) square, concrete columns.

3.2 New ILAW Disposal Facility

The current design for the new ILAW disposal facility consists of a set of disposal vaults located in the south-central part of the 200 East Area (see Figure 1). Each waste disposal vault will be an underground, open-topped, concrete vault approximately 23 m (76 ft) wide, and 207.8 m (686 ft) long. The total vault height was increased to 11.0 m to accommodate the new waste package dimensions. The top of the vault walls will extend 1 m (3.3 ft) above grade. A removable shield wall will extend an additional 1 m (3.3 ft) above the top of the vault walls to support vault loading. Each vault will be divided into 11 cells, separated by concrete partition walls. Underneath the vault will be a concrete catch basin with a leachate detection and collection system.

Each cell being filled will have a moveable, bridge-crane equipped, Gantry Building over it. Two Gantry Buildings are planned for the facility. The Gantry Building will remain in place over a cell after it is filled with ILAW packages to aid in performing partial closure of the cell.

Each vault is built above a RCRA-compliant leak detection and collection system. It consists of a cast-in-place reinforced concrete basin approximately 209.5 m (687.3 ft) long, 24.7 m (81 ft) wide with walls 1.07 m (3.5 ft) high. The basin floor is 0.6 m (2 ft) thick and contains steel reinforcing bars within. The catch basin is lined with two flexible membrane liners, and between these liners lie a layer of gravel with perforated collection pipe routed to sumps, one at each end of a vault.

3.2.1 Location

Approximately 36 hectares (90 acres) of land is allocated for the ILAW Disposal Facility in 200-East Area southwest of PUREX (202-A Building) between 1st and 4th Streets and west of Canton Avenue bounded on the east at coordinate E574653 and on the west at coordinate E574170 (Figures 1 and 6). The land is considered uncontaminated and vacant (Burbank 1997).

The preferred alternative has the storage vaults/trenches oriented with their length in a north–south direction and the Control/Administration Building located at the northwest corner along 4th Street (see Figure 7). In this alternative, the site is divided along its length into three segments. The north segment will be set aside for waste disposal vaults and will include one vault for Phase 1 and the Control/Administration Building. The middle segment will be set aside for a combination of disposal vaults and/or trenches. The south segment will be set aside for waste disposal trenches, although vaults could be constructed. Each segment will be enclosed by

chain link security fencing with 3-strand barbed wire. For the 2001 PA base analyses, all vaults are assumed to be concrete vaults as described below.

3.2.2 Design

The dimensional data for the new ILAW disposal facility vaults are summarized in Table 3.

3.2.2.1 Site Work

For Phase 1 construction and operation, portions of the site (approximately 15 hectares [37.5 acres]) will be cleared, grubbed, and leveled to facilitate the construction of one disposal vault, the Control/Administration Building and parking area, perimeter and service roads, and perimeter fence and lighting (Figure 6). Clearing and grubbing will involve complete removal and disposal of all brush, roots, and other deleterious materials. Several hectares of mature sagebrush will be affected by this construction activity.

Table 3: Dimensional Data Summary for the New ILAW Disposal Facility

Concrete Structures		
Basin		
	bottom footprint (edge):	24.7 m x 209.5 m
	bottom edge elevation* :	187.1 m (613.8 ft)
	bottom thickness:	0.6 m (minimum)
	height:	1.7 m (5.5 ft)(bottom edge to top of basin side wall)
Vault		
	Bottom : outside	207.8 m x 23.0 m
	inside cell	18.3 m x 21.0 m
	Bottom edge elevation*:	188.0 m (616.8 ft)
	Thickness:	1.0 m
	Side walls	11.0 m (high** measured from bottom of vault)
	Outer wall thickness:	1.0 m
	Cell wall thickness:	0.45 m

* Grade elevation assumed to be 198 m
**See Section 5.2 for discussion

3.2.2.2 Concrete Catch Basin

The concrete catch basin is part of the secondary containment for the leachate collection system (Figure 8). The catch basin is cast-in-place reinforced concrete, approximately 209.5 m

(687.0 ft) long, 24.7 m (81 ft) wide with walls 1.07 m (3.5 ft) high. The basin floor is 61 cm (24 in.) thick and reinforced with 2.2 cm (.88-in.) steel reinforcing bars at 20 cm (8 in.) on center, top, and bottom both ways. The catch basin floor slopes at 2% towards a trench in the center. The trench slopes toward each end of the basin from the center. The interior dimensions of the concrete catch basin extend a minimum of 25 cm (10 in.) beyond the vault walls. This allows the basin to catch any leachate that may leak through either the vault floor or the walls.

The catch basin is lined with two flexible membrane liners (FML). The upper FML serves as the primary liner; the lower FML, along with the concrete catch basin, serves as the secondary composite liner. The liner material for the FML will be high-density polyethylene (HDPE).

The concrete catch basin serves as the foundation for the FML. The interior concrete surfaces will be formed to provide a 20 cm (8-in.) radius on inside corners and a 5 cm (2-in.) radius on outside corners. Concrete surfaces in contact with the FML will have troweled finishes.

A layer of gravel that serves as a portion of the leachate collection system is placed over the primary liner. The vault is then built on top of these components.

3.2.2.3 Leachate Detection Collection and Removal System (LDCRS)

The leachate collection pit leak detection system can detect liquids that leak into the leachate collection system. The leachate system will be monitored in the control room.

A perforated collection pipe and a layer of gravel placed over the primary liner allows collected liquids to drain to a sump at either end of the vault for sampling and removal. Liquids entering the sump will be detected by instrumentation during the facility operation phase. Samples can be removed by lowering a sample collection device down the leachate riser. Leachate could be removed by use of a portable pump lowered down the riser pipe. Collected liquids will be pumped to a portable tank for disposal. The leachate collection system is shown in Figure 8.

Between the two FML layers is a drainage net that allows any liquid trapped between the liners to drain freely to a sump at either end. This sump is separate from the leachate collection sump, and liquids in the two sumps cannot mix. Liquids entering the sump will be detected by instrumentation and removed by a portable pump lowered down a riser pipe. Collected liquids will be pumped to a portable collection tank for testing and disposal.

3.2.2.4 Concrete Vault

The current underground, reinforced concrete vault design is approximately, 23 m (76 ft) wide, 207.8 m (686 ft) long, and 9.1 m (29.8 ft) deep (outer dimensions, see Figure 9). The elevation of the vault bottom is 186.5 m (612 ft) with respect to sea level. The vault wall will

extend 1 m (3.3 ft) above grade to act as a barrier against the tractor/trailer transport vehicle and to keep away any water run-off. The top of the vault extension walls will have slots (320 mm [12.8 in.] wide by 320 mm [12.8 in.] high) in the center. Removable shielding walls will be inserted in these slots before placement of waste packages into the cell. The north–south tractor/trailer drive-through on each side of the vault will be paved with asphalt. Gravel aprons will be provided on the east and west sides of the Gantry Buildings to allow for vehicle traffic past the outside of the building. The exterior walls and the concrete base will be 1 m (3.3 ft) thick. The vault will be divided into 11 cells, separated by 0.45 m (1.5 ft) thick concrete partition walls.

Figure 9 shows that waste package loading assuming the waste package dimensions are 1.2 m x 1.2 m x 1.8 m. Given the currently planned waste package dimensions, each cell will be capable of holding 12 x 14 packages in a given layer. A total of 6 layers are planned for a given cell. This will require extending the total height of the vault by 1.9 m for the ILAW performance assessment calculations. For the ILAW analysis the vault is assumed to extend only 1.0 m above the grade. Therefore, the elevation of the vault bottom is 188.0 m (see Table 4). The grade elevation at the new facility site is assumed to be 198.0 m (649.5 ft). The vault is sized to contain 1008 ILAW packages (1.4 m x 1.4 m x 1.4 m) per cell. The total vault capacity is 11,088 packages.

4.0 ENGINEERED BARRIERS AND SOIL

The closure cap system is an essential part of the overall disposal system. As such, the closure cap system design must be addressed as an integral part of the design for the overall disposal facility system and developed in parallel with the other major parts of the system. The functional objectives, design requirements, and associated performance goals for the closure cap system must be defined accordingly.

The following subsections provide a more detailed description of the regulatory guidance and requirements guiding the closure cap system design.

Current conceptual design work for both the existing and new ILAW disposal facilities indicates the closure cap barrier system will be composed of a layered assemblage of different barriers. Refer back to Figure 10 for a cross-sectional illustration of the concept used for the current conceptual design. The general configurations for both the existing and new disposal facilities are shallow-land burial systems using a vault enclosure for the emplaced waste products. The vault enclosure would be surrounded by a layered system of engineered barriers.

The closure cap will sit on top of the temporary closure cover of the vault. Each layer within the closure cap will be sloped with a two percent grade to allow runoff and minimize erosion. A barrier overhang will be used to control potential water infiltration problems at the edges of the barrier. "Barrier overhang" is the terminology used to describe the projection of the functional barrier surface beyond the perimeter of the waste zone. The barrier overhang will extend 6 m (9.7 ft) beyond the edge of the disposal vault. Beyond the barrier overhang, the barrier layers above the low-permeability layer(s) will extend further but at a steeper slope of 3:1

(horizontal:vertical) until they reach the existing ground elevation. The grading fill layer of the barrier located underneath the low-permeability layer(s) will extend beyond the barrier overhang as well. This layer will support the other 3:1 sloped layers extending beyond the barrier overhang.

The specific choice of barrier materials, barrier thickness, and degree of capping barrier slope are all still subject to change. They will be tailored to the function and performance requirements for these uppermost layers as the design and performance assessment work progresses. Figure 11 provides a cross-sectional elevation view of the closure cap barrier system concept. This or a similar barrier layer system will be built over the vaults following completion of waste emplacement, backfilling, and then temporary and final roofing of the vault. The approximate height of this assemblage of barriers would be at least 1.7 m (5.6 ft) (BHI 1996). Table 4 provides a comprehensive summary of the key functions and characteristics of each of the proposed barrier layers for this particular concept.

Detailed assessments of four surface barrier designs that constitute potential generic remedial alternatives for 200 Area waste sites were assessed in a recent focused feasibility study (BHI 1996). The designs presented in this study were as follows:

Hanford Barrier. Designed to provide 1,000-year isolation of waste sites containing Greater than Class C Low Level Waste (LLW), Greater than Class C mixed waste, and significant inventories of transuranic (TRU) constituents.

Modified RCRA Subtitle C Barrier. Designed to provide 500-year isolation of waste sites with dangerous waste, Category 3 LLW, Category 3 Low Level (LL) mixed waste, and Category 1 LL mixed waste (see Table 5).

Standard RCRA Subtitle C Barrier. Designed to provide 30-year isolation of dangerous waste sites.

Modified RCRA Subtitle D Barrier. Designed to provide 100-year isolation of waste sites with Category 1 LLW and nonhazardous/nonradioactive solid waste.

The Modified RCRA Subtitle C Barrier is assumed to be the appropriate surface barrier design for the ILAW disposal facilities. This assumption is based on the following information:

The ILAW disposal facilities will not contain significant quantities of TRU constituents nor LLW with greater-than-Class C activity.

The proposed disposal facilities may contain waste regulated as dangerous waste, but this may not apply if the waste is delisted. However, the ILAW disposal facilities will contain LLW with Category 3 activity.

4.1 Partial Closure Activities

Partial closure activities for the new ILAW disposal vaults will consist of constructing a temporary closure cover over an individual disposal cell within a vault after the cell is filled with ILAW packages. This will be done for each disposal cell within a vault. The Gantry Building will remain over the cell until the temporary closure cover is installed. The purpose of this temporary barrier will be to prevent infiltration of water from the time that the cell is filled to when the final closure cap is added. A final closure cap will be constructed once all of the cells within a vault are filled and the Gantry Buildings are moved from the vault.

The following activities will occur for each cell once it is filled with ILAW packages:

Concrete shield covers (1.4 m x 1.4 m x 0.3 m) are placed above waste packages

Empty spaces between the rows of waste packages will be filled with a filler material (assumed to be sand).

The top surface of the concrete shield covers will be covered with 0.1 m (4 in) (minimum) of a filler material (assumed to be sand).

The filler material layer will be covered by 0.5 m (1.6 ft) of controlled density fill.

The temporary shielding walls above the extension walls of the cell will be relocated to the next cell. The slots of the cell wall where the temporary shielding walls were located will be filled with controlled density fill.

A temporary geomembrane liner will be laid over the cell after controlled density fill has been placed to prevent rain water intrusion. Once the liner is placed, the Gantry Building can be moved from the cell.

This partial closure activity is assumed to also apply to the existing disposal vaults.

Table 4: Summary of Modified RCRA Subtitle C Barrier Layers

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
1	50 (20)	Silt loam topsoil with pea gravel admix	McGee Ranch silt loam containing 15 wt. % pea gravel, 2.36 to 9.5 mm in diameter, conforming to ASTM D448 No. 8 aggregate; to be placed at a bulk density of approximately 1.46 g/cc.	The topsoil material was identified for optimal water retention properties and should provide a good rooting medium for cover vegetation. The pea gravel is designed to minimize wind erosion of the silt loam without significantly affecting its moisture retention capabilities.
2	50 (20)	Compacted topsoil	McGee Ranch silt loam without pea gravel, compacted to 90% of optimum dry density as determined by standard Proctor test; in-place bulk density will be approximately 1.76 g/cc.	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 2 will increase the amount of moisture removed by evapotranspiration.
3	15 (6)	Sand filter	Clean, screened sand meeting the following particle sizes: D_{15} = 0.15 to 0.50 mm, D_{50} = 0.375 to 1.2 mm, and D_{85} = 0.70 to 2.5 mm.	This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layer 5.
4	15 (6)	Gravel filter	Clean, screened aggregate meeting the following particle sizes: D_{15} = 1.5 to 2.0 mm, D_{50} =15 to 20 mm, and D_{85} <37.5 mm.	Same as Layer 3.
5	15 (6)	Lateral drainage aggregate	Naturally occurring aggregate, minus 32-mm (1 1/4-in.) material, conforming to the grading identified in WDOT M41-10,	The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection

Layer No.[1]	Thickness cm (in.)	Layer Description	Specifications	Function
			9-03.9(3) for base course, with D_{10} >1 mm and k >1 cm/s.	and/or discharge.
6	15 (6)	Asphaltic concrete with spray-applied asphalt coating	Asphaltic concrete, consisting of asphalt conforming to WDOT M41-10, 9-02.1(4) - Grade AR-4000W, and aggregate with particle size gradation conforming to ASTM C 136. Asphalt will make up 7.5 wt. % of total mixture. A spray-applied, styrene-butadiene asphalt material will be sprayed onto the asphaltic concrete surface in two layers, each 100 mils thick minimum.	This layer will function as a hydrologic barrier and as a biointrusion barrier.
7	10 (4)	Asphalt base course	Crushed aggregate, minus 16-mm (5/8-in.) diameter material, conforming to WDOT M41-10, 9-03.9(3) for top course surfacing material.	The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer.
8	Variable	Grading fill	Clean, bank run sand and gravel conforming to WDOT M41-10, 9-03.18.	This layer will provide a smooth, level subgrade for construction of the overlying layers.

[1] Barrier layers are listed in sequence from top to bottom (BHI 1996)

4.2 Closure Cover Installation

This section provides a general description of the techniques used for the installation of the closure cap. The closure cover for the existing vaults will be continuous over all four units while individual covers will be used for the new ILAW vaults. The closure cover for the existing vaults will use the shielding berm for the high point of the cover and one direction over all four vaults. Individual covers over each new disposal vault are planned because separate excavations are planned for construction of each vault, which requires that they be separated a greater distance to allow for clearance of the 1-1/2 to 1 excavation slopes. A continuous cover over these vaults would result in consumption of excessive quantities of material. The closure cover installation process will consist of the following tasks.

Gravel will be added to obtain a two percent slope. The height of this gravel layer will be such that the total cap thickness at the edge of the vault is 5 m (as per NRC requirements [10CFR61]).This layer will be smoothed to establish a smooth, planar-base surface for accurate and controlled placement of the overlying layers. A 10 cm (4 in.) thick asphalt base course will be placed over the gravel. This base course layer will provide a stable base for placement of the overlying low-permeability asphalt layer. Grade stakes are used to ensure that thicknesses and overall slopes are maintained.

The next task will be the installation of a water infiltration barrier. The asphaltic concrete mixture will be specially formulated to produce a minimum hydraulic conductivity and will be applied 15 cm (6 in.) thick. A spray-applied asphalt will then be applied over the layer to seal any voids or defects in the surface. This layer will function as a low-permeability barrier as well as an intrusion barrier. A slope of two percent will carry infiltration to the layer edges where it will enter the surrounding soil. The asphalt will prevent burrowing animals from reaching the waste and will act as a barrier against inadvertent intrusion by man.

Next, a 15 cm (6 in.) thick layer of drainage gravel will be laid down. The function of this layer will be to allow moisture that reaches this layer to laterally migrate to the barrier edge.

The next task will be the installation of a two-layer graded filter layer. The first of these two layers installed will be a 15 cm (6 in.) thick gravel filter layer. The gravel in this layer will be sized to be compatible with the lateral drainage gravel layer below and the forthcoming sand filter layer above. Once the gravel filter layer is installed, a 15 cm (6 in.) thick sand filter layer will be installed. The purpose of these two layers is to prevent topsoil particles from moving downward and clogging the lateral drainage layer.

After the filter layers are installed, a 50 cm (20 in.) thick layer of compacted topsoil will be installed. This layer will supplement the moisture storage capacity of the layer to be installed above it. The material used for the topsoil will be McGee Ranch silt loam without pea gravel. The topsoil will be compacted to 90 percent of optimum dry density as determined by standard Proctor test. The in-place bulk density of the topsoil will be approximately 1.76 g/cm^3.

Another 50 cm (20 in.) thick layer of topsoil will be installed next. This layer also contains McGee Ranch silt loam in it, but it will also contain 15 wt.% pea gravel, 2.36 to 9.5 mm in

diameter, mixed uniformly. The topsoil mixture will be placed at a bulk density of approximately 1.46 g/cm^3. The pea gravel is designed to minimize wind erosion of the silt loam without significantly affecting its moisture retention capabilities. Construction quality assurance will be conducted throughout installation of each layer to ensure that the appropriate slopes are maintained and that the desired compaction is attained.

Next, the ground will be prepared for planting and fertilized. Once this is complete, the ground will be seeded with mixed perennial grasses and planted with shrubs.

5.0 ILAW DISPOSAL FACILITY CONCEPTUAL MODELS

The existing and new ILAW disposal facility designs will form the basis for the performance assessment calculations scheduled for the 2001 PA. To facilitate these calculations, conceptual models have been developed for the base analysis case. These conceptual models incorporate the important design features impacting contaminant transport from the waste product to the far field vadose zone. From these conceptual models, numerical models will be developed to conduct the transport calculations for important waste products from the waste form to the far field vadose zone. Other numerical models will be used to calculate the transport of these released waste products through the vadose zone and the groundwater to potential receptors identified in the scenarios for the ILAW PA (Mann 1999).

The disposal facility conceptual models identify the vault geometry and layout, the planned materials of construction, and selected information on the waste packages. Additional information on the materials of construction and the near field material properties pertinent to waste product transport are provided in the near-field data packages (Meyer 1999 and Kaplan 1999). Additional information on the waste form can be found in the waste form data package (McGrail et al.1999).

For the 2001 ILAW PA, all waste packages are assumed to have the design given in Table 1 of this report. The minimum surface area for the glass monolith within each package is assumed to be 10.6 m^2 (geometric surface area of the rectangular prism 1.4 m x 1.4 m x 1.2m). Cracking that occurs within the monolith during cooling is assumed to increase the surface area available for dissolution. The initial surface area estimate is provided by McGrail 1999. The nominal void space is assumed to be 1% (by free volume). The filler material is assumed to be 14% silicate sand (by free volume).

5.1 Existing Disposal Facility Conceptual Model

Section 3.1 of this report describes the current status of the existing disposal facility design. To facilitate the numerical calculations, the vault layout and geometrical dimensions have been simplified. The layout of the existing disposal vaults is shown in Figure 12. The figure provides a top view of the vault layout and the distance between the vaults. In the conceptual model, the ancillary modifications made to the site to support the loading of the disposal vaults have been removed. Specifically, the support structure for the Gantry Building,

the rail extensions and their supporting structures for the bridge crane, and the paved and graveled areas supporting the loading of the vaults have been removed so that only backfill soil is in the immediate vicinity of the existing disposal vaults.

Figure 13 provides a simplified geometry for the existing disposal vaults. In this simplified conceptual model, the leachate tank and sampling port are assumed to be effectively closed so that they do not provide any preferential path for moisture influx or contaminant transport. The catch basin is simplified to be a rectangular pad, that is 0.6 m (2 ft) thick everywhere. The HDPE layer is ignored in the model since its function as a moisture barrier is assumed to degrade in less than 100 years. The drainage pipe to the leachate tank is also not included in the model. The vault is assumed to sit on a gravel layer that is uniformly 0.3 m (1 ft) thick. The dimensions of the conceptual model vault are the same as given in Figures 4 and 5 and as provided in Table 2.

Also shown in Figure 13 is the diffusion barrier that surrounds most of each vault. This diffusion barrier is 1 m (3.3 ft) thick on the vault side walls and 0.9 m (3.0 ft) on the bottom of the disposal vault. Between the diffusion barrier and the concrete vault a layer, composed of 5.0 cm (2 in) thermal board, geotextile and HDPE mesh, has been applied to provide a path to the LDCRS for any moisture leaving the concrete vault. This layer will be exposed during the modifications planned for these vaults. This layer is assumed to be sealed during the closure process.

The inside dimensions for each vault are 15.4 m (50.5 ft) wide by 37.6 m (123.5 ft) long by 12.2 m (40 ft) in height. One layer of waste packages corresponds to 10 x 25 = 250 waste packages. Each vault will hold 7 waste package layers. Assuming the waste package geometry is a 1.4 m cube, the spacing between each waste package (including the walls) is 9.3 cm (3.7 in) along the width dimension and 10.2 cm (4.0 in) along the length dimension. This volume is assumed to be filled with silicate sand.

The interim closure for the existing disposal vaults is assumed to be as described in Section 4 of this report (see Figure 9 for general layer description). The waste packages will be stacked 7 layers high to a height of 9.8 m (32 ft). A 10 cm (4 in) filler material layer (assumed to silicate sand) is also placed between each layer of waste packages. The concrete shield covers are assumed to be 1.4 m x 1.4 m x 0.3 m and are placed just above the top layer of waste packages. The filler material is assumed to have a depth of 1.0 m (3.3 ft) above the concrete shield covers. A "controlled density fill" consisting of a mixture of portland cement, fly ash, aggregate, water, and admixtures is then placed on top of the inert filler material layer. The depth of the "controlled density fill" is 0.45 m (1.5 ft). A waterproof membrane layer (assumed to be 60 mil HPDE is placed over the interim closed vault.

The orientation and design for the final closure cap for the existing disposal vaults is described in Section 4. The cap orientation is shown in Figure 10 and extends 6 m beyond the layout of all four existing vaults. Note that the cap is placed with its western edge on an existing shield berm and slopes downward from west to east over all four vaults. The slope of the closure mound outside the area of the cap is in a 3:1 slope to the existing ground elevation.

5.2 New ILAW Disposal Facility Conceptual Model

Section 3.2 of this report describes the current status of the new ILAW disposal facility design. To facilitate numerical calculations the vault layout and geometrical dimensions have been simplified. The layout of the new disposal vaults is shown in Figure 14. The figure provides a top view of the vault layout and the distance between the vaults. In the conceptual model, the ancillary modifications made to the site to support the loading of the disposal vaults have been removed. Specifically, the support structure for the Gantry Building, the rail extension and their supporting structure for the bridge crane, and the paved and gravel areas supporting the loading of the vaults have been removed so that only backfill soil is in the immediate vicinity of the disposal vaults. Based on the Kirkbride (1999) estimate of approximately 70,000 packages needed for disposal of all planned ILAW waste, only 6 new disposal vaults would be required to complete the disposal of all ILAW (assuming the existing disposal vaults are fully utilized).

Figure 15 provides a simplified geometry for the new disposal vaults. In this simplified conceptual model, the leachate tanks and sampling ports are assumed to be effectively sealed during closure so that they do not provide any preferential path for moisture influx or contaminant transport. The catch basin is simplified to be a rectangular pad, that is 0.6 m (2 ft) thick everywhere. The HDPE layers are ignored in the model since their function as a moisture barrier is assumed to degrade in less than 100 years. The drainage pipes to the leachate tanks are also not included in the model. The vault is assumed to sit on a gravel layer that is uniformly 0.3 m (1 ft) thick. The dimensions of the conceptual model vault are the same as given in Figures 8 and 9 and as provided in Table 3.

Each new vault is divided into 11 equivalent cells (see Figure 9). The inside dimensions for each cell are 18.3 m (60 ft) long by 21 m (68.9 ft) wide by 8.1 m (26.6 ft) in height. The vault height was assumed to be increased to 10.0 m so that the vault could accommodate 6 layers of waste packages. One layer of waste packages corresponds to 12 x 14 = 168 waste packages. Each vault will hold 6 waste package layers. Assuming the waste package geometry is a 1.4 m cube, the spacing between each waste package (including the walls) is 9.3 cm (3.7 in) along the width dimension and 11.5 cm (4.5 in) along the length dimension. This free space is assumed to be filled with silicate sand.

The interim closure for the new disposal vaults is assumed to be as described in Section 4 of this report (see Figure 9 for general layer description). The waste packages will be stacked 6 layers high. A 10 cm (4 in) filler material layer (assumed to silicate sand) is also placed between each layer of waste packages. The concrete shield covers are assumed to be 1.4 m x 1.4 m x 0.3 m and are placed on the top layer of waste packages. The filler material layer is assumed to have a depth of 0.3 m (1.0 ft) above the concrete shield covers. A "controlled density fill" consisting of a mixture of portland cement, fly ash, aggregate, water, and admixtures is then placed on top of the filler material layer. The depth of the "controlled density fill" is 0.45 m (1.5 ft). A waterproof membrane layer (assumed to be 60 mil HPDE is placed over the interim closed vault.

The orientation and design for the final closure cap for the new disposal vaults is described in Section 4. The cap orientation is shown in Figure 10 and extends 6 m beyond the layout of

each new vault. Note that the cap is shaped like an inverted "v" and placed with its apex along the length dimension (north-south) and centered over each vault. The slope of the closure mound outside the area of the cap is in a 3:1 slope to the existing ground elevation.

6.0 FACILITY UNCERTAINTY CASES

A number of assumptions are currently associated with our understanding of the disposal facilities to be used in the disposal of ILAW waste. Planning has identified concepts to be used and locations for the disposal of initial waste to be provided by BNFL, Inc. under contract to the DOE. These designs are not finalized. Also, the closure system to be used for the disposal facilities has not been finalized. Sections 3 and 4 of this report provide the facility parameters to be used in the best estimate calculations for the performance assessment. Section 5 contains the disposal facility conceptual models for the ILAW base analysis case. In this section of the report we define sensitivity cases that may be used to assess the sensitivity of the performance assessment to uncertainties in the facility design.

6.1 Waste Form Geometry

The facility conceptual design has been based on a waste package geometry of 1.2 x 1.2 m x 1.8 m. Recent BNFL, Inc. planning has been considering different dimensions and geometries for the waste package. For example Kirkbride (1999) analysis of Phase I processing has used a waste package having dimensions of 1.4 m x 1.4 m x 1.4 m. Kirkbride (1999) also refers to a cylindrical geometry having a similar volume (Taylor 1999); however the dimensions for this cylindrical form have not been finalized.

Also, the projected waste loading into the 1.4 m x 1.4 m x 1.4 m was assumed to be 2.3 m^3 of waste product. The remaining volume was assumed to be filled with a filler material. The final free volume void space in the waste package was assumed to be 1%.

The uncertainty in the waste form geometry and waste loading into the packages impacts the total inventory in a given vault. A reasonable upper bound for waste loading in the disposal vaults assumes the package geometry is 1.2 m x 1.2 m x 1.8 m and each package has 95% of the available volume filled with waste glass (BNFL 1998). This optimizes the number of packages in the disposal vaults and maximizes the waste loading in each package.

6.2 Vault Layout

The layout for the existing facilities has been established; however, the new ILAW facilities are currently in the design phase. The current design layout was based upon the results from the ILAW PA analyses (Mann 1998). However, the design layout may change. The current layout for the new ILAW facility has each trench with its longest length perpendicular to the projected groundwater flow path. An alternate orientation could have each trench with its longest length parallel to the projected groundwater flow path.

6.3 Facility Closure

The current design for the closure cap for both the existing and the new ILAW disposal facilities is described in Section 4. Alternate closure cap designs exist. For example the Hanford barrier (Myers 1994) was assumed for the last performance assessment. Another case that could be considered is when there is no closure cap installed on the disposal facility. Another closure cap case (modified RCRA C with capillary break) that should be considered is the inclusion of a capillary break beneath the asphalt layer in the modified RCRA C base design. Although such a capillary break has not been designed, the dimensions for the capillary break above the asphalt barrier are assumed. Specifically, a sand layer, 1 m (3.3 ft) thick would be immediately below the asphalt layer and the gravel layer below this sand layer would be at least 0.3 m (1 ft) thick.

Failure of the closure cap before its design life also needs to be considered. For example seismic activity or subsidence of the disposal facility could lead to a break in the closure cap.

6.4 Side Hydraulic Diverter

The earlier disposal facility conceptual design (Eiholzer 1995) included a side hydraulic diverter to channel moisture away from the facility. While the current design does not contain such a diverter, its potential incorporation into future designs cannot be dismissed. An earlier study (Mann 1995) showed the impact of such a diverter on the earlier ILAW disposal facility concepts. The side wall diverter is assumed to be a 1 m (3.3 ft) thick layer next to the concrete vault walls that extends to the bottom of the vault.

6.5 Alternate Concepts

Several alternate concepts for disposal of the ILAW have been considered by the River Protection Project. These disposal options include: reuse of the process canyon facilities, reuse of the storage tanks, and other trench disposal concepts.

Several trench concepts may be envisioned to reflect the uncertainty in the new disposal facility design. For example the current, new disposal vault geometry and vault layout could be assumed with either a concrete bottom pad or backfill soil and the side walls made of backfill soil. This vault would be installed above a leachate collection system similar to the one described later in this section. The closure cover is assumed to be equivalent to the closure cap described in Section 4.

One trench concept that is receiving additional consideration is the Remote Handled (RH) trench concept. Under the ILAW disposal alternative described below the disposal facility is a Resource Conservation and Recovery Act (RCRA) compliant landfill (i.e., double lined trench with leachate collection system). Many operational aspects and ancillary activities of the landfill (e.g., leachate collection and disposition, storm water control, installation of surface barrier at

closure, etc.) would be similar to that incorporated into the Radioactive Mixed Waste Burial Trench, which was designed and constructed under the Solid Waste Program. However, operational activities related to ILAW package receipt and emplacement in the trench would be modified to accommodate the potentially higher radiation dose rate from remote-handled ILAW.

In December, 1999 the Department of Energy identified the Remote Handled trench as the baseline concept for ILAW disposal at Hanford. The RH trench complex would be constructed in the same location as the new ILAW disposal facility. The RH trench concepdtual model is depicted in Figure 16. The RH trench internal dimensions 260 m long by 80 m wide by 10 m deep. The trench sides have a 3:1 slope. Trench construction requires excavation of 1.9×10^5 m^3. The trench liner surface area is about 2.9×10^4 m^2.

The trench is provided with a primary and secondary liner as depicted in Figure 17. Beneath both the primary and secondary liner is an admix layer (bentonite clay/soil mixture) 0.5 m and 1 m thick, respectively. The operations layer is comprised of crushed concrete and soil. The thickness of this layer is assumed to be 0.9 m (3.0ft).

The specific design shown in Figure 17 was taken from the remote maintained Radioactive Mixed Waste (RMW) Land Disposal Facility (drawing H-2-131579 Rev. 3). The primary and secondary drainage gravel are for the two drainage collection systems associated with RCRA compliant disposal facilities. Both the primary and secondary drainage layers are comprised of a geocomposite drainage layer on top of HDPE. The geocomposite cage consists of geonet bonded to geotextile. Geotextile is placed above each gravel layer. The specifications for these materials as used in the RMW Land Disposal Facility Trenches are given in WHC Project W-025 specifications (WHC1994).

Because the trench walls have a fairly shallow slope (3 m run for every 1 m rise) each successive layer can be increased in both length and width. Whereas the first layer could be 14 packages wide by 132 packages long (14 by 132 matrix), the second layer could be a 22 by 140 matrix (assuming 1.5 m center to center packing of the ILAW packages). The upper-most (4th) layer could be a 42 by 160 matrix. The net result is that while a baseline new ILAW disposal facility trench capacity is 11,088 ILAW packages, the RH trench capacity could theoretically be 16,448.

Packing the ILAW packages in such large, contiguous matrix (42 by 160 packages for the 4th lift [a single layer of ILAW packages and cover soil]) would, however, create operational impediments. About 100 ecology blocks would be required to create a shielding array between the leading face and operations area of the 4th lift. When it became necessary to advance the ecology blocks, movement of such a large number would be a significant undertaking, potentially requiring several shifts to complete. During this period the trench would be unavailable for ILAW package receipt.

To facilitate continuous receipt operations the matrix size is limited to a smaller size than that which would contiguously cover the entire layer. These smaller sized matrices, termed burial cells, provide the following benefits.

- Corridors are created within the disposal matrix to facilitate access for operational activities such as the emplacement of cover soil
- The size of the exposed leading face is minimized
- The number of ecology blocks required to establish an effective radiation shield is reduced to a number that can easily be moved in a single shift
- A larger portion of the trench can be covered with a rain curtain, thereby reducing the quantity of collected leachate that must be dispositioned.

A conceptual layout of a trench with these burial cells is depicted in Figure 16. Specific details of the trench packing is presented in Table 5. Given this packing density, approximately 6 trenches are needed to accommodate the entire Phase 1 and Phase 2 ILAW production.

Table 5. Trench Packing Characteristics.

Layer	Cells per layer	Matrix size per cell	Packages per layer
1	2	6 x 132	1,584
2	3	6 x 140	2,520
3	4	7 x 150	4,200
4	6	6 x 160	5,760
		Total packages per trench	14,064

The details for the closure cover shown in Figure 16 have not been designed. For this report the closure cap is assumed to have the same relative thickness, materials and slope as the modified RCRA subtitle C closure cap defined in Section 4.

Figure 18 depicts the conceptual model layout dimensions. The layout assumes a 5 m spacing between caps for each vault. Each vault layout is depicted with the inner rectangle representing the bottom of the vault (200 m x 20 m), the middle rectangle representing the top of the vault (260 m x 80 m), and the outer rectangle includes the trench wall dimensions (272 m x 92 m).

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8.0 PEER REVIEW

Practice 134 290 1112
Publication Date 01Mar99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: HNF-4950, Rev.1
Title: Disposal Facility Data for the Hanford Immobilized Low-Activity Tank Waste
Author: Raymond J. Puigh
Date: October 20, 1999
Scope of Review: Full Document

Yes	No*	NA	
[ ]	[ ]	[X]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[X]	Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[ ]	[ ]	[X]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[ ]	[ ]	[X]	Mathematical derivations checked including dimensional consistency of results.
[ ]	[ ]	[X]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[ ]	[ ]	[X]	Software input correct and consistent with document reviewed.
[ ]	[ ]	[X]	Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[X]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[X]	Safety margins consistent with good engineering practices.
[ ]	[ ]	[X]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]		[X]**	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]	Traceability
[X]	[ ]	[ ]	Document approved (i.e., the reviewer affirms the technical accuracy of the document).

D. W. Wootan D W Wootan 10/20/99
Reviewer: (Printed and Signed) Date

* All "NO" responses must be explained below or on an additional page.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

Figure 1. Location of Existing Vaults and New ILAW Disposal Facility

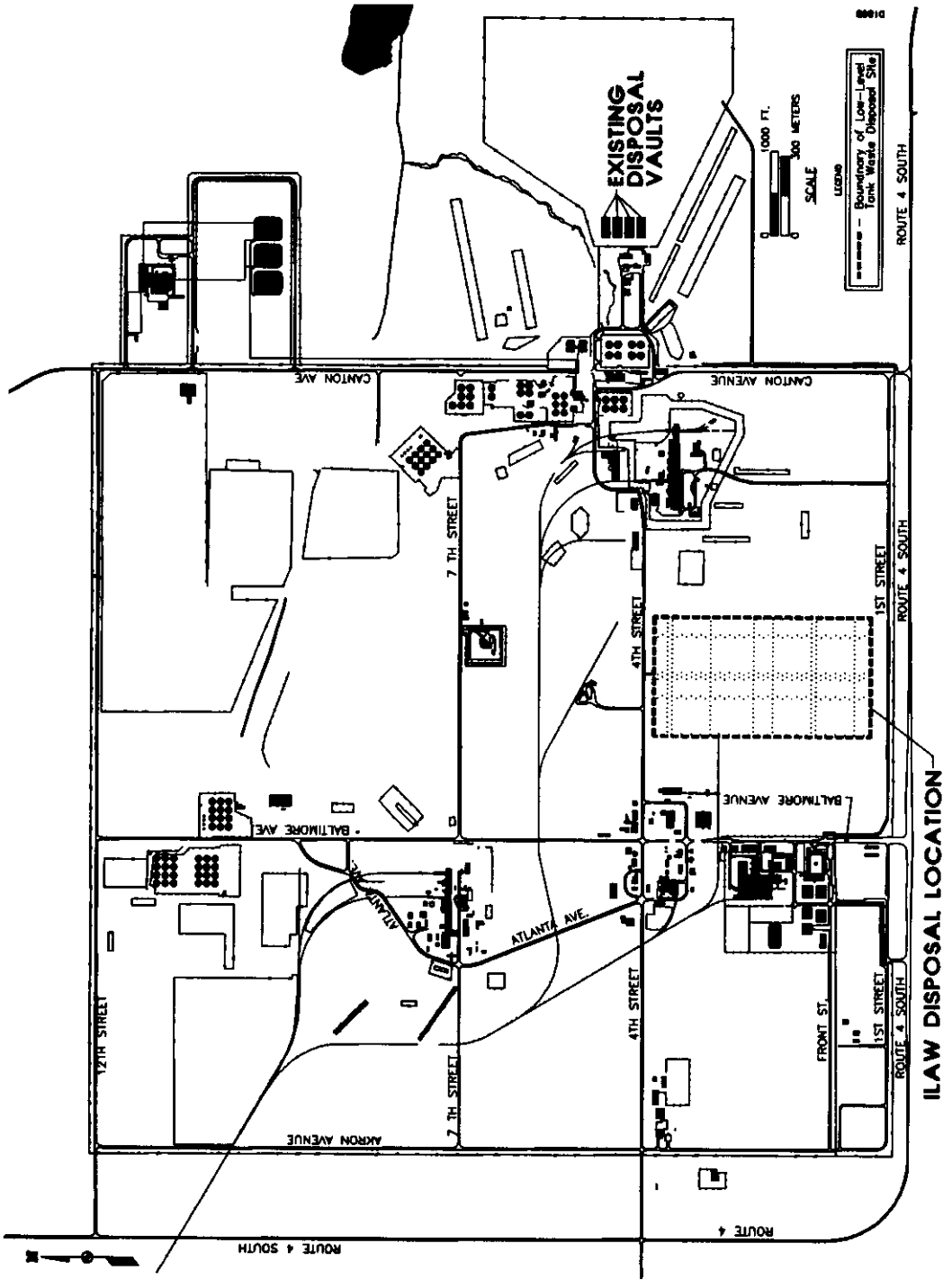


Figure 2. Existing Disposal Facility Site Plan

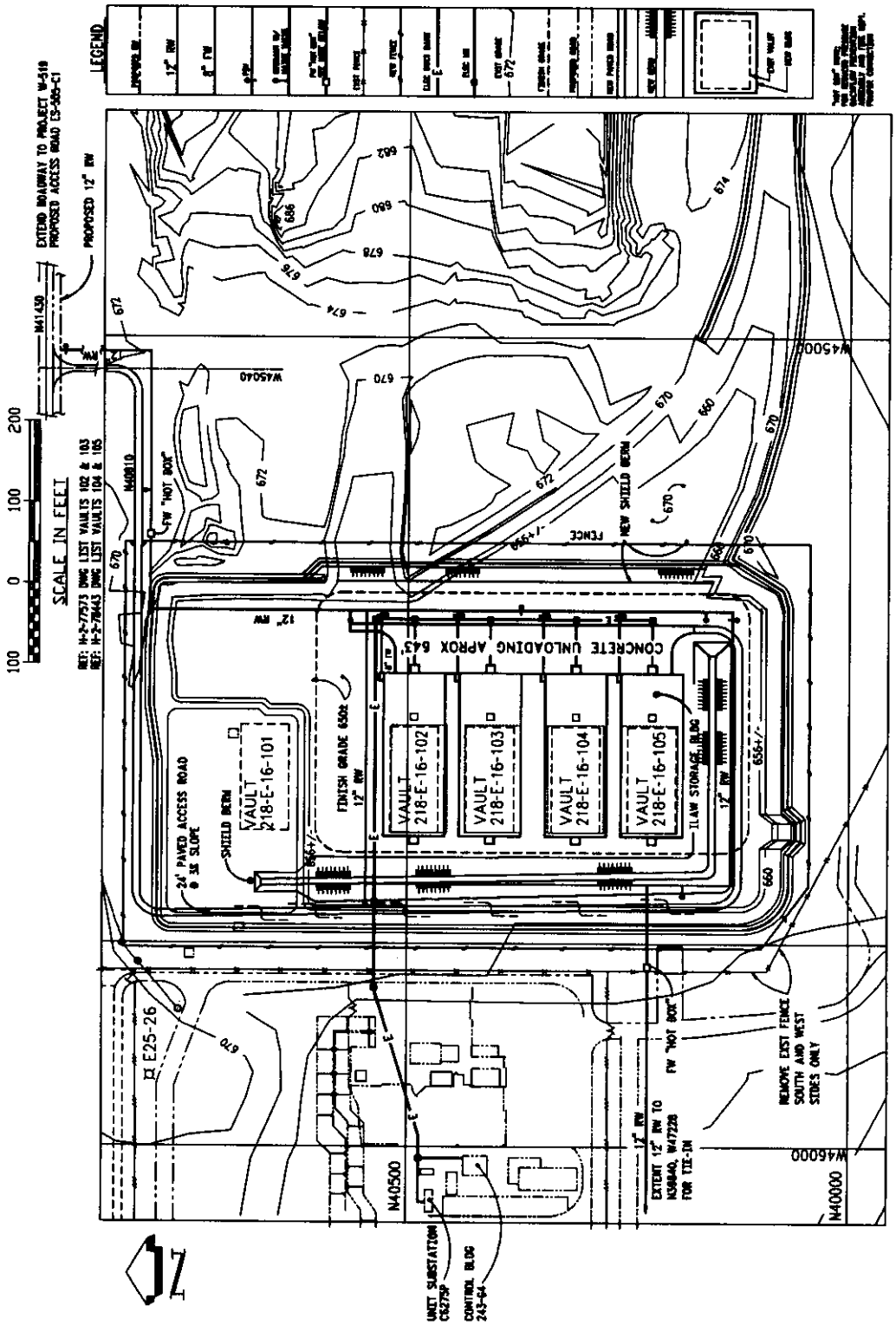


Figure 3. Existing Disposal Facility Catch Basin

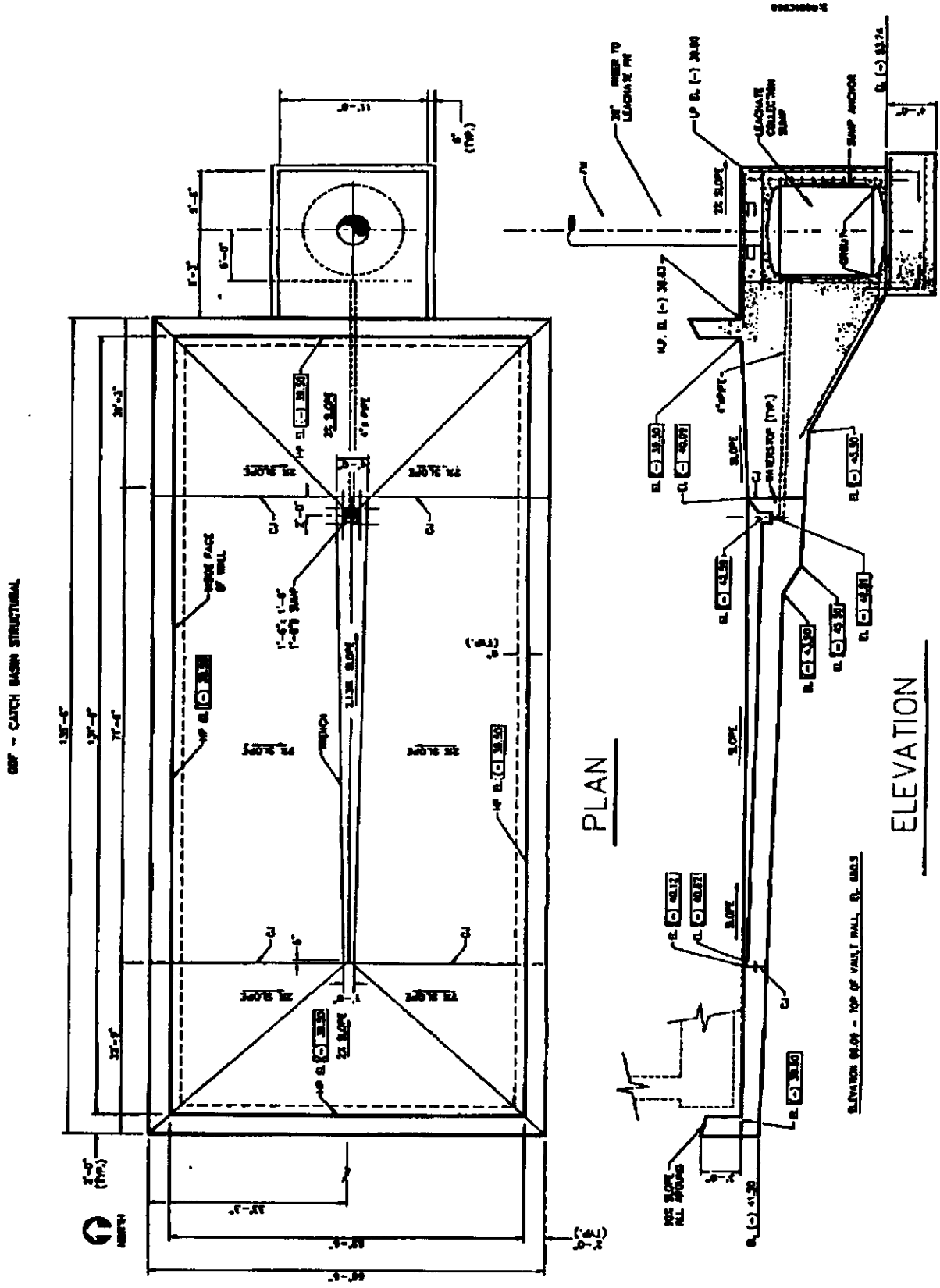


Figure 4. Existing Disposal Facility Vault

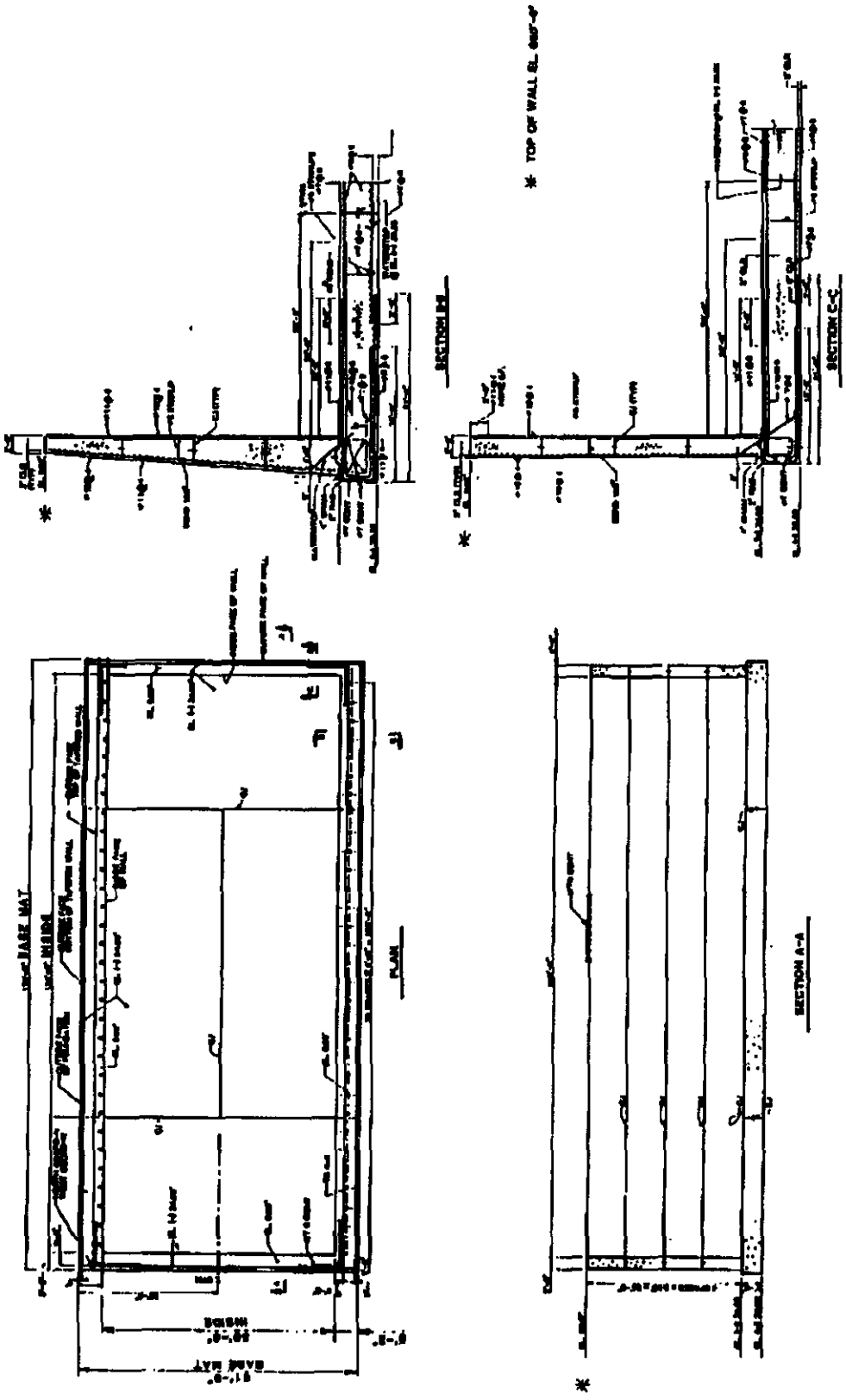


Figure 5. Existing Disposal Vault Side Wall Extension

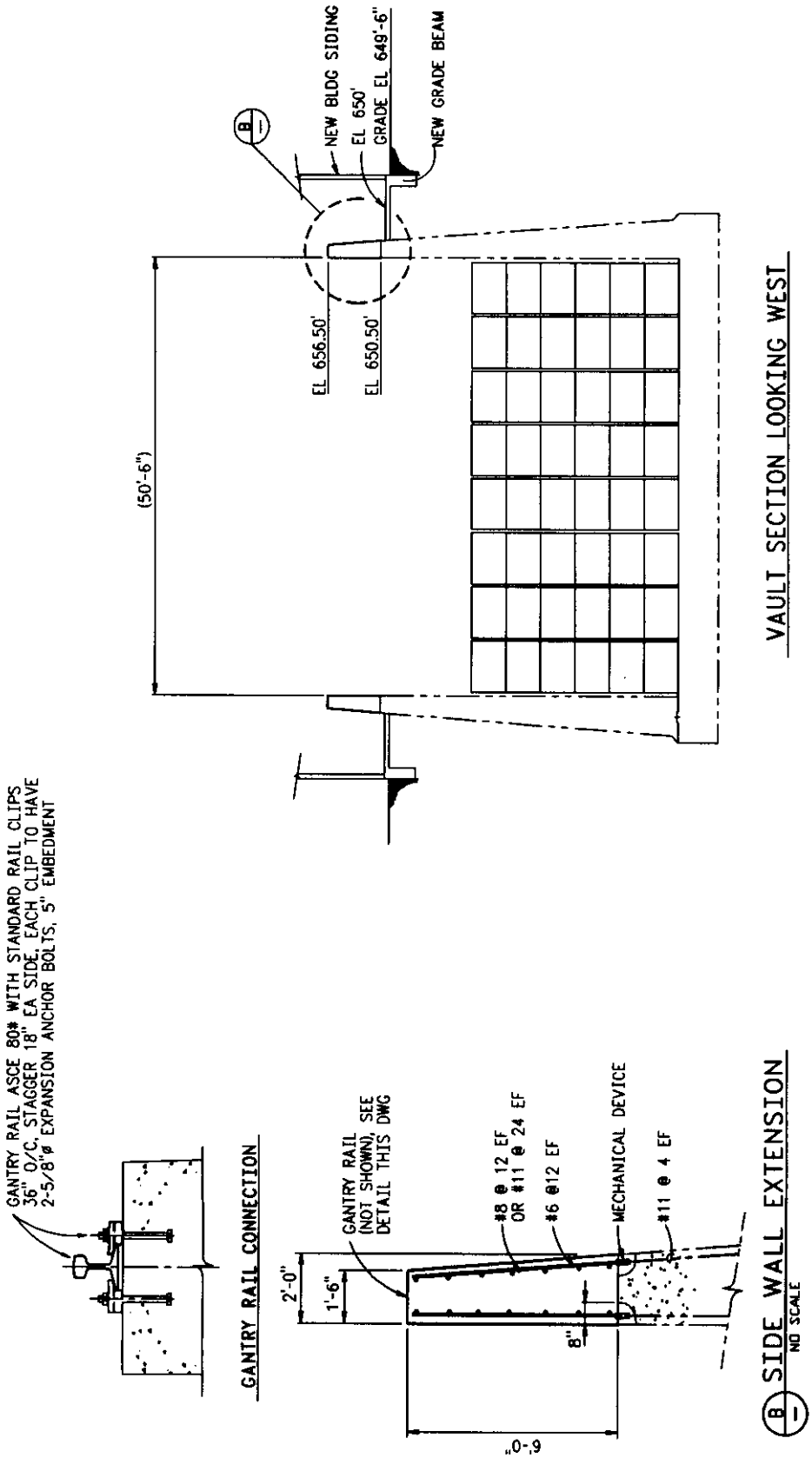


Figure 6. New ILAW Disposal Facility Site Plan

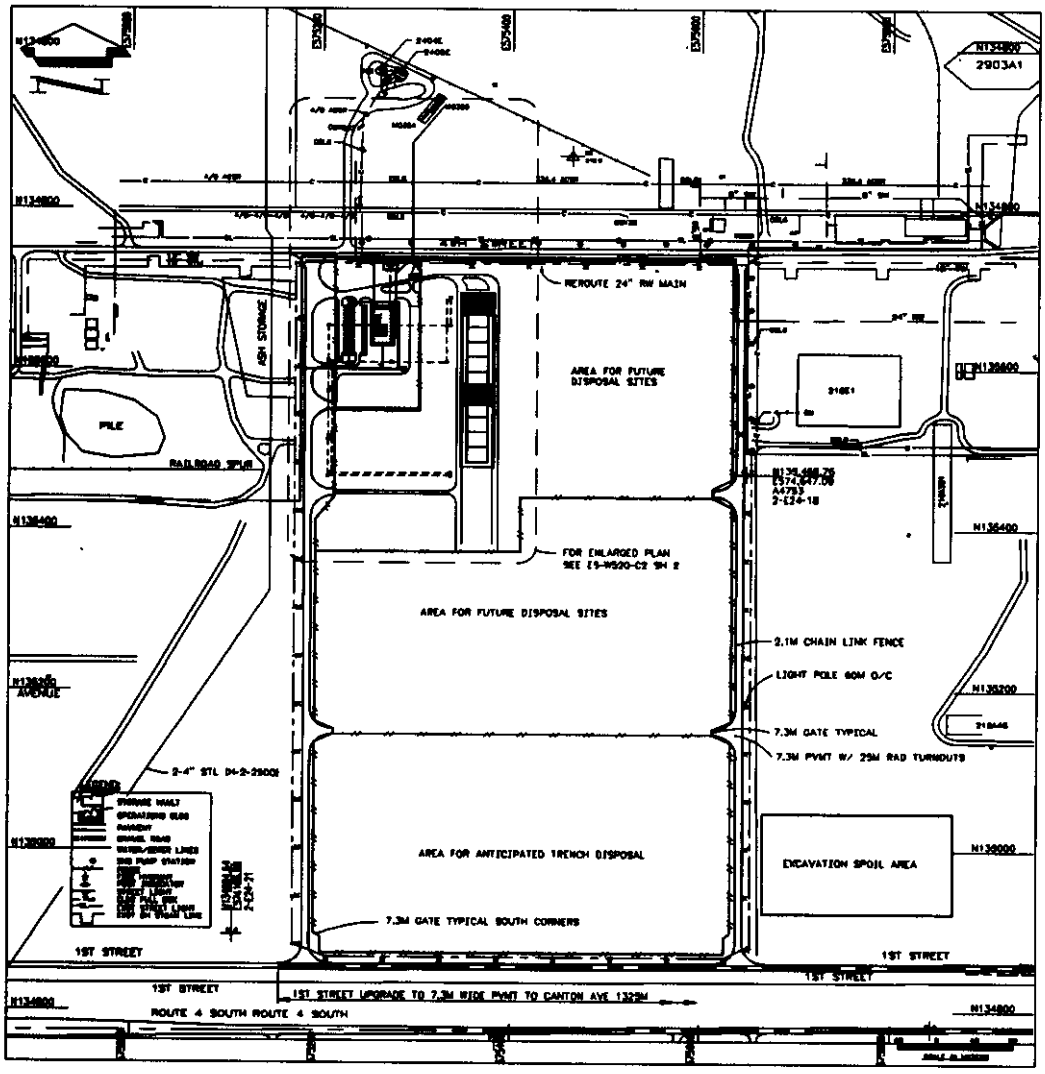


Figure 7. New Disposal Facility Vault Layout

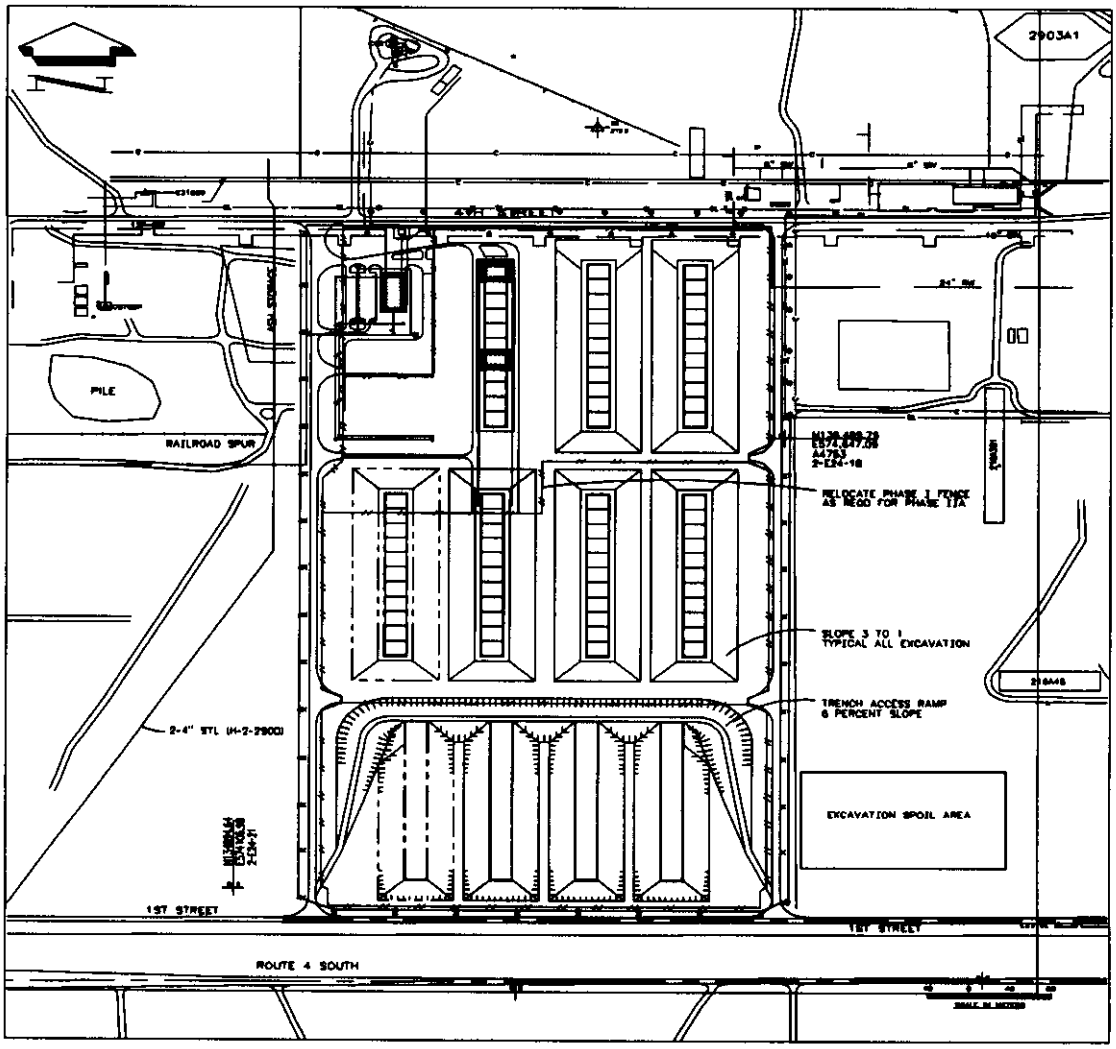


Figure 8. New Disposal Facility Catch Basin and Leachate Collection System

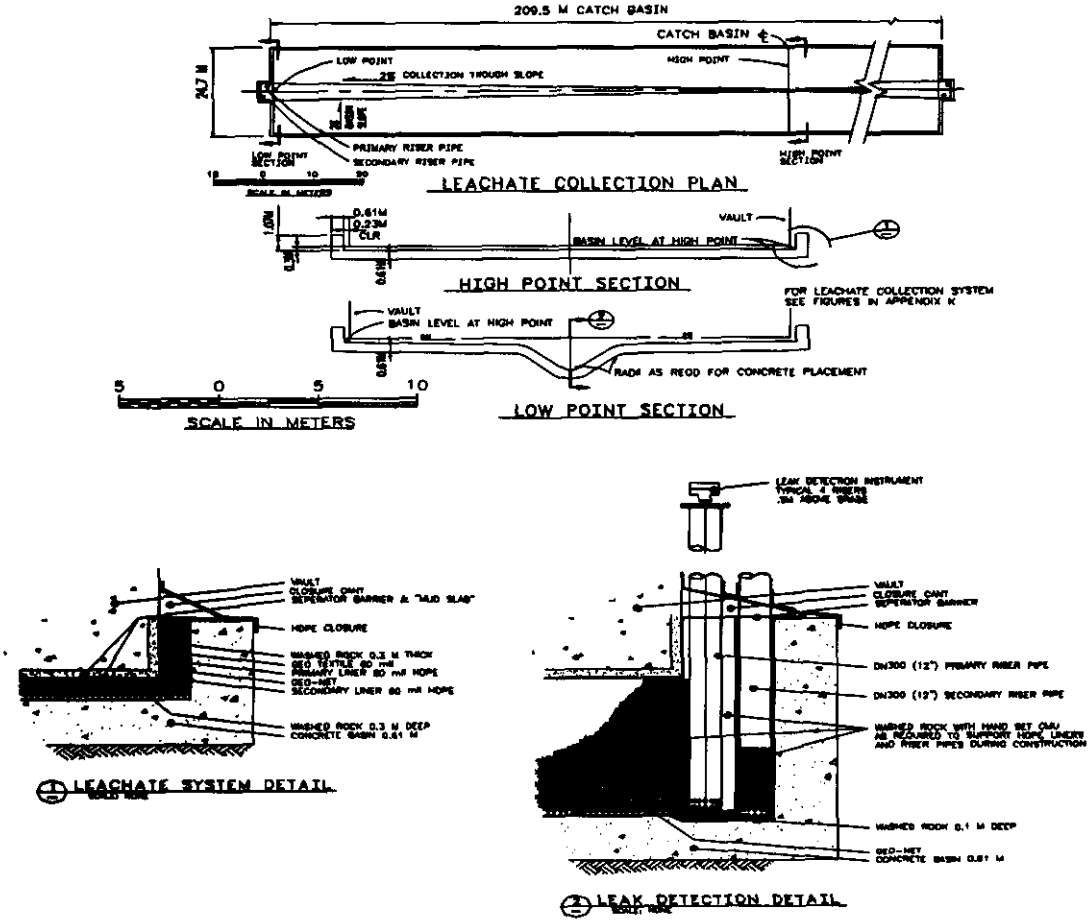


Figure 9. New Disposal Facility Vault Layout

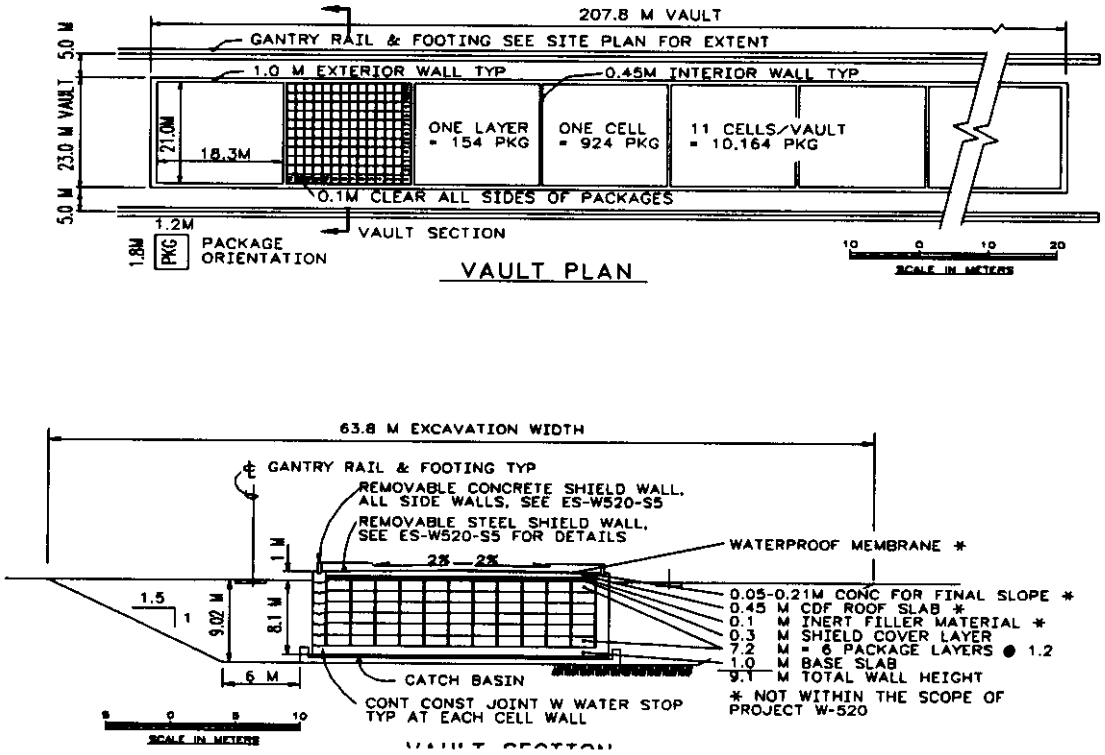
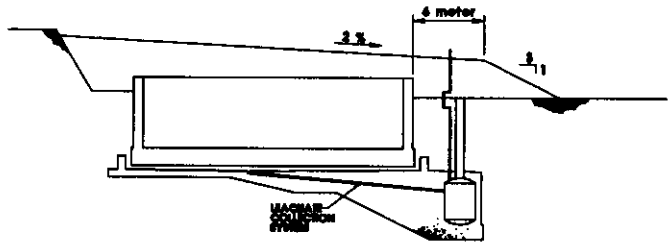


Figure 10. Cross-Sectional Elevation View of Proposed ILAW Product Disposal Facilities



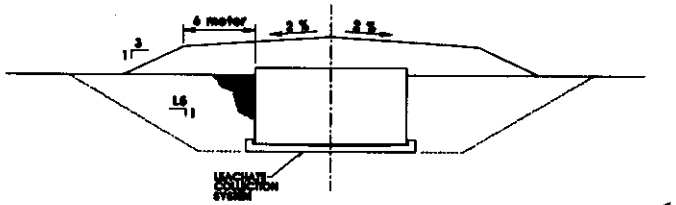


Figure 11. Modified RCRA Subtitle C Barrier, Cross-Sectional Elevation View.

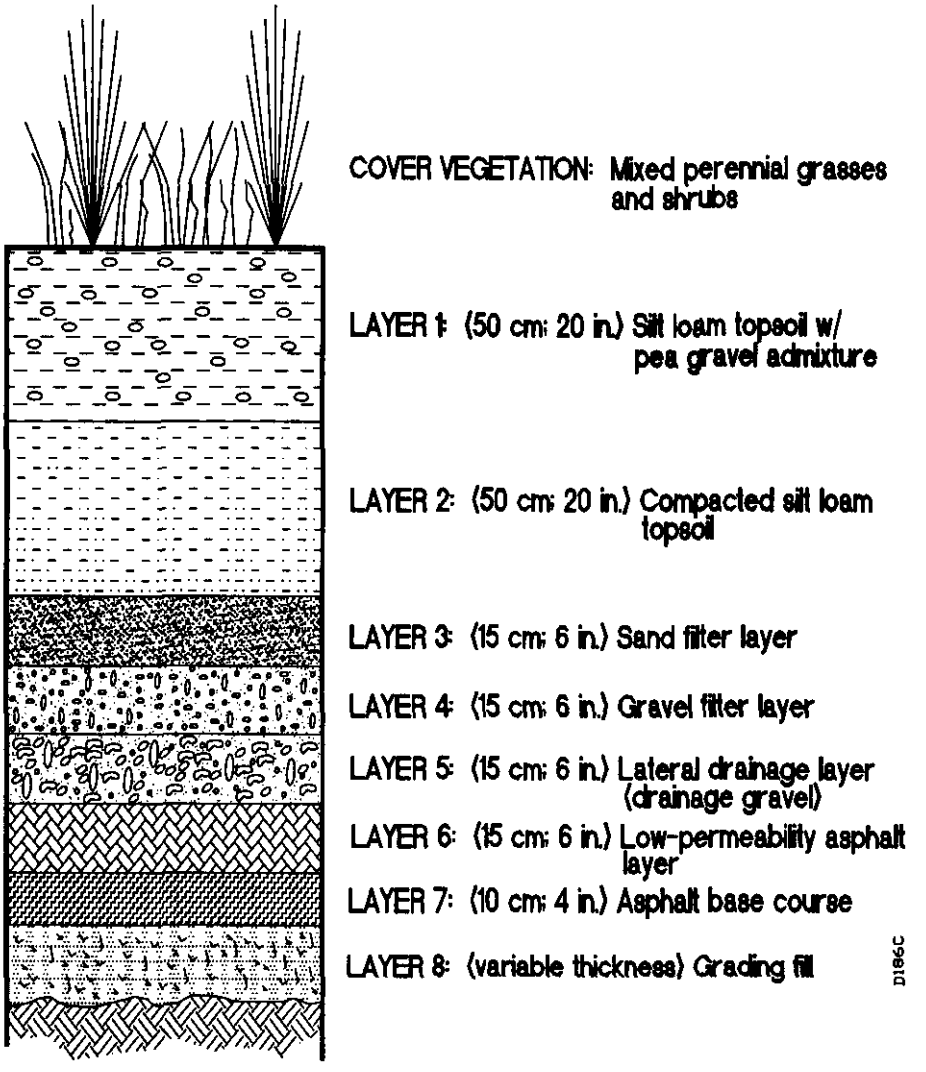


Figure 12. Existing Disposal Facility Conceptual Model Layout

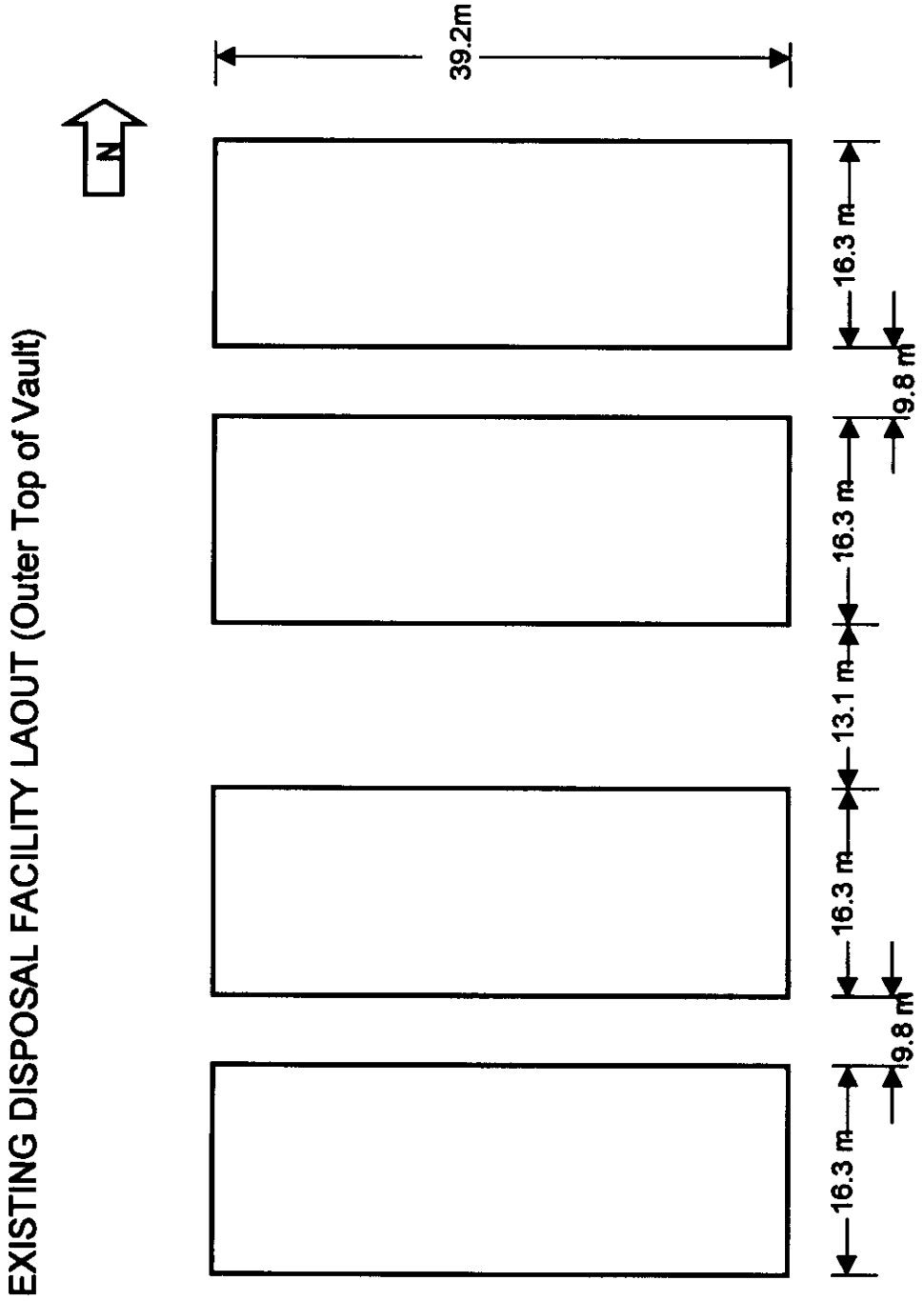


Figure 13. Existing Disposal Vault Conceptual Model

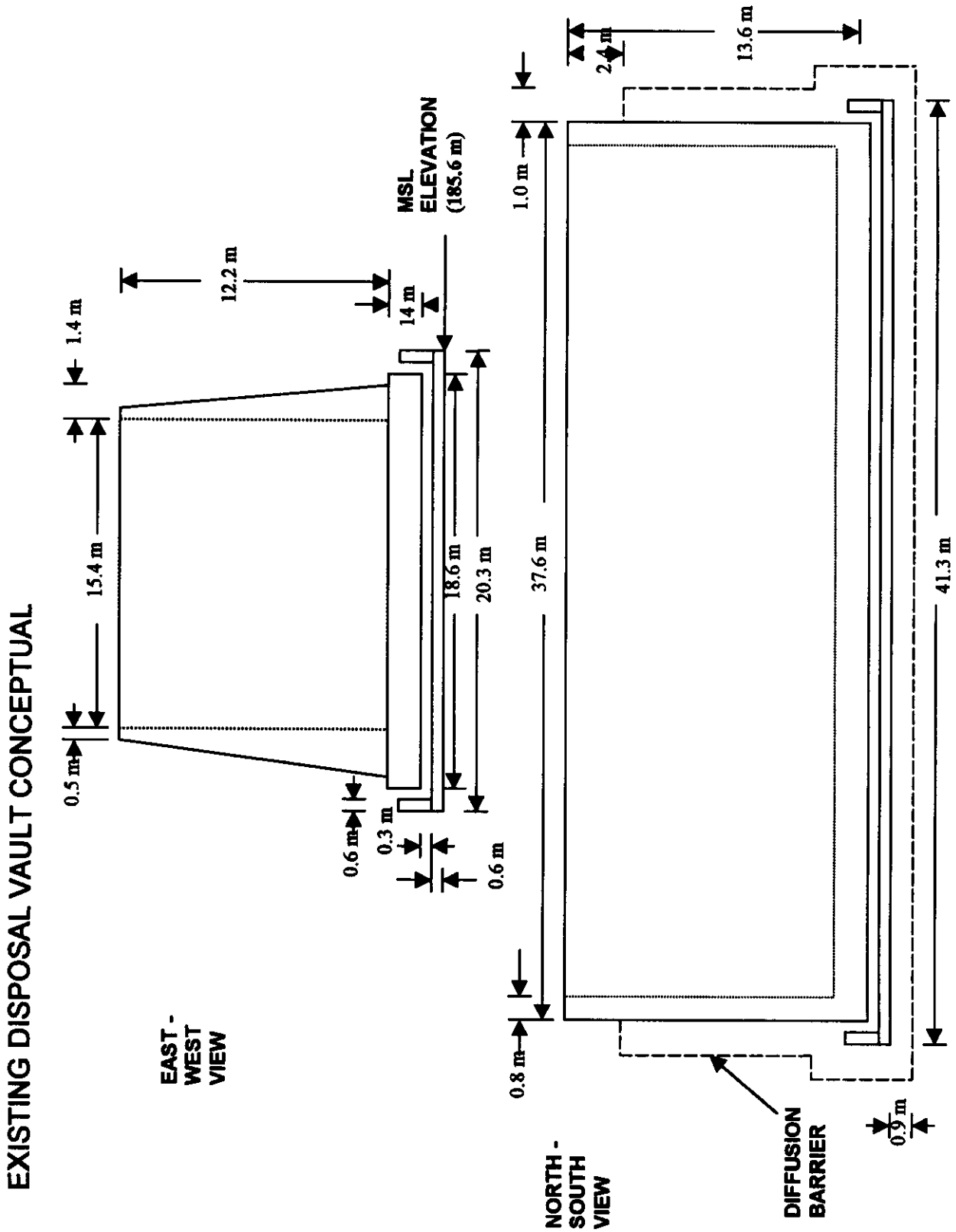


Figure 14. New Disposal Facility Conceptual Model

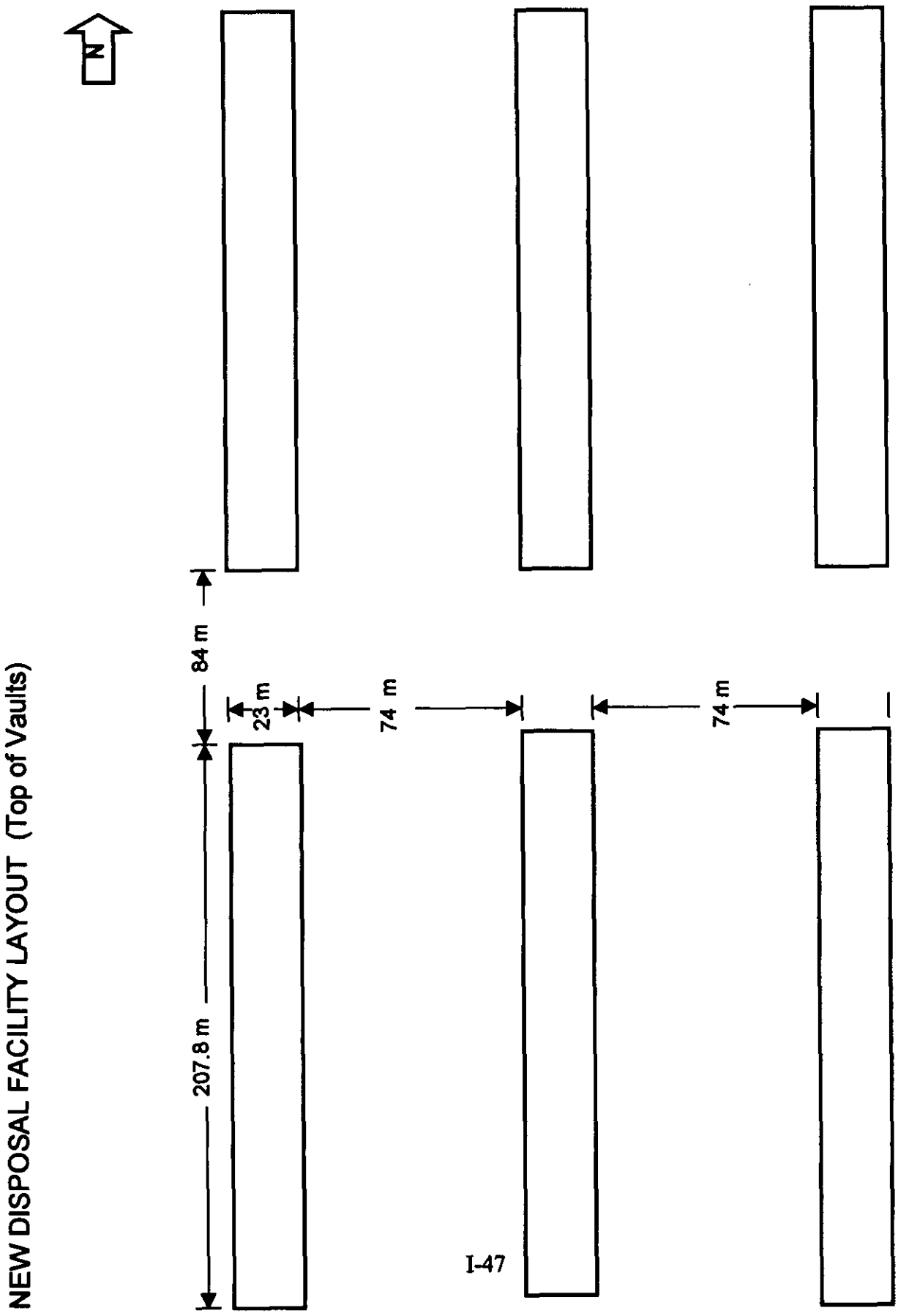


Figure 15. New Disposal Vault Conceptual Model

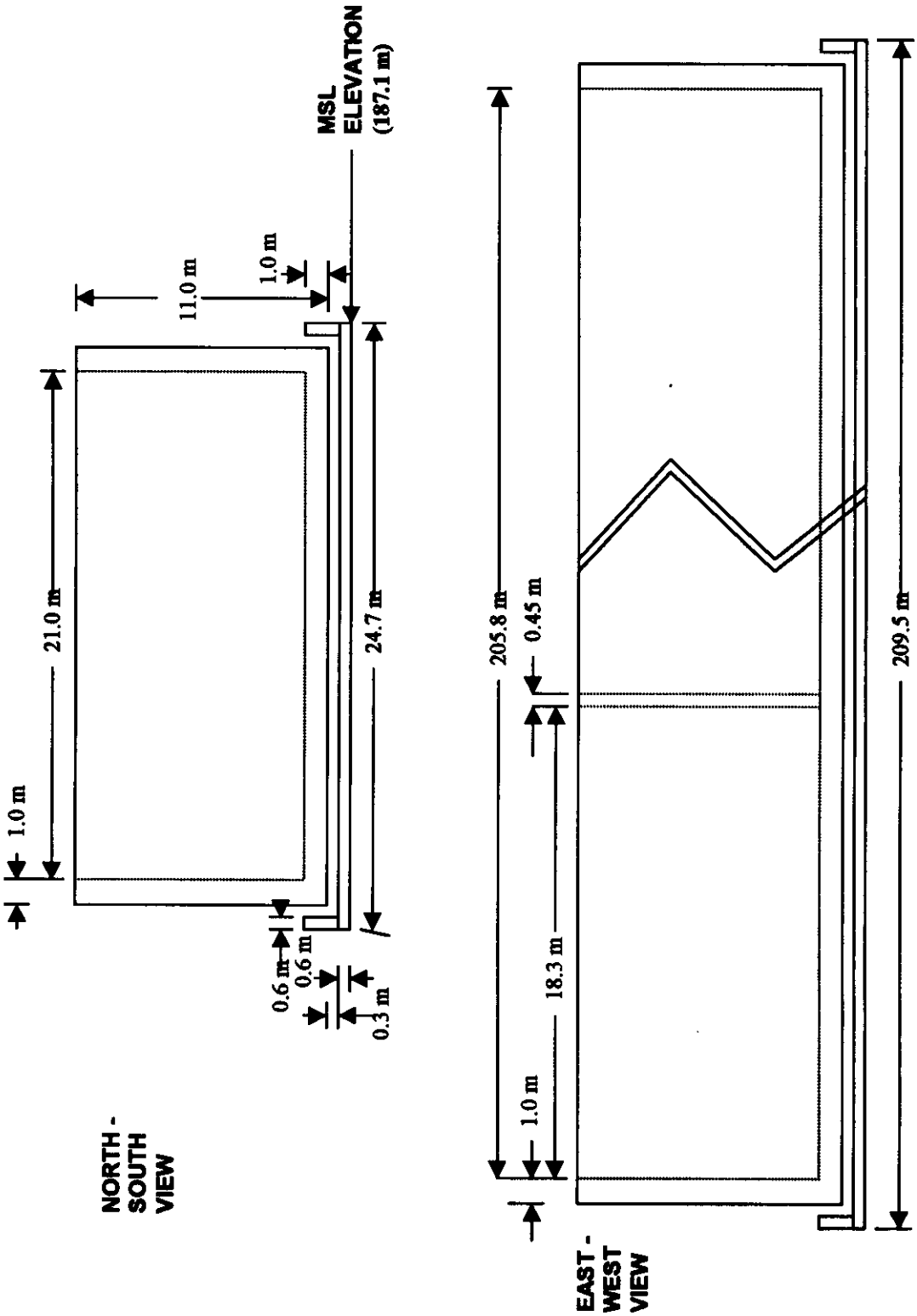


Figure 16. RH Trench Conceptual Model

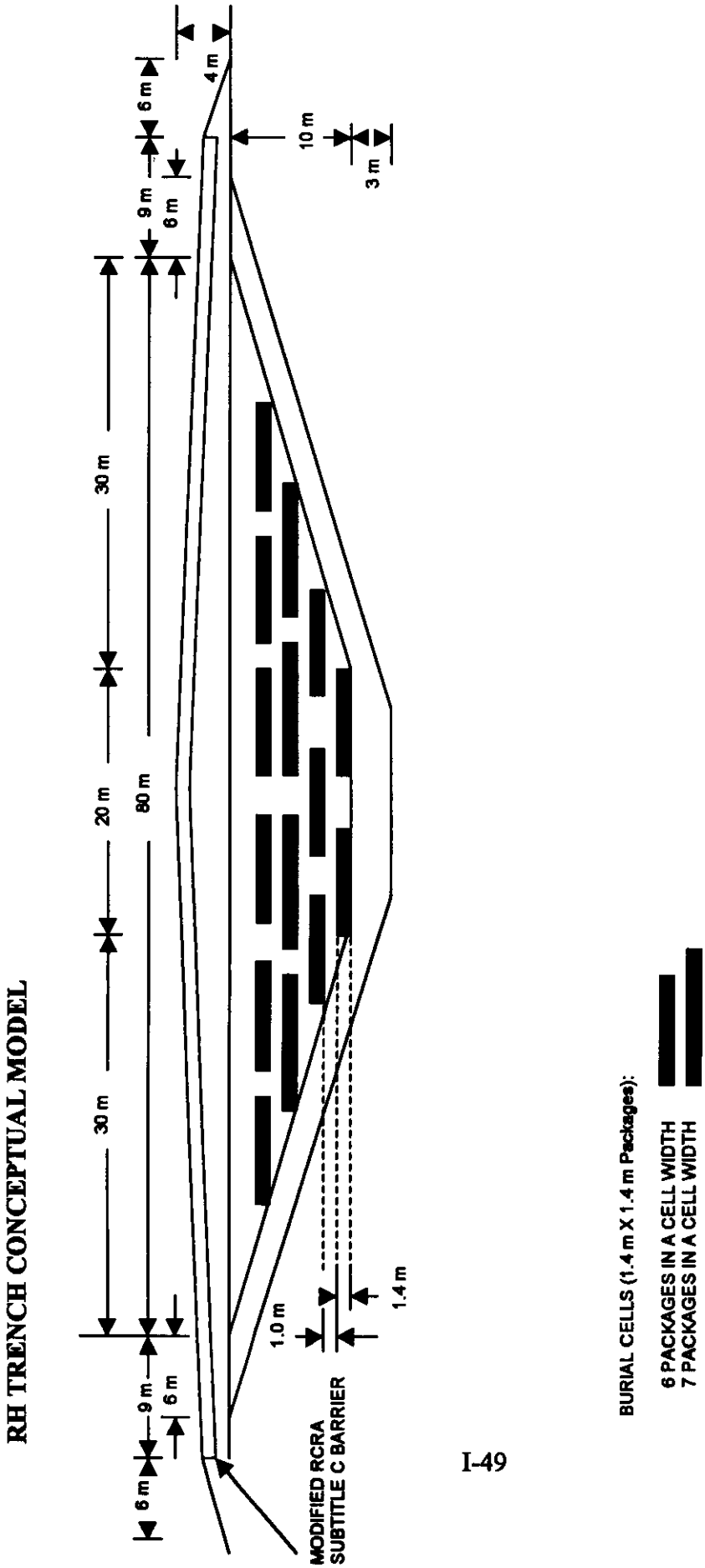


Figure 17. RH Trench Liner System Detail

RH TRENCH LINER SYSTEM DETAIL

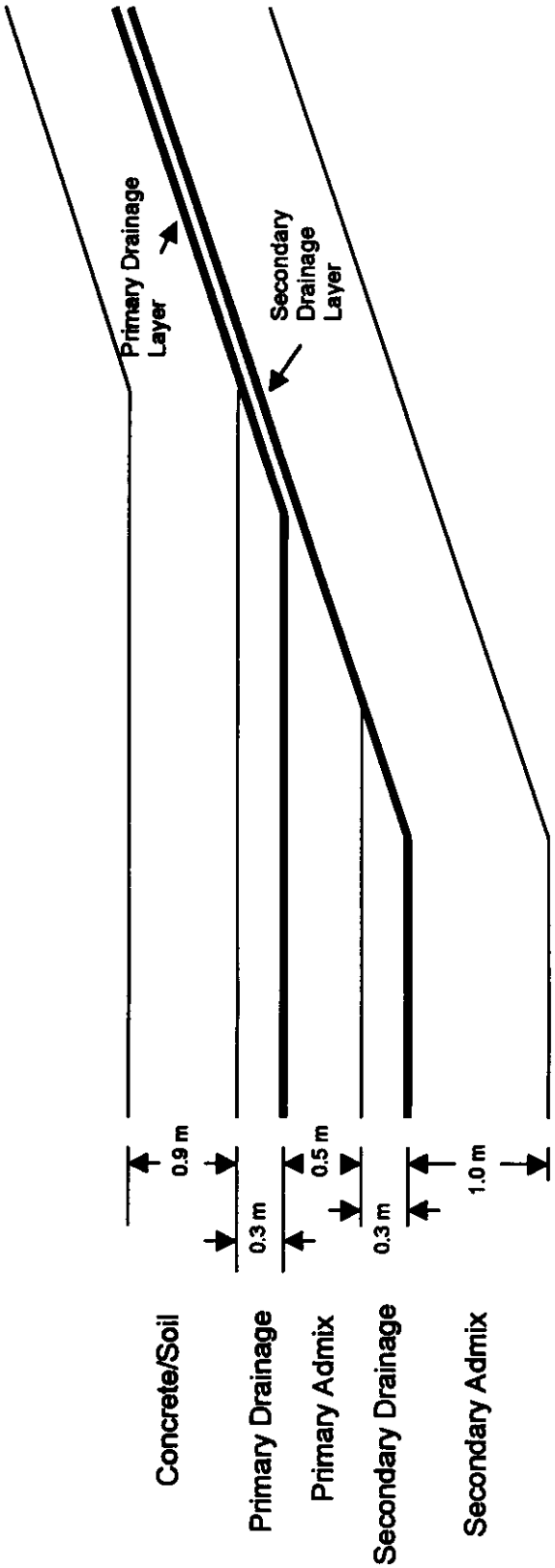
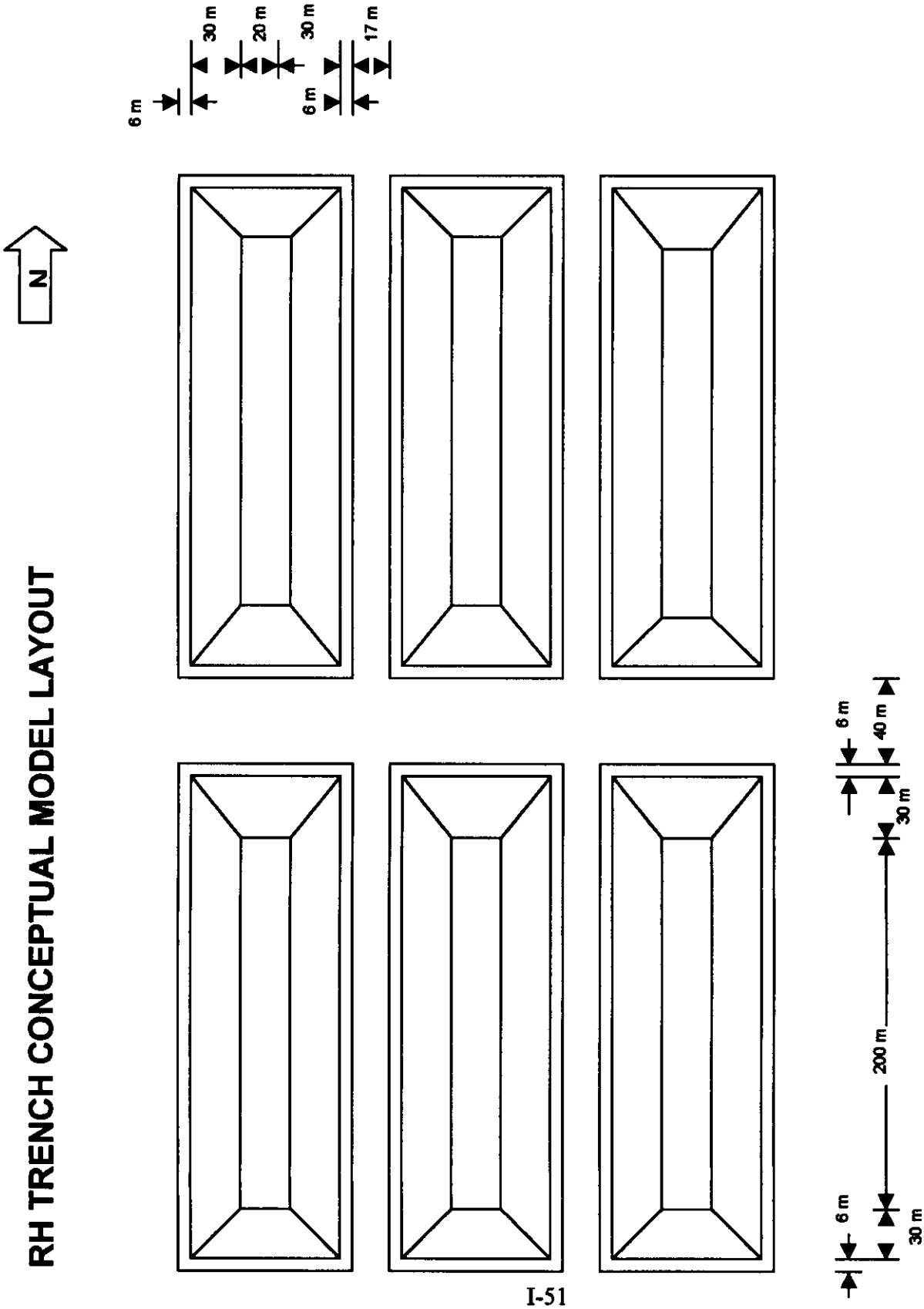


Figure 18. RH Trench Conceptual Model Layout



QUALITY ASSURANCE

Quality assurance for this report is provided through the following peer review process. A peer review plan was established that identified two technical reviews to be performed on the Facility Data Package for the Immobilized Low-Activity Tank Waste Performance Assessment. Fluor Federal Services (FFS) was responsible for an internal review of the document. The Numatec Hanford Company (NHC), Pacific Northwest National Laboratory (PNNL), and Bechtel Hanford Company (BHI) were responsible for the Hanford technical review of this document. NHC has subject mater experts on the facility design and the engineering studies that have been performed for the disposal facilities. PNNL has responsibility for the incorporation of the facility design into the modeling calculations for contaminant transport. BHI manages the Vadose Zone/Groundwater Integration Project and is responsible for assuring that appropriate data and models are used for Hanford risk assessments.

The Hanford reviewers, upon completion of their reviews, provided the author (R. Puigh) with written documentation of their comments. Acceptance of the comment resolutions was indicated by reviewers' signature on the Engineering Data Transmittal (EDT).

The peer review members were selected based on their experience and knowledge of specific subject areas. The internal peer review was provided by Raziuddin Khaleel. Dewey Burbank was chosen from NHC to provide the technical review. He was chosen based on his knowledge of the disposal facility design activities. Dr. B. McGrail and Philip Meyer from PNNL were chosen to appoint technical reviewers for the facility data report to assure the report contains all relevant information needed for the contaminant transport model calculations. Dr. Graham represents the point of contact for the review of the data package by the Hanford Site Vadose Zone/Groundwater Integration Project. Dr. Graham is responsible for appointing other Hanford technical experts as deemed necessary to review this data package.

Design data for the existing disposal vaults were developed under Westinghouse Hanford Company QA/QC procedures associated with design. The conceptual design data for the existing facility modifications and the new disposal facilities were developed under QA/QC practices for FDNW, Inc.

PNNL-13033

APPENDIX J

Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment

M.J. Fayer
E.M. Murphy
J.L. Downs
F.O. Khan
C.W. Lindenmeier
B.N. Bjornstad

December 1999

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352

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Summary

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in near-surface, shallow-land burial facilities. The LMHC project to assess the performance of these disposal facilities is known as the Hanford ILAW Performance Assessment (PA) Activity, hereafter called the ILAW PA project. The goal of this project is to provide a reasonable expectation that the disposal of the waste is protective of the general public, groundwater resources, air resources, surface-water resources, and inadvertent intruders. Achieving this goal will require predictions of contaminant migration from the facility. To make such predictions will require estimates of the fluxes of water moving through the sediments within the vadose zone around and beneath the disposal facility. These fluxes, loosely called recharge rates, are the primary mechanism for transporting contaminants to the groundwater.

Pacific Northwest National Laboratory (PNNL) assists LMHC in their performance assessment activities. One of the PNNL tasks is to provide estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of ILAW. Specifically, recharge estimates are needed for a fully functional surface cover, the cover sideslope, and the immediately surrounding terrain. In addition, recharge estimates are needed for degraded cover conditions. The temporal scope of the analysis is 10,000 years, but could be longer if some contaminant peaks occur after 10,000 years.

The elements of this report compose the Recharge Data Package, which provides estimates of recharge rates for the scenarios being considered in the 2001 PA. Table S.1 identifies the surface features and time periods evaluated. The most important feature, the surface cover, is expected to be the modified RCRA Subtitle C design. This design uses a 1-m-thick silt loam layer above sand and gravel filter layers to create a capillary break. A 0.15-m-thick asphalt layer underlies the filter layers to function as a backup barrier and to promote lateral drainage. Cover sideslopes are expected to be constructed with 1V:10H slopes using sandy gravel. The recharge estimates for each scenario were derived from lysimeter and tracer data collected by the ILAW PA and other projects and from modeling analyses.

For the best estimate case, we proposed using a recharge rate of 0.1 mm/yr for the surface cover with a shrub-steppe plant community. This rate is lower than the cover design goal of 0.5 mm/yr because it is closer to the actual drainage rate measured with lysimeters and inferred with modeling. The simulation results showed that erosion of 20% of the silt loam layer did not impair this performance nor did the deposition of 20 cm of dune sand. For the sandy gravel sideslope, we proposed using a recharge rate of 50 mm/yr. This rate is lower than the 75 mm/yr used in the ILAW 1998 PA. For the soil type known as Rupert sand with a shrub-steppe plant community, we proposed using a recharge rate of 0.9 mm/yr. This rate is lower than the 3 mm/yr used in the ILAW 1998 PA. For the soil type known as Burbank loamy sand with a shrub-steppe plant community, we proposed using a recharge rate of 4.2 mm/yr. This soil type was not considered in the ILAW 1998 PA. For the Hanford formation sediments during construction, we proposed using a recharge rate of 55.4 mm/yr. Recharge in Hanford formation sediments during construction was not considered in the ILAW 1998 PA.

Table S.1. Recharge Estimates for the Best Estimate Case (and Reasonable Bounding Cases) During Each Period of Interest to the ILAW 2001 PA.

Surface Feature	Estimated Recharge Rates for the Best Estimate Case (and Reasonable Bounding Cases) (mm/yr)			
	Time Period of Recharge Evaluation			
	Pre-Hanford	During Disposal Operations	During Surface Cover Design Life	After Surface Cover Design Life
Modified RCRA Subtitle C Cover	NA	NA	0.1 (0.01, 4.0)	0.1 (0.01, 4.0)
Cover Sideslope	NA	NA	50 (4.2, 86.4)	50 (4.2, 86.4)
Rupert Sand	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)
Burbank Loamy Sand	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)
Hanford Formation Sediments	NA	55.4 (50, 86.4)	NA	NA
NA = Not applicable.				

A limited number of sensitivity tests were conducted using numerical simulation. The results showed that the surface cover limited recharge to less than 0.1 mm/yr regardless of the plant type, the presence of plants, or any of the climate change conditions. In contrast, recharge in the Rupert sand showed a significant sensitivity to vegetation type and climate change conditions, but less sensitivity to small variations in hydraulic properties.

Several alternative conceptual models were considered to indicate the effects of conceptual model uncertainty. Under the climate change condition most likely to promote recharge (i.e., increased precipitation and decreased temperature), recharge through the cover remained <0.1 mm/yr in contrast to recharge in Rupert sand, which increased from 2.2 to 27 mm/yr. Replacement of the shrub cover with cheatgrass had no impact on recharge through the surface cover but it increased recharge in Rupert sand from 2.2 to 33.2 mm/yr. Irrigation on the surface cover caused recharge to increase from 0.1 to 26.4 mm/yr as the irrigation efficiency was reduced from 100% to 75%.

Using the available recharge estimates, we identified a set of reasonable bounding rates. The design feature with the largest projected range in performance was the sideslope (4.2 to 87.5 mm/yr). Given that sideslopes could represent a significant fraction of the surface cover footprint, we believe that efforts to improve sideslope performance are warranted.

Planning for FY 2000 includes activities to

- extend the length of record from the lysimeter facility
- estimate recharge rates using tracer data from the borehole samples to be collected in the year 2000

- add needed capability to the simulation model to address multiple plant species, seasonal effects, and snowmelt

- collect vegetation data to fill existing data gaps, including plant water status during the late fall to early spring period, differences in rooting patterns beneath shrubs and in the inter-shrub spaces, and maximum depth of rooting

- initiate a field measurement activity to get site-specific estimates of water status and fluxes within and well below the plant root zone.

Issues remaining to be addressed include the precision of lysimeter leak tests to support the use of lower recharge estimates, possible facility deposition of chloride that could impact tracer analyses, and the importance of temperature and water vapor flow when recharge rate estimates are lower than 1 mm/yr. In addition, the impacts of unstable and preferential flow and flaws in the cover need to be evaluated.

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1.0 Introduction

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in near-surface, shallow-land burial facilities.

The LMHC project to assess the performance of these disposal facilities is known as the Hanford ILAW Performance Assessment (PA) Activity, hereafter called the ILAW PA project. The goal of this project is to provide a reasonable expectation that the disposal of the waste was protective of the general public, groundwater resources, air resources, surface-water resources, and inadvertent intruders. Achieving this goal will require predictions of contaminant migration from the facility. To make such predictions will require estimates of the fluxes of water moving through the sediments within the vadose zone around and beneath the disposal facility. These fluxes, loosely called recharge rates, are the primary mechanism for transporting contaminants to the groundwater.

Pacific Northwest National Laboratory (PNNL) assists LMHC in their performance assessment activities. One of the PNNL tasks is to provide estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of ILAW (LMHC 1999).

The ILAW 1998 PA examined the long-term environmental and human health effects associated with the planned disposal of the vitrified low-level fraction of the waste presently contained in the Hanford high-level waste tanks (Mann et al. 1998). In support of that PA, Rockhold et al. (1995) provided estimates of recharge rates using historical data. Since then, the ILAW project has made significant investments in site-specific data collection. In addition to the ILAW activities, other projects have collected data that are relevant to the ILAW disposal. In preparation for a revision of the ILAW PA, called the 2001 PA, a number of data packages are being prepared (LMHC 1999). These packages will bring together recently collected site-specific ILAW data as well as relevant data collected by other projects.

Figure 1.1 shows the boundaries and major facilities of the Hanford Site (PNNL 1999). Figure 1.2 shows the locations of the two disposal sites that are being considered (Mann 1999): the ILAW Disposal Site (located southwest of the PUREX Plant) and the Existing Disposal Site (located east of the PUREX plant and formerly known as the Grout Vaults). For each disposal site, recharge rate estimates are needed for a fully functional surface cover, the cover sideslope, and the immediately surrounding terrain. In addition, recharge estimates are needed for degraded cover conditions. Mann (1999) indicated that the temporal scope of the ILAW 2001 PA is 10,000 years, but could be longer if some contaminant peaks occur after 10,000 years.

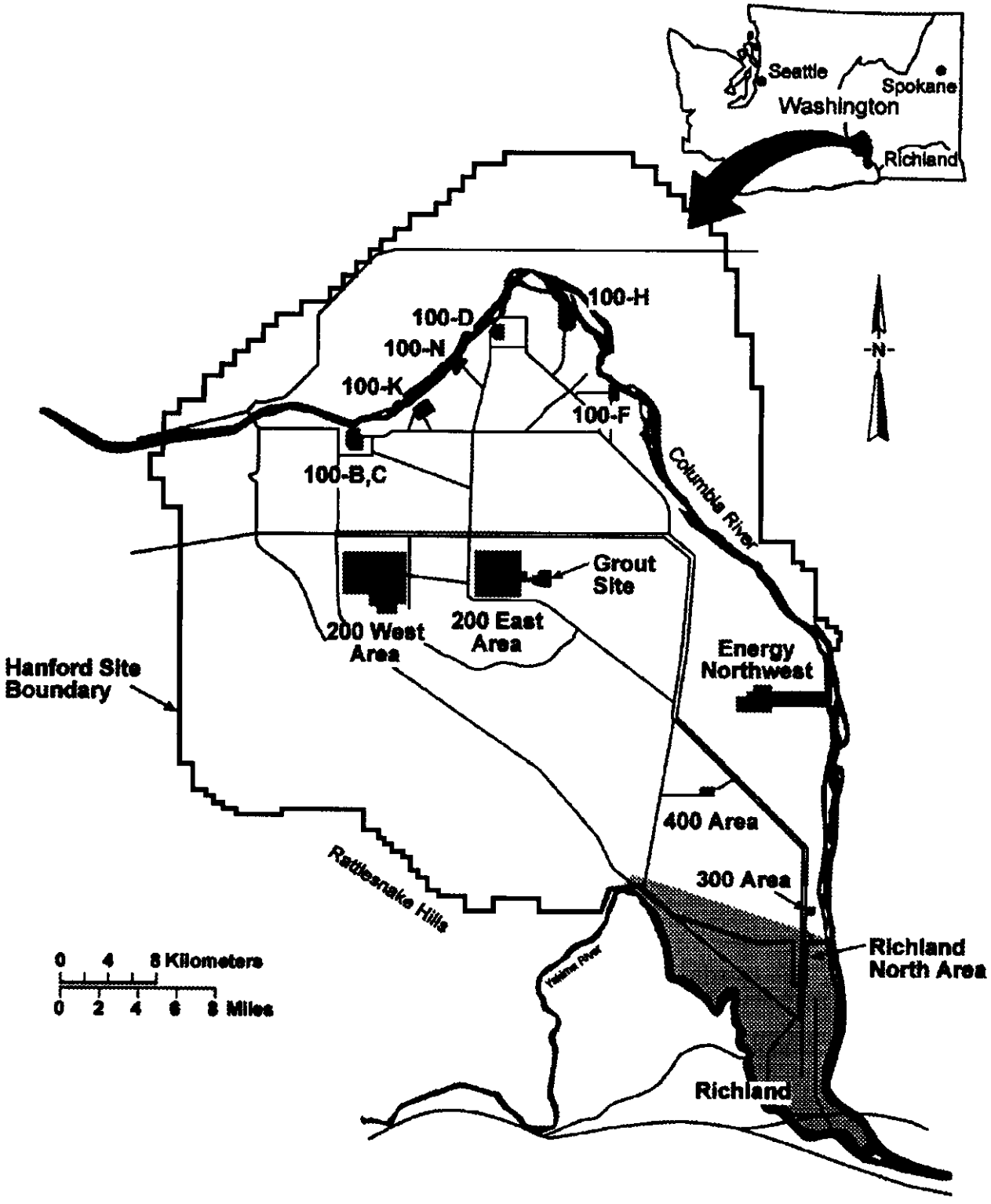


Figure 1.1. Map of the Hanford Site and Its Location Within Washington

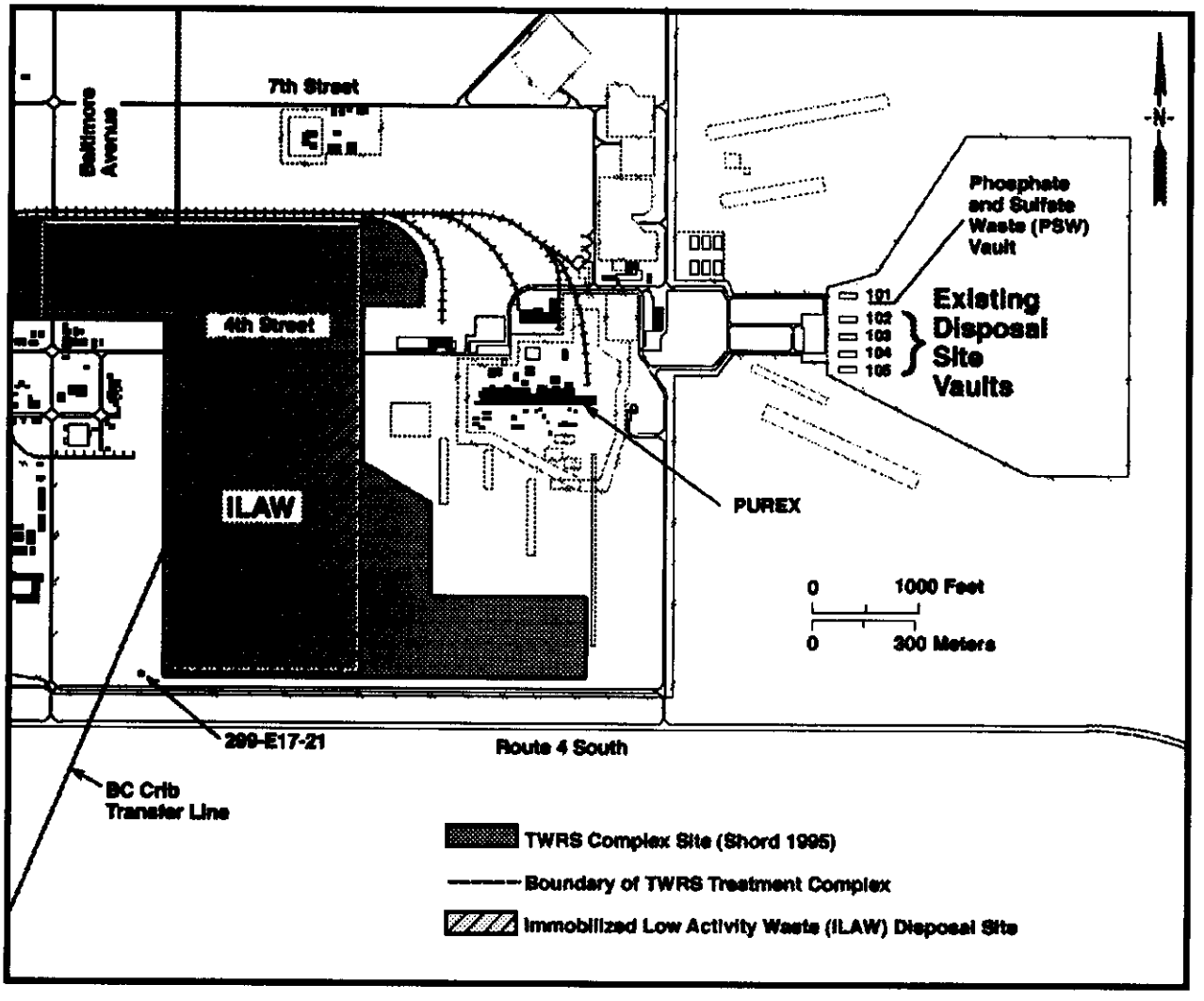


Figure 1.2. Locations of the ILAW Disposal Site and the Existing Disposal Site Vaults Within the Southeast Corner of the 200 East Area at Hanford. The ILAW Disposal Site is part of the Tank Waste Remediation Systems (TWRS) Treatment Complex, which lies within the larger TWRS Complex Site.

The elements of this report make up the Recharge Data Package. The objective of this data package is to provide recharge estimates for the scenarios being considered in the 2001 PA. Multiple estimation techniques were used to satisfy the objective, including lysimetry, tracer studies, and modeling studies. The report identifies how the data were used to generate recharge rate estimates for the best estimate case and reasonable bounding cases, as well as indicate the uncertainties in these estimates.

2.0 Background

The Hanford Site was established in 1944 as a U.S. Government nuclear materials production facility. During its history, Site missions included nuclear reactor operation, storage and reprocessing of spent nuclear fuel, and management of radioactive and hazardous wastes. Today, activities on the Site involve environmental restoration, energy-related research, and technology development. Fifty-five years of operations have resulted in the accumulation of significant quantities of radioactive and hazardous wastes as well as their intentional and unintentional release to the environment.

2.1 Source and Destination of ILAW

The legacy of the earlier Hanford missions consists of more than 209,000 m^3 of radioactive and mixed waste stored in 177 buried single- and double-shell tanks in the Hanford Site 200 Areas (Mann et al. 1998). This waste will be retrieved and separated into two fractions: high-level waste to be sent to a federal geologic repository and low-activity waste to be immobilized (i.e., ILAW) and placed in a near-surface disposal system on site. Immobilization will be accomplished through the vitrification process, which will turn the waste slurry into a glass product. Some of the more important radionuclides include ^{79}Se, ^{90}Sr, ^{99}Tc, ^{129}I, ^{126}Sn, and ^{137}Cs, as well as isotopes and progeny of uranium, plutonium, neptunium, and americium (Mann et al. 1998).

Although plans are not final, some form of glass product will be produced and placed in metal containers. These containers will be stacked within belowground disposal vaults. The spaces between containers will be filled with something like sand and the top of the vault sealed with a controlled density fill. A protective surface cover will be constructed over the vaults prior to closure.

2.2 Definition of Recharge

The precise definition of recharge is that flux of water reaching ("recharging") the water table. We have no effective way of measuring recharge at the water table, so we resort to shallow unsaturated measurements and analyses. With these, we estimate the deep drainage flux, i.e., that flux leaving the evapotranspiration zone and ostensibly traveling to the water table. Given sufficient time, the deep drainage flux will eventually manifest itself as the recharge flux. However, when deep drainage fluxes change, the change may not be manifested at the water table for hundreds to thousands of years. The length of time will depend on the vadose zone thickness and hydraulic properties and the initial and final deep drainage rates. Sediment stratification can lengthen that time further.

For the 2001 PA, scenarios involving changes in recharge rates should address the time delay between deep drainage rate changes and changes in the flux reaching the water table.

2.3 Prior Estimates of Recharge at Hanford

In the early years of the Hanford Site, the perception was that recharge occurred only along the upper elevations of Rattlesnake Mountain and the valleys to the north, and it did not occur across the remainder of the Site. The Hanford Defense Waste Environmental Impact Statement assumed that natural recharge was essentially zero in and around the storage and disposal areas (DOE 1987). A panel of nationally recognized scientists was convened in 1985 to discuss the recharge issue. The reviewers disputed the notion of zero recharge. Data collected before and after the 1985 review showed clearly that recharge can and does occur under favorable conditions. Gee et al. (1992) presented evidence that recharge rates can vary from nearly zero in silt loam soils covered by sagebrush to more than 100 mm/yr in gravel-covered soils without vegetation.

Rockhold et al. (1995) presented a review of past work related to recharge. Appendix B of their report describes the numerous studies conducted since 1969 using field measurements of soil water, matric potential, and temperature; tracer measurements; lysimeter measurements; and numerical modeling. All of these studies showed the potential for recharge to occur if conditions are right (i.e., coarse-textured rather than fine-textured soil, sparse plant community, and shallow-rooted rather than deep-rooted plants).

2.4 1998 PA

Mann et al. (1998) is commonly referred to as the 1998 PA. It was the initial effort to demonstrate the feasibility of safely disposing of ILAW at the Hanford Site. Because the ILAW PA project was only just beginning, the analyses were conducted using reasonable estimates of the parameters without having site-specific information. The intention was to initiate a program to collect data relevant to the actual disposal sites and glass product (see next section).

In lieu of site-specific data, Rockhold et al. (1995) assembled their best estimate of recharge rates to use in the 1998 PA (called the preliminary PA in 1995). Their recommendations were

> "The existing recharge data were used to provide recharge estimates that can be used in preliminary performance assessment calculations. Estimates are provided for the barrier, the barrier edge, the surrounding natural ecosystem, and the entire Hanford Site. We recommend assuming a recharge rate of 0.5 mm/yr through the Hanford protective barrier. This assumption is supported by an 8-year record of lysimeter data (Table 3.1) and is consistent with engineering design specifications over the 1000-year design life of the barrier (Wing 1994). At the barrier edge, a higher recharge rate of 75 mm/yr should be assumed. This assumption is based on four years of data for a lysimeter with a graveled surface (Table 3.1) that is similar to the riprap sideslope of the protective barrier. This estimate does not include possible overland flow or lateral drainage from the barrier. Beyond the barrier, the recharge rate of the natural ecosystem can be represented with one of two rates. If the plant community is assumed to be sagebrush, an estimate of 5.0 mm/yr should be used. This is a conservative value chosen to be slightly greater than all the rates reported by Prych (1995) using tracer measurements. If the plant community is assumed to be cheatgrass, an estimate of 25.4 mm/yr should be used. This value is based on an 8-year record of water content observations at the Grass

Site in the 300 Area (Fayer and Walters 1995). For the entire Hanford Site, we recommend using the recharge distribution map reported by Fayer and Walters (1995)."

2.5 ILAW PA Project Activities

Shortly after publication of Rockhold et al. (1995), a panel of nationally recognized scientists was convened to review the ILAW project needs for recharge information. The panel concluded that enough information existed to proceed with the 1998 PA, but that site-specific data would be needed to provide technically defensible estimates.[1] They supported efforts to use lysimetry, tracers, and modeling. The panel noted that the results might not change the recharge estimates significantly but would strengthen the technical credibility of the final recharge estimates used in the performance assessment. The panel also cautioned that uncertainty in conceptual models and supporting data should not be ignored.

Since 1995, the ILAW PA project has conducted several studies to improve the estimates of natural recharge. These studies included direct measurements of recharge using lysimetry (Appendix A), tracer evaluations of recharge (Appendix B), and numerical simulations of recharge (Appendix C). In addition to these basic studies, the ILAW PA project also supported auxiliary studies. Appendix D analyzes the origin of sand dunes at Hanford and summarizes the results of trenching a dune along the southern edge of the new ILAW Disposal Site. Appendix E describes the results of surface sediment sampling to determine the possibility of deposition of facility emissions (and their possible impact on tracer analyses). Appendix F summarizes the results of vegetation studies designed to characterize the current plant community at the disposal sites and provide better parameters for numerical simulations of recharge. Appendix G briefly summarizes the Quality Assurance Plan.

(a) Honeyman, JO. 1995. Letter to L Erickson transmitting the results of the 1995 workshop entitled "Summary of peer review comments resulting from the second Hanford groundwater recharge workshop." May 22-23, 1995, Richland, Washington.

3.0 Affected Environment

An adequate evaluation of the impacts of ILAW disposal requires an understanding of the environment within which the ILAW will be disposed. In this section, we have summarized information on the climate and meteorology, geology and soils, hydrology, and ecology. Portions of this summary were extracted from existing reports, including Neitzel et al. (1998), Hoitink et al. (1999), and Reidel and Horton and Horton and Reynolds (1998). For brevity, references in the original text were not included here.

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 1.1). The Hanford Site occupies an area of about 1450 km^2 (~560 mi^2); only about 6% of the land area has been disturbed and is actively used for the storage of nuclear materials, waste storage, and waste disposal. The Columbia River flows through the northern part of the Hanford Site and forms part of the Site's eastern boundary. The Yakima River runs near the southern boundary of the Hanford Site and joins the Columbia River at the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Kennewick, Pasco, and Richland (Tri-Cities) constitute the nearest population centers and are located southeast of the Hanford Site.

3.1 Climate and Meteorology

The Cascade Mountains, 100 km to the west, greatly influence the climate of the Hanford area by means of their "rain shadow" effect. This mountain range also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site. Climatological data have been collected at the Hanford Meteorological Station (HMS) since 1945 (Hoitink et al. 1999). The HMS is located between the 200 East and 200 West Areas at an elevation of 223 m. The data are representative of the general climatic conditions for the region and describe the specific climate of the 200 Area Plateau. The two ILAW disposal sites are close to the HMS and at nearly the same elevation.

Precipitation. Between 1946 and 1998, annual precipitation at the HMS averaged 174 mm (6.89 in.) and varied between 76 and 313 mm. Table 3.1 shows how monthly averages have varied in that time. The wettest season on record was the winter of 1996-1997 with 141 mm (5.4 in.) of precipitation; the driest season was the summer of 1973 when only 1 mm (0.03 in.) of precipitation was measured. Most precipitation occurs during the winter, with more than half of the annual amount occurring from November through February. Days with more than 13 mm (0.5 in.) precipitation occur on average less than one time each year. Rainfall intensities of 13 mm/h (0.5 in./h) persisting for 1 hour are expected once every 10 years. Rainfall intensities of 25 mm/h (1 in./h) for 1 hour are expected only once every 500 years.

Table 3.1. Monthly Precipitation Variations Between 1946 and 1998 at the HMS

Month	Monthly Precipitation (mm)		
	Maximum	Mean	Minimum
January	62.7	23.6	2.0
February	53.3	16.0	0.0
March	47.2	13.0	0.5
April	39.1	11.4	0.0
May	51.6	13.5	0.0
June	74.2	13.5	0.0
July	44.7	5.6	0.0
August	34.5	6.1	0.0
September	34.0	8.1	0.0
October	69.1	14.0	0.0
November	67.8	23.1	0.0
December	93.7	25.7	2.8
Annual		173.5	

Monthly average snowfall ranges from 8 mm (0.32 in.) in March to 137 mm (5 in.) in December. The record monthly snowfall of 600 mm (23.4 in.) occurred in January 1950. The seasonal record snowfall of 1420 mm (56 in.) occurred during the winter of 1992–1993. Snowfall accounts for about 38% of all precipitation from December through February.

Air Temperature. Daily maximum temperatures vary from normal maxima of 2°C (35°F) in late December and early January to 35°C (95°F) in late July. There are, on the average, 52 days during the summer months with maximum temperatures ≥32°C (90°F) and 12 days with maxima ≥38°C (100°F). From mid-November through early March, minimum temperatures average ≤0°C (32°F), with the minima in late December and early January averaging -6°C (21°F). During the winter, there are, on average, 3 days with minimum temperatures ≤-18°C (~0°F); however, only about one winter in two experiences such temperatures. The record maximum temperature is 45°C (113°F), and the record minimum temperature is -31°C (-23°F). Table 3.2 shows the range of monthly temperatures since 1946. The highest winter monthly average temperature at the HMS was 6.9°C (44°F) in February 1958, while the record lowest average temperature was -11.1°C (12°F) during January 1950. The record maximum summer monthly average temperature was 27.9°C (82°F) in July 1985, while the record lowest average temperature was 17.2°C (63°F) in June 1953.

Humidity. Since 1950, the average annual relative humidity at the HMS has been 54%; annual values ranged from 49 to 59%. December had the highest monthly average humidity (80%), with values that ranged from 69 to 91%. July had the lowest monthly average humidity (33%), with values that ranged from 22 to 46%.

Table 3.2. Monthly Air Temperature Variations Between 1946 and 1998 at the HMS

Month	Monthly Air Temperature (°C)		
	Maximum	Mean	Minimum
January	5.8	-0.8	-11.1
February	6.9	3.1	-3.6
March	10.8	7.3	4.1
April	14.6	11.6	8.6
May	13.3	16.6	13.3
June	24.9	20.7	17.2
July	27.9	24.7	21.4
August	27.5	23.9	21.0
September	22.4	19.0	14.9
October	15.3	11.7	8.8
November	8.1	4.5	-4.0
December	3.6	0.2	-6.1
Annual		11.9	

Solar Radiation. Since 1953, the average annual daily solar radiation at the HMS has been 172 W/m^2 (355 ly). Daily values were lowest in December, ranging from 4.4 to 95 W/m^2 and having an average value of 85 W/m^2. Average daily values were highest in July (305 W/m^2), but the highest daily value occurred in May (406 W/m^2).

Wind. Prevailing wind directions on the 200 Area Plateau are from the northwest in all months of the year. Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month. Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/h (6 to 7 mi/h), and highest during the summer, averaging 13 to 15 km/h (8 to 9 mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the Hanford Site.

3.2 Geology and Soils

Reidel and Horton and Horton (1999) provides a detailed description of the geology of the Hanford Site and the two ILAW disposal sites. A brief geology description is presented here to assist those readers who may not have access to Reidel and Horton and Horton (1999).

The Hanford Site lies within the Columbia Plateau, which is formed from a thick sequence of basalt flows. These flows have been folded and faulted over the past 17 million years, creating broad structural and topographic basins separated by asymmetric anticlinal ridges. Sediments up to 518 m (1700 ft) thick

have accumulated in some of these basins. The basalt flows are exposed along the anticlinal ridges, where they have been uplifted as much as 1097 m (3600 ft) above the surrounding area. Filling the synclinal basins in the basalt flows are sediments of the late Miocene, Pliocene, and Pleistocene age. The Hanford Site lies within one of the larger basins, the Pasco Basin. The Pasco Basin is bounded on the north by the Saddle Mountains and on the south by Rattlesnake Mountain and the Rattlesnake Hills. Yakima Ridge and Umtanum Ridge trend into the basin and subdivide it into a series of smaller anticlinal ridges and synclinal basins. The largest syncline, the Cold Creek syncline, lies between Umtanum Ridge and Yakima Ridge and is the principal structure containing the DOE waste management areas.

3.2.1 Geology

The two ILAW disposal sites are situated on the Cold Creek bar, a geomorphic remnant of the cataclysmic floods of the Pleistocene epoch. As the floods raced across the lowlands of the Pasco Basin and Hanford Site, the flood waters lost energy and began leaving behind deposits of gravels. The disposal sites are about 3 km (2 mi) north of the axis of the Cold Creek syncline, which controls the structural grain of the basalt bedrock and Ringold Formation. The basalt surface and Ringold Formation trend roughly southeast-northwest parallel to the major geologic structures of the site. As a result, the Ringold Formation and the underlying basalt dip gently to the south off the Umtanum Ridge anticline into the Cold Creek syncline. Geologic mapping at the Hanford Site has not identified any faults in the vicinity of the ILAW disposal sites. The closest faults are along the Umtanum Ridge-Gable Mountain structure north of the site and the May Junction fault east of the site.

The stratigraphy of the ILAW disposal sites consists of the basalt flows overlain by the Ringold Formation, the Hanford formation, and Holocene eolian deposits. All recharge-related measurements and estimates occur within the Hanford formation and eolian deposits; they are described below.

Hanford Formation. The Hanford formation is an informal name that represents all the deposits of the cataclysmic floods of the Pleistocene (1.6 million to 13,000 years ago). Glacial Lake Missoula formed in the Clark Fork River valley in Montana behind continental glaciers that spread south as far as the present Columbia Plateau. The lake may have given way as many as 40 times in the late Pleistocene, allowing the impounded water to spread across eastern Washington and form the Channeled Scablands. These flood waters collected in the Pasco Basin and formed Lake Lewis, which slowly drained through the small water gap in the Horse Heaven Hills called Wallula Gap.

Three principal types of deposits were left behind by the Missoula Floods: 1) high-energy deposits consisting of gravel; 2) coarse to fine sand deposits representing an energy transition environment; and 3) low-energy, slackwater deposits consisting of rhythmically bedded silt and sand of the Touchet Beds. Gravel-dominated strata consist of coarse-grained sand and granule-to-boulder gravels that display massive bedding, plane to low-angle bedding, and large-scale cross-bedding in outcrop. Sometimes the gravel strata lack a matrix material; such gravel strata have an open-framework appearance. The sand-dominated facies consists of fine- to coarse-grained sand and granules that display plane lamination and bedding and, less commonly, plane and trough cross-bedding in outcrop. Small pebbles and pebbly interbeds (<20 cm [8 in.] thick) may be encountered. The silt content of these sands varies, although

where its content is low, an open-framework texture may occur. The silt-dominated facies consists of fine- to coarse-grained sand grading up to silt to form normally graded rhythmites 0.07 to 1.0 m thick. Plane lamination and ripple cross-lamination is common in outcrop.

The Hanford formation is about 90 m (300 ft) thick at the ILAW disposal sites and consists predominantly of sands and gravelly sands. The sandy sequence is interpreted to lie between a slightly gravelly sand and a lower sandy gravel to gravelly sand. The Hanford formation thickens both to the north and south of the site. The lower gravel to gravelly sand is about 35 m (115 ft) thick and probably thins to the east on an irregular Ringold surface. The water table is in this lower gravel sequence. The Hanford formation sandy sequence is about 60 m (200 ft) thick and is the dominant facies in the ILAW disposal areas. The upper 6 m (20 ft) is composed of an irregularly distributed gravelly sand sequence. At other locations at Hanford, vertically oriented sediment features known as clastic dikes cut across the typically horizontal sediment layers (Fecht et al. 1999). These dikes could act as preferential pathways for water and contaminant transport. Clastic dikes have not yet been observed at the ILAW, probably because most of the area remains untouched by construction activities.

Holocene Deposits. Holocene deposits consisting of silt, sand, and gravel form a thin (<5 m [16 ft]) veneer across much of the Hanford Site as well as the ILAW disposal sites. The southern 200 m (656 ft) of the new ILAW Disposal Site is covered with a stabilized sand dune that is as much as 8 m (26 ft) high. Appendix D describes the nature of the dune and its relationship to the active dune field that lies to the south and southeast. Mature sagebrush is present on the ILAW sand dune, indicating that the dune has been stable since the 1940s at least. Clastic dike features are not visible on the soil surface.

3.2.2 Soils

The Holocene deposits and exposed Hanford formation sediments have experienced soil development and evolved into identifiable soil types. Hajek (1966) produced a soil map of the Hanford Site. Figure 3.1 shows that only two soil types cover the ILAW disposal sites: Rupert sand and Burbank loamy sand. These soils were described by Hajek (1966) as follows:

Rupert Sand. "This mapping unit represents one of the most extensive soils on the Hanford Project. The surface is a brown to grayish brown (10YR5/2) coarse sand, which grades to a dark grayish brown (10YR4/2) sand at about 36 in. Rupert soils developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits, which were mantled by wind-blown sand. Relief characteristically consists of hummocky terraces and dune-like ridges. This soil may be correlated as Quincy sand, which was not separated here. Active sand dunes are present. Some dune areas are separated; however, many small dunes, blow-outs, and associated small areas of Ephrata and Burbank soils are included."

Burbank Loamy Sand. "This is a dark-colored [surface is very dark grayish brown (10YR3/2); subsoil is dark grayish brown (10YR4/2)], coarse-textured soil which is underlain by gravel. The surface soil is usually about 16 in. thick but can be 30 in. thick. The gravel content of the subsoil may range from 20 to 80 volume percent. Areas of Ephrata and Rupert are included."

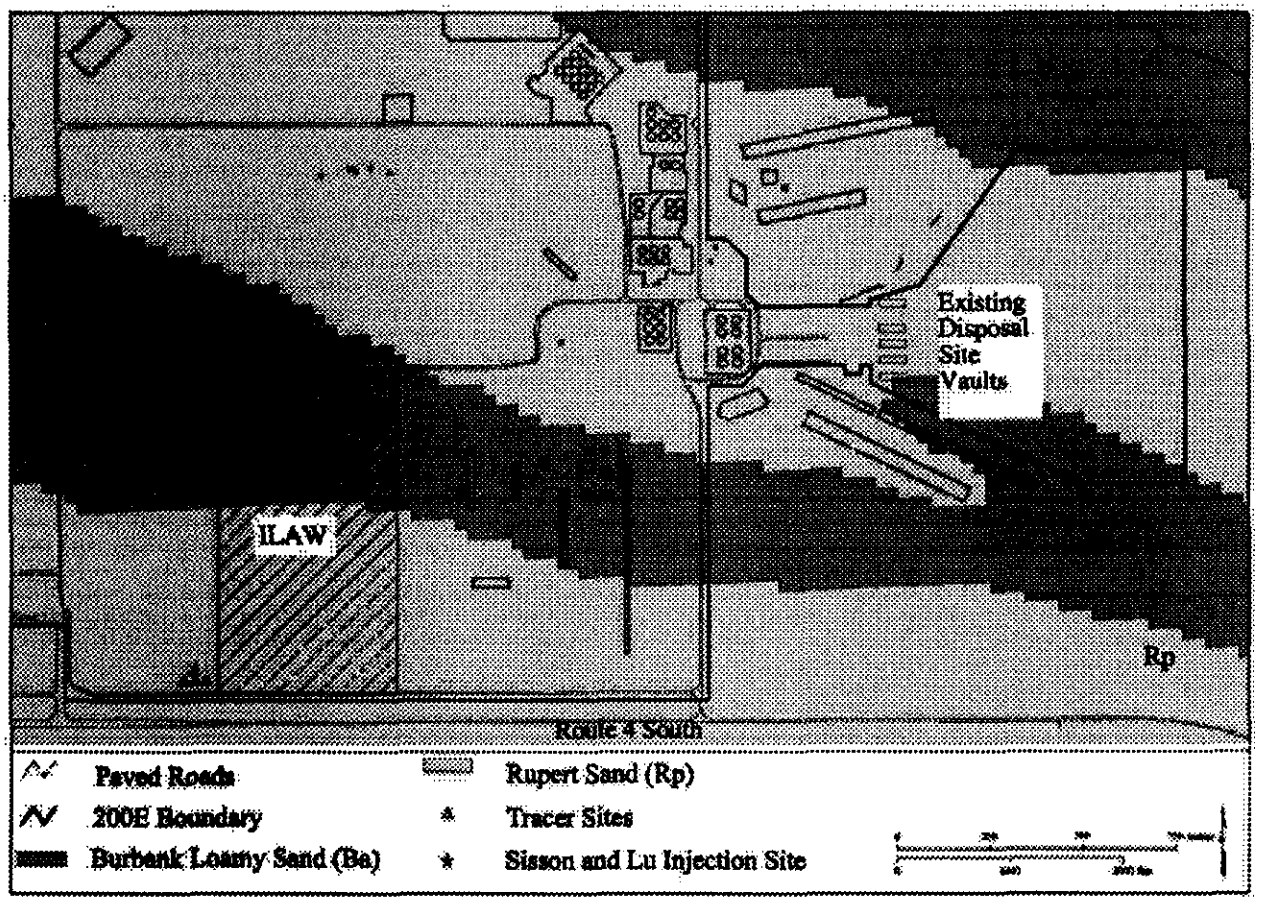


Figure 3.1. Soil Types at the Disposal Sites

Figure 3.2 shows that the topography of the two sites is similar. At the new ILAW Disposal Site, the topography is relatively flat with elevations that range between 219 and 222 m. The dune along the southern edge rises above the surrounding terrain by as much as 9 m, with a peak elevation of about 229 m. The eastern most portion of the dune has been excavated for other construction purposes. The remaining portion of the dune is not expected to exist once construction is completed.

Elevations at the Existing Disposal Site range between 204 to 206 m, about 15 m below the ILAW Disposal Site. Figure 3.2 shows the excavation for the existing disposal facility and the spoils pile directly to the east. About 300 m to the north, the topography drops off to the northeast with a slope reaching as high as 7%. The relative flatness of both disposal locations means that the final topography will be determined by the surface cover and grading of the surrounding soils.

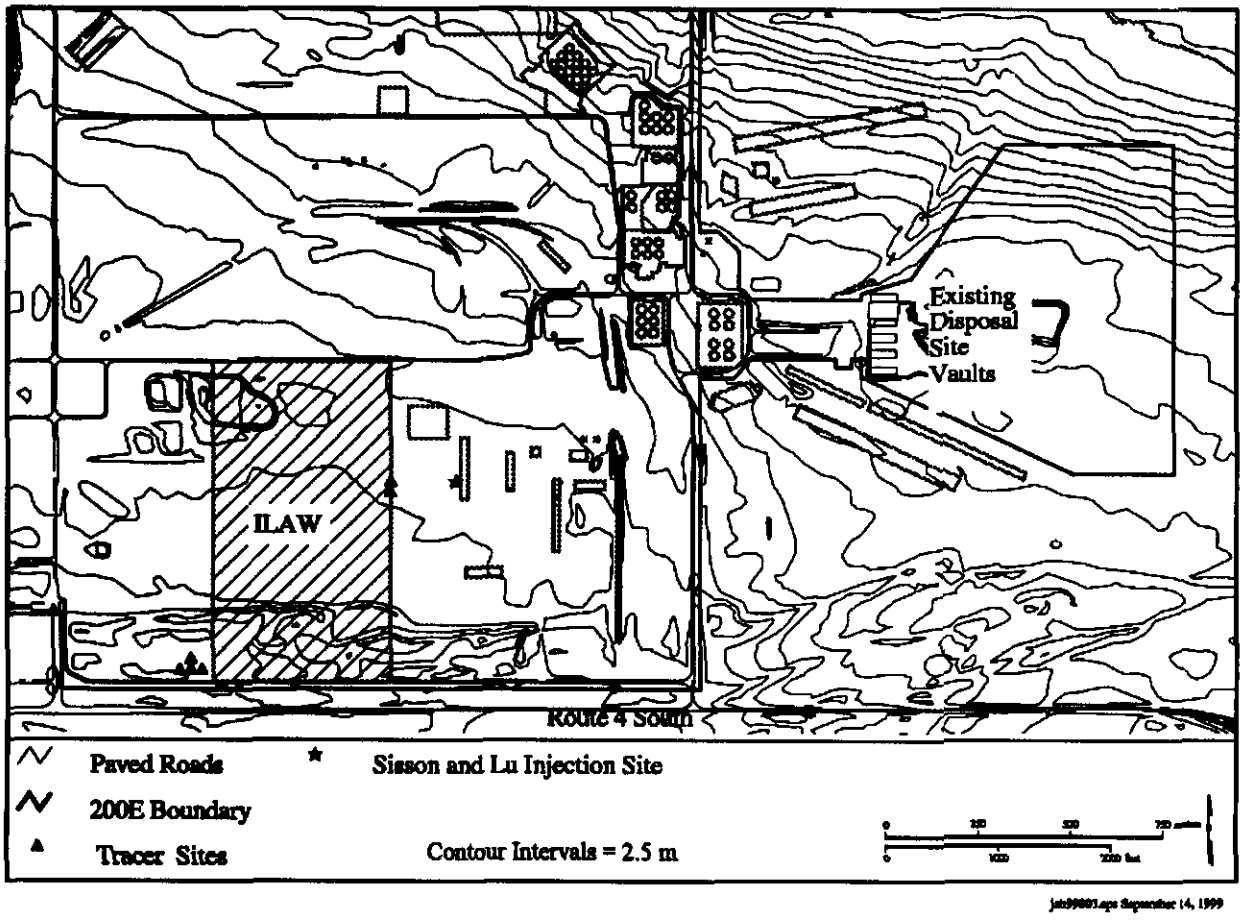


Figure 3.2. Topography at the Disposal Sites

3.3 Hydrology

The primary surface-water features associated with the Hanford Site are the Columbia and Yakima rivers. The Columbia River is the second largest river in the contiguous United States in terms of total flow and is the dominant surface-water body on the Hanford Site. Annual flows near Priest Rapids Dam just upstream of Hanford averaged nearly 3360 m^3/s (120,000 ft^3/s) during the 68 years prior to 1985. The Yakima River, which follows a small length of the southern boundary of the Hanford Site, has an average annual flow of only about 104 m^3/s (3712 ft^3/s) based on nearly 60 years of records. Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system. Both streams drain areas along the western part of the Hanford Site. Surface flow, which may occur during spring runoff or after heavier-than-normal precipitation, infiltrates and disappears into the surface sediments. The ILAW disposal sites are located well above and away from these surface-water features and are unaffected by them in any direct manner.

Natural recharge rates across the Hanford Site range from near 0 to more than 100 mm/yr (4 in./yr), depending on surface conditions (Gee et al. 1992). Low recharge rates occur in fine-textured sediments

where deep-rooted plants occur. The larger values are interpreted to occur in areas having a coarse gravelly surface and no vegetative cover (e.g., disturbed areas such as around the tank farms).

The hydrogeology of the Pasco Basin is characterized by several confined aquifers within the basalt flows and one unconfined aquifer above the basalt flows. The aquifer above the basalt is a regionally unconfined and locally semi-confined aquifer and is contained largely within the sediments of the Ringold Formation and Hanford formation.

The water table beneath the ILAW disposal sites is within the Hanford formation. Normally, groundwater flows from west to east. However, artificial recharge from wastewater disposal activities has perturbed the flow directions. Currently, the water table is flat beneath the ILAW disposal sites, so a groundwater flow direction cannot be deduced. As wastewater discharges decrease and eventually cease, we expect the general west-to-east flow to resume.

The unsaturated zone beneath the land surface at the two ILAW disposal sites is approximately 96 m (315 ft) thick. This vadose zone lies entirely within the Hanford formation and eolian sediments. The water table in the northeast corner of the new ILAW Disposal Site was at an elevation of approximately 120 m (400 ft) in 1998. The water table surface was within the lower gravel sequence of the Hanford formation; the contact between the Hanford and Ringold formations is 6 m (20 ft) below the water table.

3.4 Ecology

The Hanford Site is characterized as a shrub-steppe ecosystem that is adapted to the region's mid-latitude semiarid climate. Such ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, dominant plants in the area were big sagebrush (*Artemisia tridentata*) and an understory consisting of perennial Sandberg's bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Pseudoregneria spicata*). Other species included threetip sagebrush, bitterbrush, gray rabbitbrush, spiny hopsage, bluebunch wheatgrass, needle-and-thread grass, Indian ricegrass, and prairie Junegrass.

With the advent of settlement, livestock grazing and agricultural production contributed to colonization by non-native vegetation species that currently dominate portions of the landscape. Although agriculture and livestock production were the primary subsistence activities at the turn of the century, these activities ceased when the Site was designated in 1943. Range fires that historically burned through the area during the dry summers eliminate fire-intolerant species (e.g., big sagebrush) and allow more opportunistic and fire resistant species to establish. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% are non-native. The dominant non-native species, cheatgrass, is an aggressive colonizer and has become well established across the site. Over the past decade, several knapweed species have also become persistent invasive species in areas not dominated by shrubs.

The plant community at the two ILAW disposal sites is shrub-steppe dominated by big sagebrush, Sandberg's bluegrass, and cheatgrass. Figure 3.3 shows that most of the new ILAW Disposal Site has this cover but that the Existing Disposal Site has a significant fraction of area where disturbance occurred

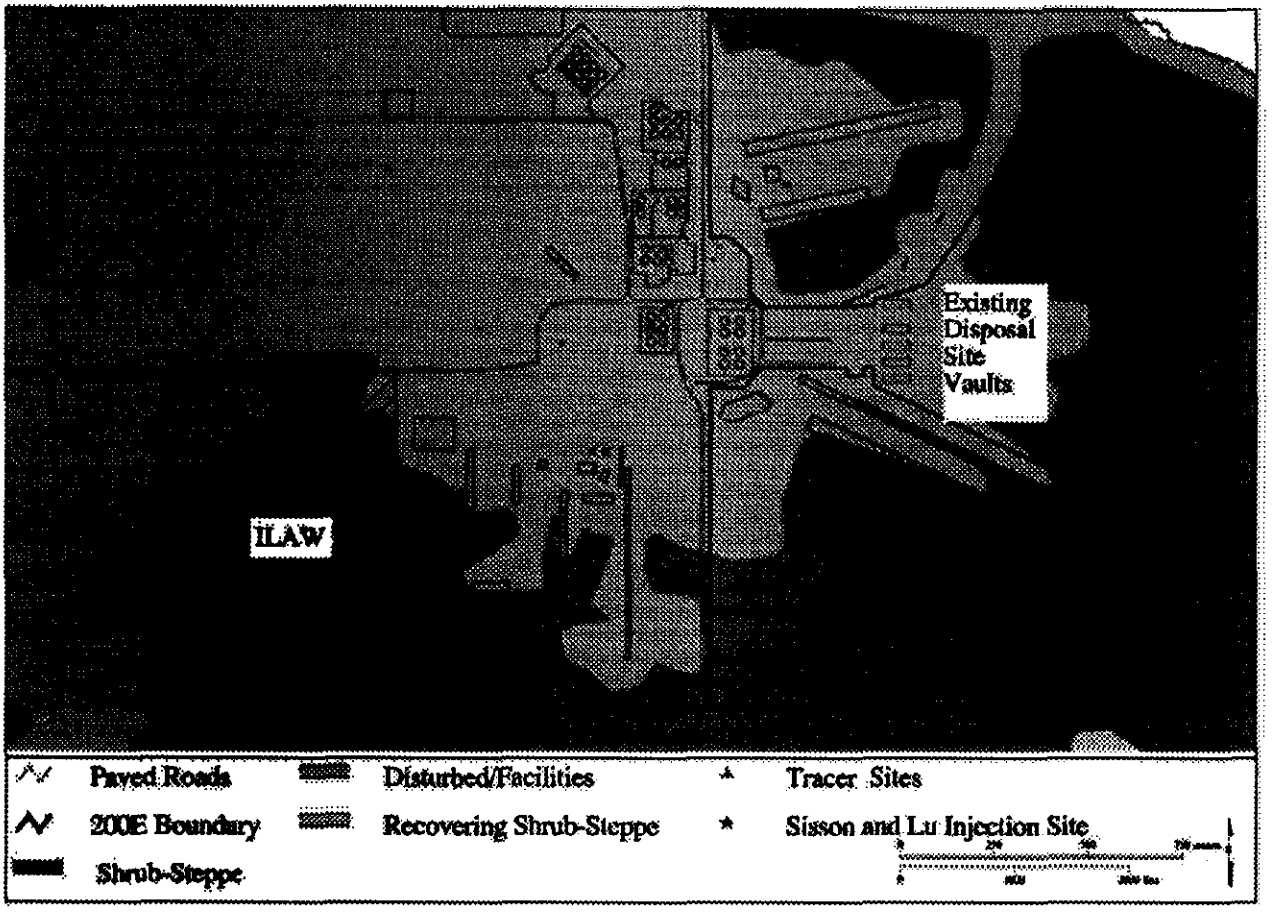


Figure 3.3. Vegetation Types at the Disposal Sites

during construction of the vaults. Appendix F describes some of the data collected recently to characterize the plant community at these two sites.

Approximately 300 species of terrestrial vertebrates have been observed on the Hanford Site, including approximately 40 species of mammals, 246 species of birds, 4 species of amphibians, and 9 species of reptiles. Terrestrial wildlife include Rocky Mountain elk, mule deer, coyote, bobcat, badger, deer mice, harvest mice, grasshopper mice, ground squirrels, voles, and black-tailed jackrabbits. The most abundant mammal on the Site is the Great Basin pocket mouse. Bird species commonly found in the shrub-steppe habitats at Hanford include the western meadowlark, horned lark, long-billed curlew, vesper sparrow, sage sparrow, sage thrasher, loggerhead shrike, and burrowing owls.

Butterflies, grasshoppers, and darkling beetles are among the more conspicuous of the approximately 1500 species of insects that have been identified from specimens collected on the

Hanford Site. The actual number of insect species occurring on the Hanford Site may reach as high as 15,000. Insects are more readily observed during the warmer months of the year.

The side-blotched lizard is the most abundant reptile species that occurs on the Hanford Site. Short-horned and sagebrush lizards are reported, but occur infrequently. The most common snake species includes gopher snake, yellow-bellied racer, and Pacific rattlesnake. The Great Basin Spadefoot Toad, Woodhouse's Toad, Pacific tree frog, and bullfrogs are the only amphibians found on the Site.

Wildlife species observed at the two ILAW disposal sites include mule deer, black-tailed jackrabbits, cottontail rabbits, coyotes, side-blotched lizards, gopher snakes, sage sparrows, shrikes, meadowlarks, and horned larks.

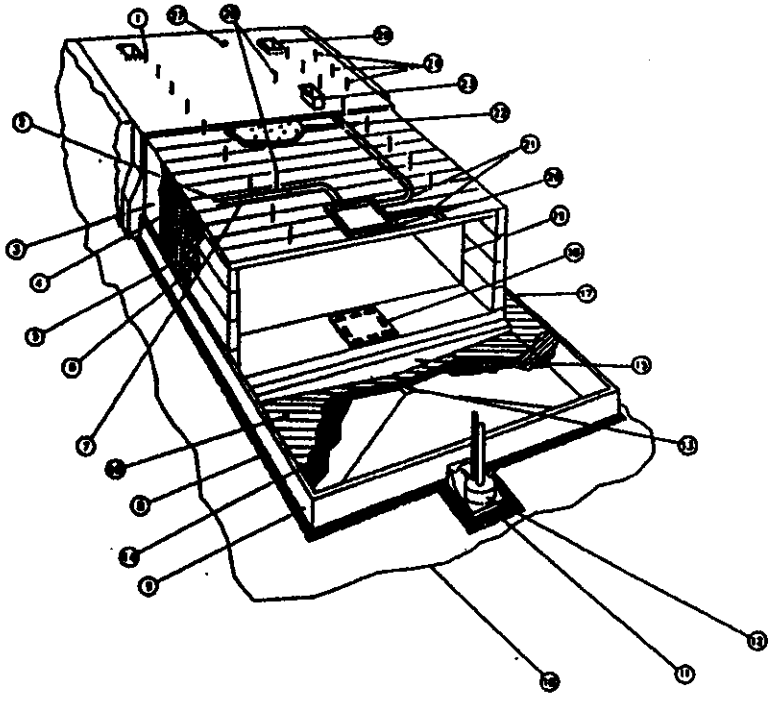
4.0 Disposal Facility Designs

The ILAW will be disposed in vaults and trenches at two locations within the 200 East Area at Hanford. Once completed, both burial facilities will receive a final surface cover and the surrounding land will be re-vegetated.

4.1 Subsurface Disposal Facilities

The two disposal facilities for ILAW are the Existing Disposal Site (formerly the Grout Site) and the proposed new ILAW Disposal Site (Figure 1.2).

Existing Disposal Facility. The existing disposal facility consists of five subsurface concrete vaults that were built and completed by 1995. Kincaid et al. (1995) described the site and facility extensively. One of the vaults was completed prior to the others and received a grouted waste called phosphate-sulfate waste. The remaining four vaults were built in pairs but never used. Figure 4.1 shows the engineered nature of these vaults. Figure 4.2 shows how the vaults were arranged in pairs. Spacing between each vault is roughly 10 m. The total areal extent of the four empty vaults is about 40 by 90 m. The vaults are currently covered with gravel as indicated just below the RCRA cover in Figure 4.2, but the protective barrier and RCRA cover shown in Figure 4.2 were never placed.



ITEM	DESCRIPTION
1	GROUT CAP INJECTION PORTS
2	GROUT FEED LINE
3	1/2" THERMAL BOARD (2 LAYERS)
4	GEOTEXTILE
5	(HDPE) PLASTIC CURTAIN
6	DRAINAGE NET (2 LAYERS) IS
7	EXCESS LIQUID TRANSPORT LINE
8	DIFFUSION BREAK
9	CONCRETE BASIN
10	STRUCTURAL BACKFILL OR NATIVE SOIL
11	CONCRETE SUMP ENCASEMENT
12	LEACHATE COLLECTION SUMP & RISERS
13	LEACHATE REMOVAL PIPE
14	HDPE LINER
15	DRAINAGE GRAVEL
16	GEOTEXTILE
17	GEOTEXTILE OVER GRAVEL & UNDER VAULT
18	60 mil HDPE PLASTIC SPLASH PAD SECURED WITH EIGHT 70 lb SANDBAGS
19	ASPHALT COATING
20	VAULT PIT
21	EXCESS LIQUID TRANSFER LINES FROM PUMP PITS
22	CONCRETE CAP
23	CCTV CAMERA ASSEMBLY
24	GROUT CORE SAMPLE ACCESS
25	EXCESS LIQUID PUMP PITS
26	LEVEL ELEMENTS
27	VENTILATION INLET

NOTES:
1. HDPE-HIGH DENSITY POLYETHYLENE
2. CCTV-CLOSED CIRCUIT T.V.

Figure 4.1. Grout Disposal Facility - Grout Disposal Vault, Cutaway View (after Mann et al. 1998)

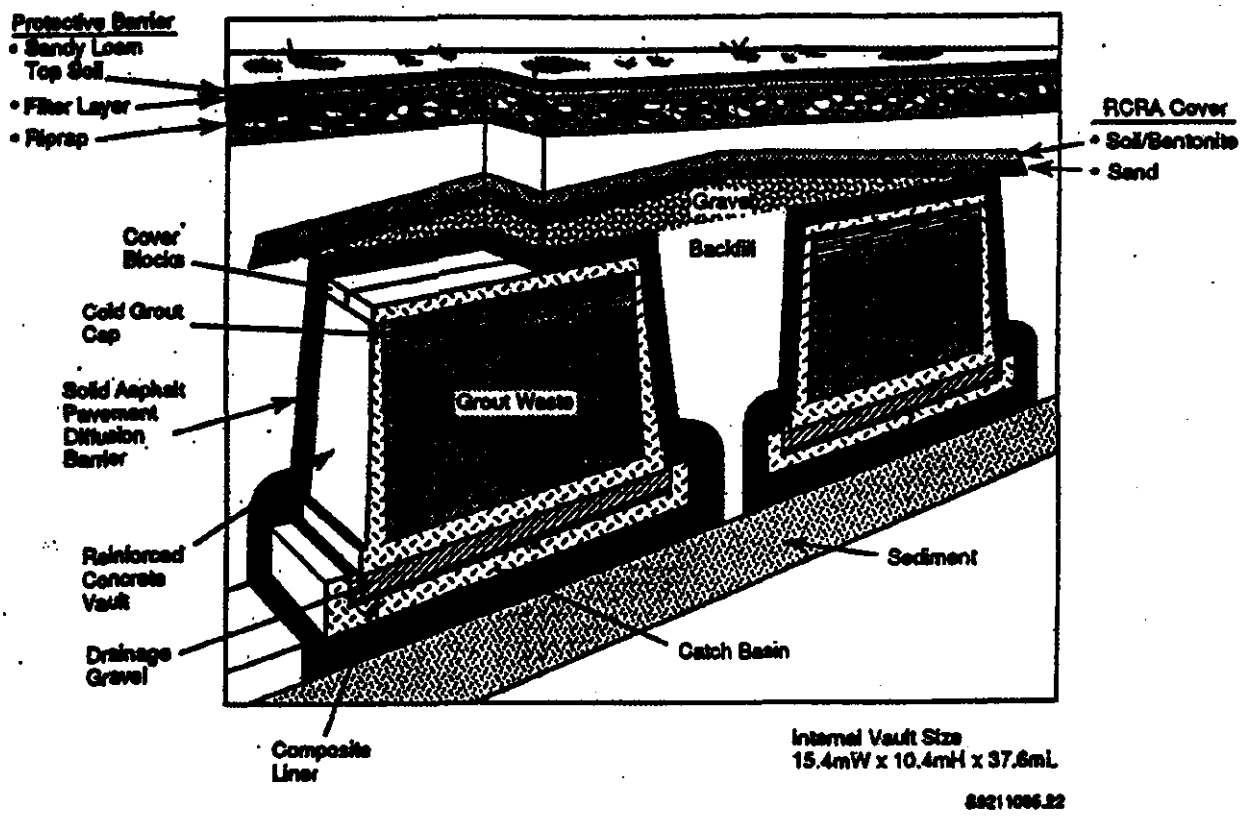


Figure 4.2. Grout Disposal Facility - Closed Vault Pair (after Mann et al. 1998). The RCRA cover and protective barrier were never constructed.

Placement of the ILAW in the existing disposal facility will involve excavation and modifications to the vaults. We expect that the vaults will be returned to their original condition after being filled. A final surface cover (Section 4.2) will then be emplaced. After the final cover is placed, we expect the vertical distance from the soil surface to the top of the ILAW to be no less than 5 m.

New ILAW Disposal Facility. Several designs have been proposed for the new ILAW disposal facility (Burbank and Klem 1997; Mann et al. 1998; PHMC 1998; Burbank and Hohl 1999; Puigh 1999) but a final decision has not yet been made. Fortunately, all of the designs have enough similar details to proceed with the analyses. The current plan is to build concrete vaults below grade. Nominal dimensions of the vaults will be 23 m wide, 208 m long (oriented north-south), and 9.1 m high. The long dimension of the vaults will be segmented to allow incremental filling followed by sealing with a controlled density fill. Each vault will have a leachate detection and collection system. Once all segments of a vault are completely filled, a surface cover (Section 4.2) will be placed within 180 days. Vault spacing is expected to be 50 m. After the final cover is placed, we expect the vertical distance from the soil surface to the top of the ILAW to be no less than 5 m.

4.2 Surface Cover

Burbank and Klem (1997) considered three cover designs in their cost calculations, but recent project discussions indicated the current preferred design is the modified RCRA subtitle C design proposed by DOE/RL (1996). The following description is taken loosely from that report (entitled "Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas").

The modified RCRA subtitle C cover is the baseline cover design for sites containing dangerous waste and several categories of low-level and mixed waste. This cover was designed to provide long-term containment and hydrologic protection for a performance period of 500 years. The performance period was based on radionuclide concentration and activity limits for Category 3 low-level waste. Table 4.1 lists the design criteria. The Modified RCRA Subtitle C Barrier is composed of eight layers of durable material with a combined minimum thickness of 1.7 m (5.5 ft). Table 4.2 provides the layer thicknesses and descriptions. This design incorporates *Resource Conservation and Recovery Act of 1976* "minimum technology guidance," with modifications for extended performance. One major change is the elimination of the clay layer, which may desiccate and crack over time in an arid environment. The geomembrane component also has been eliminated because of its uncertain long-term durability. The design incorporates provisions for biointrusion and human intrusion control. However, the provisions are modest relative to the corresponding features in the Hanford Barrier design, reflecting the reduced toxicity of the subject waste and the reduced design-life criterion.

Table 4.1. Summary of Design Criteria for the Modified RCRA Subtitle C Barrier

1.	Minimize moisture infiltration through the cover.
2.	Design a multilayer cover of materials that are resistant to natural degradation processes.
3.	Design a durable cover that needs minimal maintenance during its design life.
4.	Design a cover with a functional life of 500 years.
5.	Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone).
6.	Prevent burrowing animals from accessing and mobilizing contamination.
7.	Ensure that the top of the waste is at least 5 m (16.4 ft) below final grade or include appropriate design provisions to limit inadvertent human intrusion.
8.	Facilitate drainage and minimize surface erosion by wind and water.
9.	Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoils present.
10.	Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer).
11.	For frost protection, the lateral drainage layer and the low-permeability asphalt layer must be located at least 0.75 m (30 in.) below final grade.

Table 4.2. Summary of Modified RCRA Subtitle C Barrier Layers

Layer No.	Thickness cm (in.)	Layer Description	Specifications	Function
1	50 (20)	Silt loam topsoil with pea gravel admix	McGee Ranch silt loam containing 15 wt% pea gravel, 2.36 to 9.5 mm in diameter, conforming to ASTM D448 No. 8 aggregate; to be placed at a bulk density of approximately 1.46 g/cc.	The topsoil material was identified for optimal water retention properties and should provide a good rooting medium for cover vegetation. The pea gravel is designed to minimize wind erosion of the silt loam without significantly affecting its moisture retention capabilities.
2	50 (20)	Compacted topsoil	McGee Ranch silt loam without pea gravel, compacted to 90% of optimum dry density as determined by standard Proctor test; in-place bulk density will be approximately 1.76 g/cc.	Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 2 will increase the amount of moisture removed by evapotranspiration.
3	15 (6)	Sand filter	Clean, screened sand meeting the following particle sizes: D_{15} = 0.15 to 0.50 mm, D_{50} = 0.375 to 1.2 mm, and D_{85} = 0.70 to 2.5 mm.	This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layer 5.
4	15 (6)	Gravel filter	Clean, screened aggregate meeting the following particle sizes: D_{15} = 1.5 to 2.0 mm, D_{50} =15 to 20 mm, and D_{85} <37.5 mm.	Same as Layer 3.
5	15 (6)	Lateral drainage aggregate	Naturally occurring aggregate, minus 32-mm (1 1/4-in.) material, conforming to the grading identified in WDOT M41-10, 9-03.9(3) for base course, with D_{10} >1 mm and k >1 cm/s.	The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection and/or discharge.
6	15 (6)	Asphaltic concrete with spray-applied asphalt coating	Asphaltic concrete, consisting of asphalt conforming to WDOT M41-10, 9-02.1(4) - Grade AR-4000W, and aggregate with particle size gradation conforming to ASTM C 136. Asphalt will make up 7.5 wt% of total mixture. A spray-applied, styrene-butadiene asphalt material will be sprayed onto the asphaltic concrete surface in two layers, each 100 mils thick minimum.	This layer will function as a hydrologic barrier and as a biointrusion barrier.
7	10 (4)	Asphalt base course	Crushed aggregate, minus 16-mm (5/8-in.) diameter material, conforming to WDOT M41-10, 9-03.9(3) for top course surfacing material.	The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer.
8	Variable	Grading fill	Clean, bank run sand and gravel conforming to WDOT M41-10, 9-03.18.	This layer will provide a smooth, level subgrade for construction of the overlying layers.

The designs proposed by DOE/RL (1996) do not provide guidance for sideslopes. We expect that the final cover will be elevated relative to its surroundings, thus requiring sideslopes. Although the ILAW project has not yet chosen a sideslope design, the result of sideslope testing at Hanford can be used to indicate possible sideslope performance.

4.3 Closure Conditions Around the Surface Cover

Burbank and Klem (1997) indicated that the disturbed lands around the cover would be re-contoured and re-vegetated with native plant species. We expect that typical Hanford procedures for surface grading and re-vegetation will be pursued. We assume that some effort will be made to promote any surface water drainage away from the cover. We also assume that the topsoil used will be similar to the existing topsoil to promote re-vegetation. An alternative conceptual model is that the Hanford formation sands from the excavation will be used for the topsoil.

5.0 Analysis Cases and Tests

The mandate for the recharge task was to identify the scenarios that must be evaluated for the 2001 PA and provide estimates of appropriate recharge rates. These scenarios must be framed within the categories of the best estimate case and reasonable bounding cases. In addition, sensitivity tests must be conducted and alternative conceptual models evaluated to demonstrate our understanding of the system. Section 6.0 describes the methods used to estimate recharge. Section 7.0 describes the estimates and their assignment to the best estimate case and the bounding cases.

5.1 Best Estimate Case

The best estimate case represents the situation where all disposal facility features function as expected assuming a shrub-steppe plant community, current climate, no irrigated farming, and no significant subsidence impacts on the cover. Based on the facility design, there are five surface features that need separate evaluations:

- Modified RCRA Subtitle C Cover
- Cover sideslope
- Rupert sand
- Burbank loamy sand
- Hanford formation sediments.

These features will be evaluated for conditions that existed prior to Hanford, during disposal facility operations, during the design life of the surface cover, and following the design life of the surface cover. Table 5.1 shows which features are evaluated for each time period of interest to the 2001 PA. After the cover design life of 500 years, the performance of a possibly degraded surface cover will be evaluated (see the upper bounding cases in next section).

Table 5.1. Surface Features To Be Evaluated During Each Period of Interest to the 2001 PA

Surface Feature	Time Period of Recharge Evaluation			
	Pre-Hanford	During Disposal Operations	During Surface Cover Design Life	After Surface Cover Design Life
Modified RCRA Subtitle C Cover			√	√
Cover Sideslope			√	√
Rupert Sand	√	√	√	√
Burbank Loamy Sand	√	√	√	√
Hanford Formation Sediments		√		

5.2 Reasonable Bounding Cases

To specify that a bounding case is "reasonable" presumes some knowledge of its probability of occurrence. Some cases, such as complete replacement of shrub-steppe by cheatgrass, are theoretically possible but not probable (or reasonable). We consider these cases as alternative conceptual models and discuss them in Section 5.4. Some cases, such as renewed glacial activity, were considered too speculative for consideration.

For the reasonable bounding cases, we assumed a shrub-steppe plant community, current climate, and no irrigated farming. We identified a single lower reasonable bounding case that represents the situation in which recharge rates are at their lowest possible values. We identified two upper reasonable bounding cases in which recharge rates are at their highest possible values. These bounding cases represent possible variations in how the system might work and give an indication of the level of uncertainty in the recharge estimates.

5.2.1 Lower Bounding Case

We interpret this case to be a fully functional surface cover and a dense shrub-steppe community on the cover and the surrounding soils.

5.2.2 Upper Bounding Cases

We interpret these cases to be situations in which recharge is potentially higher than the best estimate case because of degradation of the cover or variations in soil and plant effects.

Erosion of the Surface Cover. Wind and water erode 0.2 m of silt loam from the surface of the cover.

Dune Sand Deposition on the Surface Cover. Wind deposits a 0.2-m layer of dune sand.

5.3 Sensitivity Tests

Recharge sensitivities can be determined through the controlled manipulation of selected parameters and processes. For this report, we elected to vary vegetation (type, presence, and density), soil hydraulic properties, and climate.

5.4 Uncertainty Tests

In our conceptual model of recharge, we assumed a shrub-steppe plant community, current climate conditions, and no irrigated farming. Three alternative conceptual models were prepared and tested to demonstrate the impact of these assumptions on recharge estimates.

Vegetation Change. Through fire, disturbance, disease, or successful competition with the native species, the shallow-rooted alien species cheatgrass becomes the dominant plant. Cheatgrass is so successful that it precludes the deeper-rooted plants from re-establishing.

Climate Change. Precipitation rates increase and temperatures decrease to the maximum levels inferred from a pollen record that covers the last 100,000 years.

Irrigation. If, for whatever reason, farming is allowed on or near the disposal sites, irrigation will be a necessity.

A fourth assumption that we made, no significant subsidence, is currently being evaluated (LMHC 1999). Once the likelihood and degree of subsidence is established, we will evaluate the impacts on our recharge estimates.

6.0 Recharge Estimation Methods

Recharge rates at the Hanford Site can range from near zero to more than 100 mm/yr (Gee et al. 1992). To effectively cover this range, three complementary methods are used to estimate recharge rates: lysimetry, the tracer technique, and computer simulations. For a discussion of these and other methods, see the January-February 1994 issue of the *Soil Science Society of American Journal*. This issue contains a series of papers that were presented at a symposium titled "Recharge in Arid and Semiarid Regions." Rockhold et al. (1995) described how these methods were used at Hanford. Some of that description is included here along with additional considerations relevant to the presence of the subsurface ILAW disposal facility.

6.1 Lysimetry

The goal of lysimetry is to provide both performance data and model testing data for specific combinations of soil, vegetation, and precipitation. A lysimeter is a system that can be used to collect water that has flowed through and below the reach of the evaporation process and plant roots to become deep drainage and eventually recharge. The only method available for directly measuring recharge is lysimetry. One of the strengths of lysimetry is that it can provide a control volume in which a number of water balance components can be measured directly. This control volume provides the data needed to calibrate numerical models that can then be used to forecast recharge.

The Hanford Site has used lysimeters for multiple purposes (Gee and Jones 1985; Freeman and Gee 1989; Wittreich and Wilson 1991; Gee et al. 1993; Ward et al. 1997). The lysimeters used to provide data for this report include containers that isolate the soil from its surroundings and field-scale pads that collect drainage but do not isolate the soil.

The primary source of lysimeter data is the Field Lysimeter Test Facility (FLTF). Appendix A describes this facility and provides an overview of the data available. The facility was constructed in FY 1987 to test the performance of capillary barrier cover designs (Gee et al. 1989). The FLTF contains 18 large lysimeters (surface area > 2 m^2; depth from 1.5 to 3.0 m) and six smaller lysimeters (surface area is 0.07 m^2; depth 3.0 m). Treatments include variations of material types and thicknesses, the presence of vegetation, and the use of irrigation to mimic the increased precipitation of a possible future climate. Data from this facility include drainage, water content, matric potential, temperature, and vegetation observations.

Another source of lysimeter data for this report is the Hanford Prototype Barrier, a full-scale barrier constructed above an actual waste site (Ward et al. 1997). The Prototype Barrier design differs slightly from most of the tests in the FLTF in that the surface silt loam layer is 2 m thick (rather than 1.5 m) and the upper meter contains gravel for erosion control (only two FLTF lysimeters contain gravel in the silt loam layer, and only in the upper 0.3 m). More importantly, the Prototype Barrier differs from the FLTF tests in that it is a full-scale test that includes sideslope effects.

The Prototype Barrier is instrumented to measure variables such as water content, matric potential, temperature, and drainage. One of the unique and valuable features of the Prototype Barrier is the presence of asphalt collection pads for drainage collection. These pads are part of the asphalt layer that underlies the entire Prototype Barrier. Individual collection pads were constructed using asphalt curbing to separate the different collection zones. Four 322-m^2 collection zones underlie the main portion of the Barrier. Two similar zones lie beneath each of the two different sideslope designs (one is sandy gravel, the other is basalt riprap). In addition, a collection lysimeter was constructed beneath the northeast portion of the barrier, under the asphalt layer that lies beneath the basalt sideslope treatment. This lysimeter provides a measure of the effectiveness of the asphalt layer in preventing drainage.

Although they provide the only direct measure of recharge, lysimeters have disadvantages. Lysimeters are usually fixed in space, which limits their ability to quantify the effects of spatial variability. The soils filling the lysimeter may not represent the natural stratification or layering that may be present. The length of record is much shorter than time periods of interest. The lysimeter walls and base alter the natural gradients of temperature, air flow, and vapor flow that could be of importance when trying to measure recharge rates less than 1 mm/yr. Lysimeter walls restrict lateral root growth and promote downward growth. When they involve irrigation, the lysimeter tests are subject to the "oasis effect," in which heat from the un-irrigated surroundings increases the evapotranspiration rate above what it would have been if the entire area had been irrigated. Finally, one of the issues with using lysimeters is verifying that no leaks of drainage water have occurred.

6.2 Tracers

The goal of the tracer method is to estimate historical recharge using measurements of tracer distributions in the soil and sediments of the vadose zone. The advantage of this method is that multiple tracers are available that enable estimates of recharge rates for durations of tens to thousands of years. The vertical distribution of tracers represents the integration of many recharge events and can be used to estimate the mean recharge rate for the time scale of interest for a performance assessment.

The two tracers used for this report are chloride (Cl) and chlorine-36 (^{36}Cl). Chloride originates from sea water, is deposited naturally, and can provide recharge estimates spanning hundreds to thousands of years. Chlorine-36 originates from two sources: cosmic irradiation of atmospheric chloride and nuclear weapons testing. The natural process of cosmic irradiation produces very minute quantities of ^{36}Cl. In contrast, nuclear weapons testing in the 1950s and early 1960s injected considerable quantities of ^{36}Cl into the atmosphere. The ^{36}Cl originated from sea level testing, which caused the thermal neutron irradiation of chloride in sea water (Phillips 1994). The quantities of ^{36}Cl created by the testing were far higher than natural production rates and thus became a marker in the environment. The ^{36}Cl data can be used to estimate the average recharge rate over the last 40 years. Appendix B describes the tracer data collected for the ILAW PA project.

Both chloride and ^{36}Cl are conservative, nonvolatile, and almost completely retained in the soil when water evaporates or is transpired by plants (Phillips 1994). Some chloride is taken up by plants (e.g., Rickard and Vaughan 1988; Sheppard et al. 1998). Over hundreds to thousands of years, we expect plant cycling has a minimal impact on the evolution of the chloride distribution in the profile beneath plant

nets. In contrast, bomb-pulse ^{36}Cl has been around only ~40 years, so caution must be exercised when interpreting such data. In soils with high pH and high adsorption of other anions, anion exclusion can result in faster movement of chloride. Previous studies have shown a direct correlation between clay content and anion exclusion (Warrick et al. 1971). Most of the sandy soils on the Hanford Site have relatively low percentages of clay, so the effects of anion exclusion in these soils should be relatively minor.

Appendix B describes the calculation of chloride deposition at the ILAW Disposal Site. The value, 38.4 mg/m^2/yr, is consistent with earlier estimates that ranged from 32.7 to 49.4 mg/m^2/yr (Murphy et al. 1996; Prych 1998). At a site to the west of the 200 West Area, Murphy et al. (1996) estimated the deposition rate to be 40.0 ± 7.3 mg/m^2/yr. Although year-to-year variability in chloride deposition rates likely exists, we expect the long-term average is adequately represented.

Phillips (1994) suggested that systematic uncertainties in estimated chloride deposition rates can be as great as 20% if the chloride mass balance technique is extended to estimate recharge rates prior to the Holocene epoch (approximately 10,000 years ago). Because the Hanford Site was flooded by glacial melt water about 13,000 years ago, we are not extending our interpretation beyond that time. Therefore, we expect that the uncertainty in chloride deposition rates at the Hanford Site is less than 20%.

There is some uncertainty about the local influence that Hanford Site operations may have had on the time-dependent concentrations of both chloride and ^{36}Cl deposited at Hanford. The issue of locally generated chloride is under review (see Appendix E). Murphy et al. (1991) examined the issue relative to ^{36}Cl and concluded there was no nearby source that would confuse the ^{36}Cl signal in the sediment.

The primary source of tracer data for this report is the analyses of samples collected from boreholes that were drilled by the ILAW PA project in 1995 and 1998. The analyses are described in Appendix B. In addition, a few measurements of tracer profiles have been performed by other projects at the Hanford Site (Murphy et al. 1996; Prych 1998). These data were also used for this report. Descriptions of the measurement procedures can be found in Appendix B, Murphy et al. (1991), Murphy et al. (1996), and Prych (1998). The analysis methods are briefly described below.

Chloride. Recharge is estimated from the chloride concentration within a soil profile as follows:

$$J_R = \left(\frac{Cl_o}{Cl_{sw}} \right) P \qquad (6.1)$$

where J_R is the liquid water flux at the depth of measurement, Cl_o is the chloride concentration of the precipitation, Cl_{sw} is the chloride concentration in the soil water, and P is the annual precipitation rate. Because chloride can be deposited by dry fallout, the value of Cl_o is adjusted to represent the total annual wet and dry chloride deposition rate divided by the annual precipitation rate. The value of Cl_{sw} can be determined by plotting cumulative chloride content with depth against cumulative water content at the same depths. The slopes of straight-line segments correspond to Cl_{sw} for the depth interval (Phillips

1994). Changes in the slopes of different line segments, corresponding to the different depth intervals, can represent the temporal variability of recharge rates and/or deposition rates.

Chlorine-36. An upper limit of the average recharge can be estimated from $^{36}Cl/Cl$ ratios by integrating the water content profile above the depth of the peak ratio or the centroid of the $^{36}Cl/Cl$ profile. A rough estimate can also be obtained by dividing the depth of the peak or centroid by the time since the bomb tests. A disadvantage of this method is that ^{36}Cl could still be within the root zone and thus yield too high an estimate of recharge (Tyler and Walker 1994). The likelihood of this problem happening increases for those sites at Hanford where recharge rates are lower than 10 mm/yr. Plant uptake and release can complicate the interpretation of the ^{36}Cl signal.

6.3 Modeling

The goals of modeling are to provide short-term estimates of recharge rates when there are little to no data and to leverage the existing short-term data into estimates of long-term recharge rates. Simulations of recharge at Hanford have been successful at highlighting the important factors that affect recharge and predicting recharge rates for specific cases. Modeling is the primary tool for forecasting recharge rates for future climate and land use scenarios. The simulations also allow the results of the lysimetry and tracer methods to be merged on a consistent basis.

The UNSAT-H computer code was used to estimate recharge rates for this report (Fayer and Jones 1990). UNSAT-H can simulate nonisothermal water flow processes in both liquid and vapor phases and hysteresis in the soil hydraulic properties. This model has been tested using data from several of the lysimeter experiments at Hanford and elsewhere (Fayer et al. 1992; Fayer and Gee 1992; Khire et al. 1997). Fayer and Gee (1997) tested UNSAT-H and a simpler model and concluded that UNSAT-H provided far better estimates of drainage through a surface cover. Scanlon (1992) used a similar unsaturated flow model to estimate recharge rates in the Chihuahuan Desert of Texas. Appendix C describes the modeling activity undertaken to estimate recharge rates for this report.

One of the disadvantages of numerical modeling is that it requires numerous parameters to represent climate, soils, and vegetation characteristics. In many instances, these parameters are unknown or only marginally known. Another disadvantage is the use of conceptual simplifications to make the modeling tractable. For example, Appendix F suggests that the current plant model may need to be revised. Numerical modeling with a code such as UNSAT-H is the most flexible method for estimating recharge rates, but its data-intensive needs and conceptual simplification could lead to recharge estimates that have the most uncertainty.

6.4 Additional Considerations

Several features of the ILAW disposal could affect the analysis of recharge rates, including physical effects, water consumption, temperature, and preferential flow. Physically, the vaults/disposal volume will be located 3 m below the base of the surface cover. At this depth, we do not anticipate any direct physical effect on recharge rates. The very low permeability of the vaults could affect the flow of air through the vadose zone, but we assume that any air exchange with the deep vadose zone is too small to

affect recharge rates significantly. The vaults could also affect the overall temperature gradient within the vadose zone, but we assume the effect to be too small to affect recharge rates significantly.

Silicate glasses such as the ILAW undergo corrosion when in water. The rate of corrosion depends on factors such as glass composition and the availability of water, which is consumed in the corrosion process. The maximum consumption rate was calculated to be 0.34 g of water per gram of glass (BP McGrail, personal communication). This level of water consumption will set up a matric potential gradient that causes water to move toward the ILAW. We recognized that this consumption might increase water flow through the cover. However, we assumed that, because the water was consumed in the corrosion process, the overall effect of this increased downward water movement was not significant to the analysis of recharge.

Radionuclides within the ILAW will undergo radioactive decay and thus generate heat. McGrail and Bacon (1998) reasoned that the long half-life and small concentration of radionuclides in ILAW would minimize any temperature increase over ambient conditions. Using the latest inventory of ^{90}Sr and ^{137}Cs in the ILAW, McGrail and Bacon (1998) estimated the maximum temperature increase would be 0.25°C between the vault center and the immediately surrounding soil. They concluded that this small temperature rise was within the expected seasonal temperature fluctuations at the site (about 2°C) and therefore not a significant factor affecting the performance of the disposal facility. We assumed that this small temperature perturbation would not affect recharge rates significantly.

Preferential flow paths such as clastic dikes could affect recharge under the right conditions. However, the vadose zone in and around the disposal facility will be excavated, thus eliminating any dikes that may be present near the soil surface. Therefore, we assumed that dikes would not be a factor in recharge. Preferential flow could also occur as a result of focused overland flow, such as at the toe of the cover sideslope. We intend to address this recharge mechanism in the next revision of the data package, once the surface cover and facility designs are more definite. Finally, preferential flow can occur at a very local scale as a result of flow instabilities that lead to "fingering." Hendricks and Yao (1996) found that, for a sand dune in New Mexico, instabilities occurred during a precipitation event only when the total precipitation exceeded 4 cm. At Hanford, total precipitation in a 24-h period has exceeded 4 cm only twice between 1947 and 1997 (by less than 1 cm in both cases). Therefore, we assumed that flow instabilities would not be a dominant phenomenon affecting recharge at Hanford.

7.0 Results

The recharge estimation process uses data from multiple and sometimes conflicting sources. The estimation process was an effort to maximize the value of the information in hand without forgetting the limitations of that information. In this section, we analyze the data and recharge estimates for the best estimate and bounding cases, demonstrate some recharge sensitivities, estimate recharge for three alternative conceptual models, and assign recharge rates to the best estimate and bounding cases. Following that, we outline the activities planned for FY 2000 and end with a summation of the known remaining issues.

7.1 Analyses for the Best Estimate and Reasonable Bounding Cases

For each of the surface features identified in Section 5.0, we have assessed the data available for estimating recharge rates. Where data are conflicting, we present alternate recharge estimates.

7.1.1 Modified RCRA Subtitle C Cover

The surface cover over the ILAW vaults will determine the flux of water directly down to and around the vaults. The FLTF data collected under ambient precipitation conditions showed that drainage rates through the cover were less than 0.001 mm/yr (Appendix A). For the drainage caissons, this rate represents about 3 mL/yr. When rates are seemingly this low, we should exercise caution because other factors could be affecting the results and ought to be considered (e.g., temperature gradients, leaks, and water storage within the basalt). Simulations of the cover indicated rates would be less than 0.1 mm/yr, but no attempt was made to see if the rate might be lower. In the previous PA (Mann et al. 1998), a recharge rate of 0.5 mm/yr was assigned to the cover. This value represented the design objective of the Hanford Prototype Barrier (Wing 1994). The data and simulations reported here support the use of a lower recharge estimate for the cover. Although there are indications of lower rates, we propose using a rate of 0.1 mm/yr for an intact surface cover with or without vegetation.

7.1.2 Sideslope

The surface cover may be elevated above the surrounding terrain. If so, the cover will need sideslopes to maintain its stability as well as to blend into the terrain. No specific sideslope designs have yet been chosen. However, the ongoing testing of sideslopes at the Hanford Prototype Barrier provided some useful performance data. Two sideslopes are being tested: basalt riprap and sandy gravel. The high cost of basalt riprap makes the use of sandy gravel attractive. Ward et al. (1997) reported that drainage though the sandy gravel sideslope was 31.4% of the precipitation in a 3-year period. Assuming that fraction remained constant for the long-term average precipitation rate of 160 mm/yr, the long-term drainage rate would be 50 mm/yr. Assuming a 1:10 (V:H) sandy gravel sideslope with vegetation (the same as the Prototype), we estimate a recharge rate of 50 mm/yr under ambient precipitation.

The asphalt layer terminates under the sideslope. The water draining through the sideslope will be collected and routed laterally and infiltrate just beyond the edge of the asphalt. Ward et al. (1997)

detected this infiltration zone at the Hanford Prototype Barrier. In addition to the sideslope drainage water, the asphalt layer will also convey any water that drains through the cover's surface layer. This additional water should be inconsequential relative to the quantity of sideslope drainage water.

7.1.3 Rupert Sand

Rupert sand covers most of the two disposal sites. We assume that, following closure, the disturbed area surrounding the covers will be reconstituted to mimic Rupert sand. The chloride tracer data in Appendix B suggest a range of recharge rates depending on location and depth. The chloride data above the 5- to 10-m depth represent more recent recharge rates. The analysis of these data shows a recharge rate ranging from 0.013 to 0.065 mm/yr, with an overall average of 0.03 mm/yr. In contrast, the chloride data below 10 m represent recharge rates thousands of years ago (based on the accumulated chloride above 10 m). These data indicate a recharge rate range from 0.16 to 1.8 mm/yr, with an average rate of 0.9 mm/yr. If we ignore the time difference and simply average the multiple estimates, we get an average recharge rate of 0.4 mm/yr.

We have some concern about chloride contamination from nearby facilities. The presence of facility-generated chloride within the soil profile would cause, if unrecognized, an underestimate of the recharge rate using the traditional chloride method. Figure 7.1 shows a photograph looking southeast over the new ILAW Disposal Site. In the foreground are the 200 East Area coal-fired power plant and the water purification plant. Both facilities are suspected to be emitters of chloride. The coal plant, in particular, is a likely source because it began operations in late 1944 and did not use emission controls until 1980, when a baghouse (to filter out particulates) was installed. The new ILAW Disposal Site is directly downwind given that the prevailing wind direction is from the northwest. To determine whether coal plant emissions had deposited chloride at the tracer sampling sites, we collected soil samples from ten locations and analyzed them for multiple constituents, including known constituents of coal. Appendix E describes the testing and results, which were inconclusive but suggestive of deposition. Additional testing is being performed to clear up the uncertainty. If chloride from local facilities was deposited at the ILAW sites, we should still be able to use the deeper chloride data that reflect pre-Hanford conditions.

Appendix B shows that bomb-pulse ^{36}Cl still resides entirely within the root zone (the upper 2 m of soil). While still in the root zone, ^{36}Cl cannot be used to estimate recharge. However, we can establish a rough upper limit. Assuming an average root zone water content of 0.1 cm^3/cm^3, the recharge rate would have to be much less than 5 mm/yr to explain the absence of ^{36}Cl below 2 m.

We have two other estimates of recharge in Rupert sand. One of those estimates was derived from the simulations in Appendix C that suggested a recharge rate of 2.2 mm/yr. The other estimate came from Murphy et al. (1996), who measured chloride concentrations in Rupert sand located near the Wye barricade. This site is about 13 km to the southeast of the ILAW disposal sites. At that distance, the site should be unaffected by any emissions from the coal plant or other facilities. The shrub density in that general area is far less than at the ILAW Disposal Site. Using the chloride tracer method, Murphy et al. (1996) estimated a recharge rate of 4 mm/yr. This value is much higher than the estimates for the ILAW

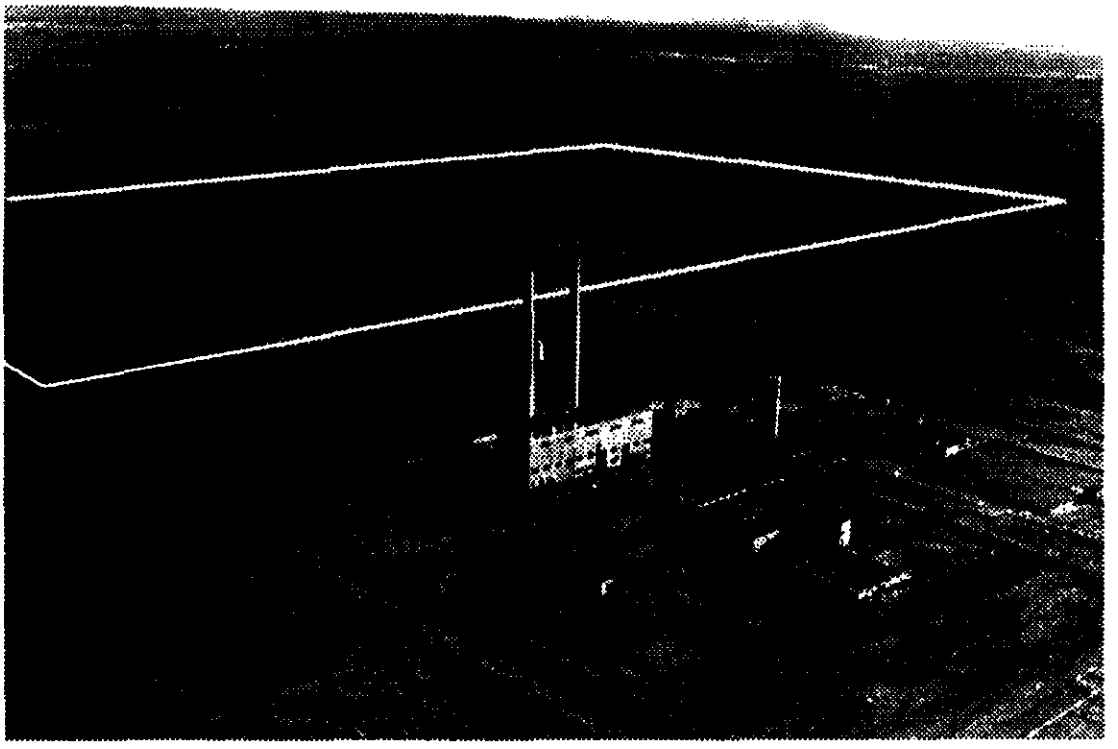


Figure 7.1. Aerial View of the New ILAW Disposal Site. The viewing direction is southeast. The 200 East Coal Power Plant and Water Purification Plant are in the foreground. The Existing Disposal Site, which is not shown, is 1.4 km directly east of the coal plant.

Disposal Site despite both sites being classified as shrub-steppe on Rupert sand. The distinctly different recharge estimates likely reflect differences in soil hydraulic properties and vegetation between the two sites.

There is enough variability in the data to exercise caution with this estimate. We propose using the average ILAW-specific estimate of 0.9 mm/yr for Rupert sand based on the deeper chloride data until the concern about facility emissions is resolved.

7.1.4 Burbank Loamy Sand

Prych (1998) estimated recharge for Burbank loamy sand using samples from two boreholes drilled less than 1 km north of the ILAW disposal sites. Using the chloride data above the 10-m depth, Prych estimated rates of 0.02 and 0.04 mm/yr. Using the chloride data below the 10-m depth, Prych estimated the recharge rates to be 2.8 and 5.5 mm/yr, which yields an average rate of 4.2 mm/yr. The borehole site is further from the coal plant than the ILAW sites, but it is directly downwind of the peak wind direction (from the southwest). The simulation results in Appendix C showed a recharge rate of 5.5 mm/yr in this soil.

Because of our concern about the shallower chloride data, we would rather use the mean of the deeper chloride estimates reported by Prych (1998). Therefore, we propose using a recharge rate of 4.2 mm/yr for Burbank loamy sand.

7.1.5 Hanford Formation Sand

During vault construction and filling, Hanford formation sand will be exposed and vegetation will likely not exist. Fayer and Walters (1995) reported that an unvegetated 7.6-m deep lysimeter containing Hanford sand drained 443 mm from July 1985 to June 1993 for an average rate of 55.4 mm/yr. For the conditions envisioned during facility construction, we propose using a recharge rate of 55.4 mm/yr.

During construction, we expect water will be used for dust control and compaction. The most likely period for water application will be late spring to early fall when the soil is typically driest. Under these conditions, we expect that the added water will not drain deep enough to impact recharge rates.

7.2 Sensitivity Tests

Some of the modeling results in Appendix C indicate the sensitivity of certain parameters and processes. These include vegetation presence, type, and abundance; soil properties; and climate.

7.2.1 Vegetation

The simulation results showed that the recharge rate through the surface cover was not sensitive to the type of plant or even to the presence of plants, at least to the model precision level of 0.1 mm/yr that was achieved. In contrast, recharge under the Rupert sand increased from 2.2 mm/yr under shrub-steppe to 33.2 mm/yr under cheatgrass to 44.3 mm/yr when plants were absent. Without plants, recharge under the Burbank loamy sand increased by a factor of 10 (from 5.2 to 52.5 mm/yr).

The robustness of the vegetation on Rupert sand was also tested by varying the leaf area index to encompass the range of values measured at the ILAW Disposal Site in 1998 (Appendix F). Increasing the shrub leaf area index by 60% reduced the predicted recharge from 2.2 to 1.6 mm/yr. Decreasing the shrub leaf area index by 60% increased the predicted recharge from 2.2 to 5.6 mm/yr. In both cases, the variation in recharge was within a factor of 2 to 3 of the base estimate of 2.2 mm/yr.

7.2.2 Soil Properties

The simulation results showed a minor sensitivity to soil properties. Two alternate hydraulic property descriptions for Rupert sand were used in separate simulations. These properties were obtained from a field infiltration test conducted at the new ILAW Disposal Site. The resulting predicted recharge rates were 2.7 and 3.3 mm/yr, compared to the base case estimate of 2.2 mm/yr.

7.2.3 Climate

The simulation results showed that the surface cover would be unaffected by any envisioned change in climate. In contrast, the simulation results showed that recharge in the soils would be significantly affected. Using Rupert sand, the nine combinations of three temperature regimes and three precipitation regimes yielded estimated recharge rates that ranged from less than 0.1 to 27 mm/yr. When precipitation was 50% of modern levels, recharge was less than 0.1 mm/yr regardless of the temperature scenario. For modern precipitation levels, estimated recharge ranged from 0.6 to 7.5 mm/yr for the high to low temperature regimes, respectively. For the high precipitation regime (128% of modern levels), the recharge rates increased, ranging from 5.2 to 27 mm/yr.

7.3 Uncertainty Tests

One method to gauge the uncertainty in recharge estimates is to analyze alternative conceptual models. The model results in Appendix C were used to address a change in the vegetation, a change in the climate, and irrigation.

One of the two cover degradation scenarios was that 20% of the silt loam layer was eroded. The simulation results in Appendix C showed that the eroded cover with shrub-steppe vegetation performed as well as the intact cover, i.e., it limited drainage to less than 0.1 mm/yr. The second degradation scenario involved the deposition of 20 cm of dune sand on the cover. The simulation results showed that the cover with dune sand and shrub-steppe vegetation also performed as well the intact cover. The simulation results also showed that the replacement of shrubs with cheatgrass for this particular situation resulted in drainage of 18.4 mm/yr, and the removal of all plants caused drainage to increase to 32.7 mm/yr. We expect that deep-rooted plants like sagebrush will always be present, therefore we propose using a rate of 0.1 mm/yr for the degraded cover scenario.

7.3.1 Vegetation Change

The simulation results in Appendix C showed that a surface cover without vegetation limited recharge to less than 0.1 mm/yr. This level of performance is as good as a cover with shrub-steppe vegetation. Without conducting a simulation with cheatgrass, we assumed that a cover with cheatgrass would limit recharge to less than 0.1 mm/yr. The same simulation results were obtained for an eroded cover without plants, showing how robust the silt loam cover is at reducing recharge, even in the absence of plants.

The results in Appendix C indicate that a shift from shrub-steppe to cheatgrass on the Rupert sand will raise the recharge rate from 2.2 to 33.2 mm/yr. This higher estimate of recharge is not unreasonable. Fayer and Walters (1995) used water content measurements to estimate recharge rates for a cheatgrass community growing on Rupert sand in the 300 Area. For an 8-year period, they estimated the average recharge rate was 25.4 mm/yr.

7.3.2 Climate Change

The prediction of climate change is a current research topic. Because we cannot foresee the future, we have used the past to see what has happened and possibly could happen again. Appendix C describes the analysis. Under climate change conditions most likely to promote recharge (i.e., higher precipitation and lower temperature), the surface cover continued to limit drainage to less than 0.1 mm/yr as did the eroded surface cover. With 20 cm of dune sand on the cover, this climate scenario resulted in a recharge rate of 16.9 mm/yr. Recharge in the Rupert sand jumped from 2.2 to 27 mm/yr and in the Burbank loamy sand from 5.2 to 36.8 mm/yr. In all cases, a shrub-steppe community was present.

7.3.3 Irrigation

All of the land use options currently being considered for Hanford exclude farming on and near the waste disposal sites. Because such institutional controls cannot be guaranteed to survive forever, we evaluated the impacts of irrigated agriculture on recharge. Appendix C describes the numerical simulations that were conducted. For a potato crop grown on the surface cover, recharge was 26.4 and <0.1 mm/yr for irrigation efficiencies of 75 and 100%, respectively. For Rupert sand, the rates were 57 and 30 mm/yr for the same efficiencies. We assumed there would be no farming on Burbank loamy sand because of the high gravel content. An effort was started in FY 1999 to evaluate current and projected irrigation practices around Hanford (LMHC 1999). The results of that effort will be used to improve and refine our recharge estimates for irrigated farming.

7.4 Assignment of Recharge Rates to Scenarios

The data and analyses just discussed were used to assign recharge rates to each of the scenarios identified in Section 5.0. The estimated rates were assigned to the best estimate and to the lower and upper bounding cases.

7.4.1 Best Estimate Case

Table 7.1 shows the estimated recharge rates for each surface feature during each phase of the disposal evaluation. As discussed in Section 7.1, the cover, cover sideslope, and Hanford formation estimates are based on lysimeter data. The Rupert sand and Burbank loamy sand estimates are based on chloride data.

7.4.2 Reasonable Bounding Cases

The lower bounding case represents the situation in which recharge rates are at their lowest possible values. The upper bounding cases represent situations in which recharge rates are at their highest possible values. Table 7.2 summarizes the rate assignments for both cases. We did not include climate change, sand dune migration, or irrigation effects in setting the bounding estimates.

Table 7.1 Recharge Estimates for the Best Estimate Case for Disposal Facility Features During Each Period of Interest to the ILAW 2001 PA. These estimates reflect current climate conditions. The surface cover, Rupert sand, and Burbank loamy sand have shrub-steppe vegetation.

Surface Feature	Estimated Recharge Rate (mm/yr)			
	Time Period of Recharge Evaluation			
	Pre-Hanford	During Disposal Operations	During Surface Cover Design Life	After Surface Cover Design Life
Modified RCRA Subtitle C Cover	NA	NA	0.1	0.1
Cover Sideslope	NA	NA	50	50
Rupert Sand	0.9	0.9	0.9	0.9
Burbank Loamy Sand	4.2	4.2	4.2	4.2
Hanford Formation Sediments	NA	55.4	NA	NA
NA = Not applicable.				

Table 7.2. Recharge Estimates for the Reasonable Bounding Cases During Each Period of Interest to the ILAW 2001 PA

Surface Feature	Estimated Upper and Lower Reasonable Bounding Recharge Rates (mm/yr)			
	Time Period of Recharge Evaluation			
	Pre-Hanford	During Disposal Operations	During Surface Cover Design Life	After Surface Cover Design Life
Modified RCRA Subtitle C Cover	NA	NA	0.01, 4.0	0.1, 4.0
Cover Sideslope	NA	NA	4.2, 86.4	4.2, 86.4
Rupert Sand	0.16, 4.0	0.16, 4.0	0.16, 4.0	0.16, 4.0
Burbank Loamy Sand	2.8, 5.5	2.8, 5.5	2.8, 5.5	2.8, 5.5
Hanford Formation Sediments	NA	50, 86.4	NA	NA
NA = Not applicable.				

The lower bounding case was a fully functional surface cover and a dense shrub-steppe community on the cover and the surrounding soils. We proposed using a recharge rate of 0.01 mm/yr for the cover. Lysimeter evidence suggests the rate is lower, but we are not yet ready to claim credit for that lower rate. We proposed using a rate of 4.2 mm/yr for the cover sideslope. This rate actually comes from our best estimate for Burbank loamy sand. This soil type has a large fraction of gravel (similar to a sandy gravel sideslope) and a shrub-steppe plant community (which sideslope tests to date have not included). We proposed using a recharge rate of 0.16 mm/yr for Rupert sand. This rate is the lowest of the four rates

estimated from site-specific chloride data. We proposed using a recharge rate of 2.8 mm/yr for the Burbank loamy sand. This rate is the lower of two rates estimated from chloride data. We proposed using a recharge rate of 50 mm/yr for the Hanford formation sediments during construction. This rate actually comes from drainage data collected from the sandy gravel sideslope test at the Prototype Barrier. The sideslope test has no shrubs and an extremely sparse cover of annuals.

The upper bounding case was a degraded surface cover and a sparse shrub-steppe community on the cover and the surrounding soils. We proposed using a recharge rate of 4.0 mm/yr for the cover. This rate was the estimate derived from Rupert sand with a sparse shrub cover. Simulation results suggest the rate is lower, but we are not yet ready to claim credit for that lower rate. We proposed using a rate of 86.4 mm/yr for the cover sideslope. This rate actually comes from lysimeter drainage data collected from an unvegetated sandy gravel test in the FLTF. We proposed using a recharge rate of 4.0 mm/yr for Rupert sand. This rate was the estimate derived from chloride data in Rupert sand with a sparse shrub cover. We proposed using a recharge rate of 5.5 mm/yr for the Burbank loamy sand. This rate is the higher of two rates estimated from chloride data. We proposed using a recharge rate of 86.4 mm/yr for the Hanford formation sediments during construction. This rate actually comes from lysimeter drainage data collected from an unvegetated sandy gravel test in the FLTF.

7.5 Plans for FY 2000

The ILAW PA project continues to support data collection and analysis activities to improve the estimates of recharge for its scenarios of interest. Current plans call for FY 2000 activities in lysimetry, tracers, modeling, vegetation studies, the initiation of field tests, and continuation of updates to the Recharge Data Package. These plans are described briefly below; details can be found in LMHC (1999).

We will continue to monitor the lysimeters at the FLTF. For some lysimeters, the performance data will eventually span 14 years (by the year 2001), providing a valuable data set for verifying barrier performance and testing model predictions. A subset of the lysimeters is being used to collect performance data for degraded and modified barriers and for recharge in the adjacent land following a change in vegetation, all under both ambient and enhanced precipitation. These tests were initiated in FY 1998 and FY 1999 and will provide performance data through the year 2001.

The chloride and ^{36}Cl tracer methods will again be employed to estimate recharge rates. Additional ILAW boreholes will be drilled in a manner similar to the borehole drilled in FY 1998 (see Appendix B). Additional shallow boreholes (~15 m) may be drilled near the new boreholes to provide additional sediment material. The sediments will be analyzed using procedures similar to those used previously and recharge rates will be estimated for each borehole.

The capabilities of the UNSAT-H computer code will be increased to address multiple plant species, plant response to seasonality effects, and snow/snowmelt effects. These additional capabilities will

address comments received during an earlier peer review workshop (Honeyman 1995).[1] The modified version of the code will be formally documented and the theory and user manual will be published. The modified code will be tested using data from the lysimeters and the vegetation subtask. An uncertainty analysis will be conducted using UNSAT-H within an existing uncertainty analysis framework.

Based on previous work, additional transects will be sampled for roots in the ILAW Disposal Site. The data will be collected to depths deeper than sampled earlier (i.e., at least 2 m) to confirm the observation of shrub/inter-shrub differences and to provide data to describe the spatial variability of rooting patterns. Based on these and earlier data, a hypothesis will be proposed for describing such rooting behavior. The results will be used to support recharge simulations. We will continue to sample plant water status throughout the year so that the relationship of plant behavior to weather will be clearer and more quantifiable. These measurements will be coordinated with the Field Recharge Study (see below) so that correlations can be made between soil water status and plant water status. Based on these and earlier data, a hypotheses will be proposed for describing transpiration during these times. The results will be used to support recharge simulations.

Acceptance of the ILAW PA will depend, in part, on demonstrating a good understanding of the processes that affect natural recharge rates at the two disposal sites. Although lysimeter, modeling, and tracer studies are being conducted and will be useful, some direct field testing at the sites is necessary. The objectives of the field recharge study are to observe field water behavior during several winters, document the variability of such behavior, provide soil water status information for the vegetation task (i.e., the study of plant water status), and provide a set of field data for model testing. Two locations will be identified at the disposal sites and instrumented to measure water content and matric potential at multiple depths within and below the root zone. The layout will be designed to differentiate between water movement beneath shrubs and water movement in the inter-shrub spaces. These measurements will be coordinated with the Vegetation Task so that correlations can be made between soil water status and plant water status. The data will also be used to support the design of a waste form release field test (LMHC 1999).

Beyond FY 2000, several issues need to be more fully evaluated. These issues include unstable and preferential flow, uniformity and longevity of the cover, and flaws in the cover. These flaws include differential settling and cracking, discontinuities, and points of flow convergence.

7.6 Remaining Issues

As with any estimation activity involving multiple data sources, spatial variability, and time frames of thousands of years, there are many issues and concerns that need and deserve attention. Three of the more important issues are lysimeter drainage resolution, possible facility deposition of chloride, and the importance of temperature and water vapor flow when recharge rates are low.

(a) Honeyman JO. 1995. Letter to L Erickson transmitting the results of the 1995 workshop entitled "Summary of peer review comments resulting from the second Hanford groundwater recharge workshop." May 22-23, 1995, Richland, Washington.

Lysimeters that have materials in them do not lend themselves well to testing for leaks because the presence of the material can affect the leak test, which is the case for most of the leak tests conducted to date. Recently, some lysimeters were emptied for new tests. The interiors of the lysimeters were in good shape and showed no obvious sign of corrosion near the base where a sealant had been applied. These lysimeters were leak tested, but the tests were short in duration. While we can say the leak rate was less than 0.5 mm/yr, we cannot say with certainty that there was no leakage. Overall, the leak tests show that there were no major leaks, but they have not been precise enough to state unequivocally that the leak rate is zero. The next time a lysimeter is to be emptied for a new test, it should be leak tested much more extensively to verify that leakage is less than 0.01 mm/yr.

The appropriate use of the chloride method to estimate recharge rates in the 200 Areas depends on resolving the issue of possible facility emissions of chloride. Appendix E suggested that sulfate may be a marker of coal plant emissions, although sulfate is somewhat less mobile than chloride (Bohn et al. 1979). Several soil profiles will be analyzed for sulfate in the summer of 1999. If high sulfate and chloride concentrations are not depth-correlated, then we can use the entire chloride profile to estimate deep drainage fluxes along with their dates (see Appendix B). If they are depth-correlated, indicating deposition of coal plant emissions, we will continue to use the deeper chloride data that are located below the sulfate pulse (and presumably pre-Hanford). However, we will not be able to age-date the fluxes using the chloride accumulation technique.

Some of the recharge estimates are in the range of 1 mm/yr and less. At these rates, temperature and vapor flow are more important to accurate estimates of recharge than they are when rates are greater than 10 mm/yr. Past studies have considered these processes using field measurements of temperature and matric potential (e.g., Enfield et al. 1973). However, the methods used to estimate recharge for the ILAW disposal sites did not fully address these processes. Lysimeters, by their nature, de-couple the interior soil from the surrounding soil, thus preventing vapor flow and altering temperature gradients. Because it moves only in liquid water, the chloride tracer cannot indicate the magnitude of the vapor flow contribution to recharge (positive or negative). One way to gather data relevant to low recharge rates is to install instrumentation at the ILAW Disposal Site. In situ measurements of temperature and matric potential gradients at multiple depths would help resolve the magnitude of the low recharge fluxes.

8.0 Conclusions

LMHC is conducting a performance assessment for the proposed disposal of ILAW in the 200 East Area of the Hanford Site. The goal of the PA is to provide a reasonable expectation that the disposal is protective of the general public, groundwater resources, air resources, surface water resources, and inadvertent intruders. PNNL assists LMHC in their performance assessment activities. One of the PNNL tasks is to provide estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of ILAW. Specifically, recharge estimates are needed for a fully functional surface cover, the cover sideslope, and the immediately surrounding terrain. In addition, recharge estimates are needed for degraded cover conditions. The temporal scope of the analysis is 10,000 years, but could be longer if some contaminant peaks occur after 10,000 years.

The elements of this report compose the Recharge Data Package, which provides estimates of recharge rates for the scenarios being considered in the 2001 PA. The estimates were derived from lysimeter and tracer data collected by the ILAW PA and other projects and from modeling analyses.

For the best estimate case, we proposed using a recharge rate of 0.1 mm/yr for the surface cover with a shrub-steppe plant community. This rate is lower than the cover design goal of 0.5 mm/yr because it reflects the actual performance measured with lysimeters and inferred with modeling. The simulation results showed that erosion of 20% of the silt loam layer did not impair this performance nor did the deposition of 20 cm of dune sand. For the sandy gravel sideslope, we proposed using a recharge rate of 50 mm/yr. This rate is lower than the 75 mm/yr used in the 1998 ILAW PA. For the soil type known as Rupert sand and a shrub-steppe plant community, we proposed using a recharge rate of 0.9 mm/yr. This rate is lower than the 3 mm/yr used in the 1998 ILAW PA. For the soil type known as Burbank loamy sand and a shrub steppe-plant community, we proposed using a recharge rate of 4.2 mm/yr. This soil type was not considered in the 1998 ILAW PA. For the Hanford formation sediments during construction, we proposed using a recharge rate of 55.4 mm/yr. Recharge in Hanford formation sediments during construction was not considered in the 1998 ILAW PA.

A limited number of sensitivity tests were conducted. The results showed that the surface cover limited recharge to less than 0.1 mm/yr regardless of the plant type, the presence of plants, or any of the climate change conditions. In contrast, recharge in the Rupert sand showed a significant sensitivity to vegetation type and climate change conditions, but less sensitivity to small variations in hydraulic properties.

Several alternative conceptual models were considered to indicate the effects of conceptual model uncertainty. Replacement of the shrub cover with cheatgrass had no impact on recharge through the surface cover, but it increased recharge in Rupert sand from 2.2 to 33.2 mm/yr. Under the climate change condition most likely to promote recharge (i.e., increased precipitation and decreased temperature), recharge through the cover remained <0.1 mm/yr in contrast to this recharge in Rupert sand, which increased from 2.2 to 27 mm/yr.

Irrigation on the surface cover caused recharge to increase from 0.1 to 26.4 mm/yr as the irrigation efficiency was reduced from 100 to 75%.

Using the available recharge estimates, we identified a set of reasonable bounding rates. The design feature with the largest projected range in performance was the sideslope (4.2 to 87.5 mm/yr). Given that sideslopes could represent a significant fraction of the surface cover footprint, we believe that efforts to improve sideslope performance are warranted.

Issues remaining to be addressed include the precision of lysimeter leak tests to support the use of lower recharge estimates, possible facility deposition of chloride that could impact tracer analyses, and the importance of temperature and water vapor flow when recharge rate estimates are lower than 1 mm/yr. In addition, the impacts of unstable and preferential flow and flaws in the cover need to be evaluated.

9.0 References

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Appendix A

Field Lysimeter Test Facility Data to Support the ILAW 2001 PA

M. J. Fayer, R. E. Clayton, D. Felmy, and J. C. Ritter

Appendix A

Field Lysimeter Test Facility Data to Support the ILAW 2001 PA

A.1 Introduction

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in near-surface, shallow-land burial facilities. The LMHC project to assess the performance of these disposal facilities is known as the Hanford ILAW Performance Assessment (PA) Activity, hereafter called the ILAW PA. Acceptance of ILAW disposal at Hanford depends on demonstrating that public health and the environment are adequately protected. Achieving this goal will require predictions of contaminant migration from the facility. To make such predictions will require estimates of the fluxes of water moving through the sediments within the vadose zone beneath and around the disposal facility. These fluxes, loosely called recharge rates, are the primary mechanism for transporting contaminants to the groundwater.

Mann (1999) indicates that two disposal sites will be considered: the ILAW Disposal Site (located southwest of the PUREX Plant) and the site of the former Grout Vaults. For each, recharge rate estimates are needed for a fully functional surface cover, its sideslope, and the immediately surrounding terrain. In addition, recharge estimates are needed for degraded conditions and for the case of irrigated farming directly on the cover. Mann (1999) indicates that the temporal scope of the 2001 ILAW PA is 10,000 years, but could be longer as some contaminant peaks occur after 10,000 years.

Pacific Northwest National Laboratory (PNNL) assists LMHC in their performance assessment activities. One of the PNNL tasks is to provide defensible estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of ILAW (LMHC 1999). A major goal of the recharge task is to collect sufficient data for the conditions and scenarios deemed to be important for evaluating the performance of the disposal facilities. These rate estimates will be provided using lysimetry, tracer studies, and modeling studies.

The recharge task uses the lysimeters at the Field Lysimeter Test Facility (FLTF) in the 200 West Area to collect recharge-related data. The two goals of the lysimeter work are to accurately quantify the recharge flux for scenarios pertinent to the ILAW project and provide a set of long-term monitoring data with which to test the recharge model (e.g., Fayer et al. 1992). This model will be used to extend the observations and estimate recharge rates for potential future scenarios. This appendix summarizes the lysimeter data that have been collected from the FLTF through March 31, 1999.

A.2 Background

The Protective Barrier Program constructed the FLTF in FY 1987 to test the performance of capillary barrier cover designs (Gee et al. 1989; Wing 1994). Figure A.1 shows the location of the FLTF within the 200 Areas. Figure A.2 shows the layout of the FLTF.

The facility contains a total of 24 lysimeters of three types: 14 drainage, 4 weighing, and 6 small-tube lysimeters. The drainage lysimeters are vertical cylinders that are 3 m deep and 2 m in diameter (surface area of 3.08 m^2). The drainage lysimeters compose the walls of the FLTF.

The weighing lysimeters are boxes with length and width dimensions of 1.5 m and a depth of 1.7 m. The boxes rest on platform scales to enable hourly weight measurements of water gain and loss. The weighing lysimeters are at the south end of the FLTF (Figure A.2).

The small-tube lysimeters are vertical cylinders that are 3 m deep and 0.3 m in diameter (surface area of 0.07 m^2). Unlike the others, the small-tube lysimeters are clear Plexiglas to facilitate root and soil observations. These lysimeters are arrayed along the inner walls of the FLTF but are not shown in Figure A.2.

Treatments involve variations of material types and thickness, presence of vegetation, and the use of irrigation to mimic the possible increased precipitation of future climate. Data from this facility include drainage, water content, matric potential, temperature, and vegetation observations. Discussions of the early data from this facility can be found in Gee et al. (1989), Campbell et al. (1990), Campbell and Gee (1990), and Gee et al. (1993a).

Because a surface barrier is part of the current conceptual model of the ILAW Disposal Site, the data collected at the FLTF are being used to support recharge estimation for the performance assessment. In 1994, the emphasis of the Protective Barrier Program switched from monitoring the FLTF to constructing and monitoring a prototype barrier in the 200 East Area (Gee et al. 1993b). The change in program emphasis created an opportunity for the ILAW PA disposal project to conduct testing in the facility for soil-vegetation-climate treatments of importance to the ILAW PA project.

Fayer and Felmy (1996)[1] described the testing and measurement techniques supported by the ILAW PA project from June 1995 to September 1996. The ILAW-supported activities were at a reduced level relative to the measurement activity conducted under the Protective Barrier Program. Since 1996, the irrigation and monitoring activities have continued on the same limited basis and results have been described briefly in monthly reports. In FY 1998, seven lysimeters were modified to address three important PA scenarios: sand deposition on the barrier, erosion of barrier material, and complete coverage of the barrier by a sand dune. In FY 1999, two additional lysimeters were modified to collect performance data on the modified Resource Conservation and Recovery Act (RCRA) Subtitle C surface

(a) Fayer MJ and D Felmy. 1996. "Integrated Recharge Assessment: Summary of FY 1996 Activities at the FLTF." Letter Report to Fred Mann, September 27, 1996.

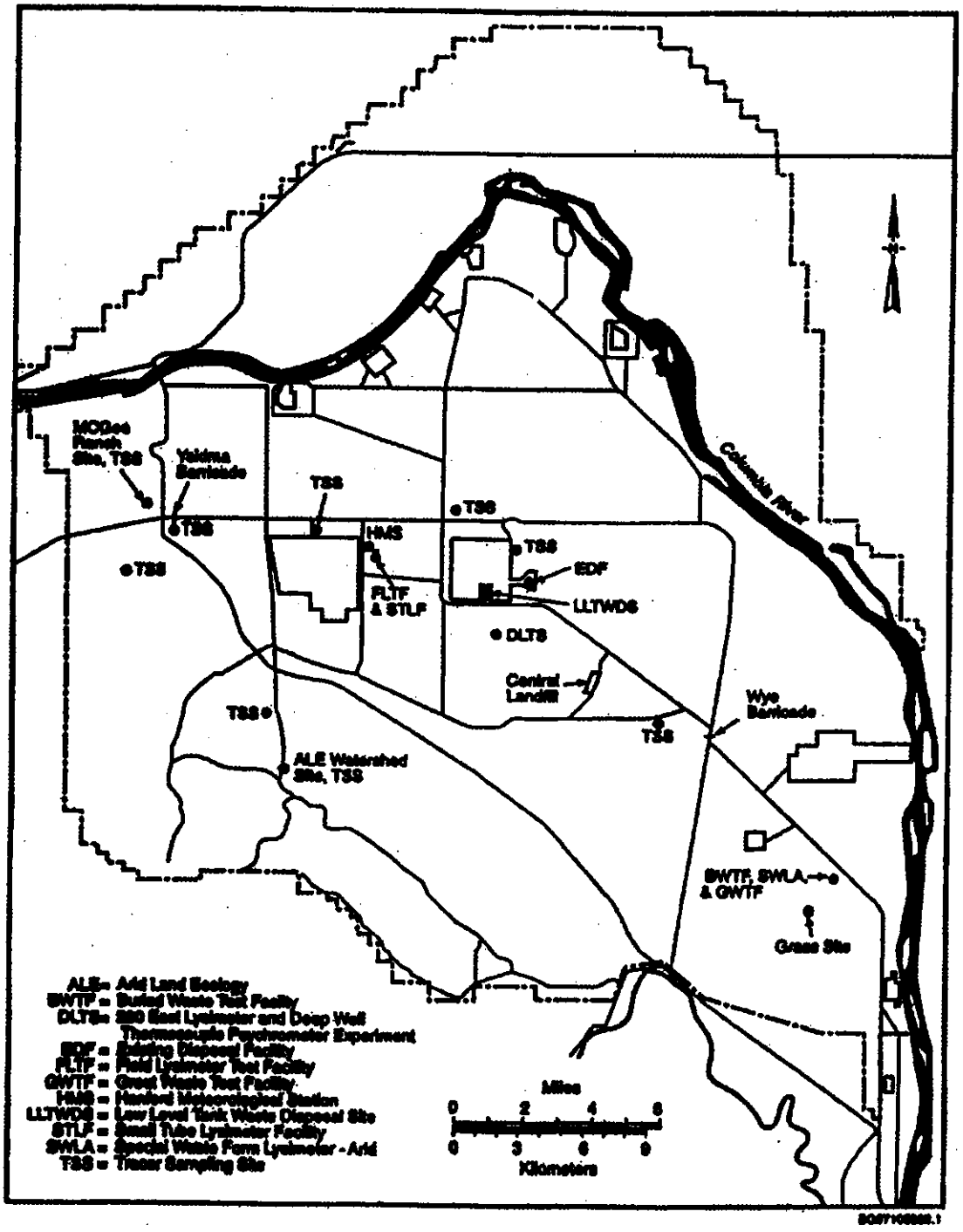


Figure A.1. Location of the FLTF

cover design (DOE/RL 1996). The ILAW project is considering this design as a cost-effective substitute to the Hanford Protective Barrier (Myers and Duranceau 1994).

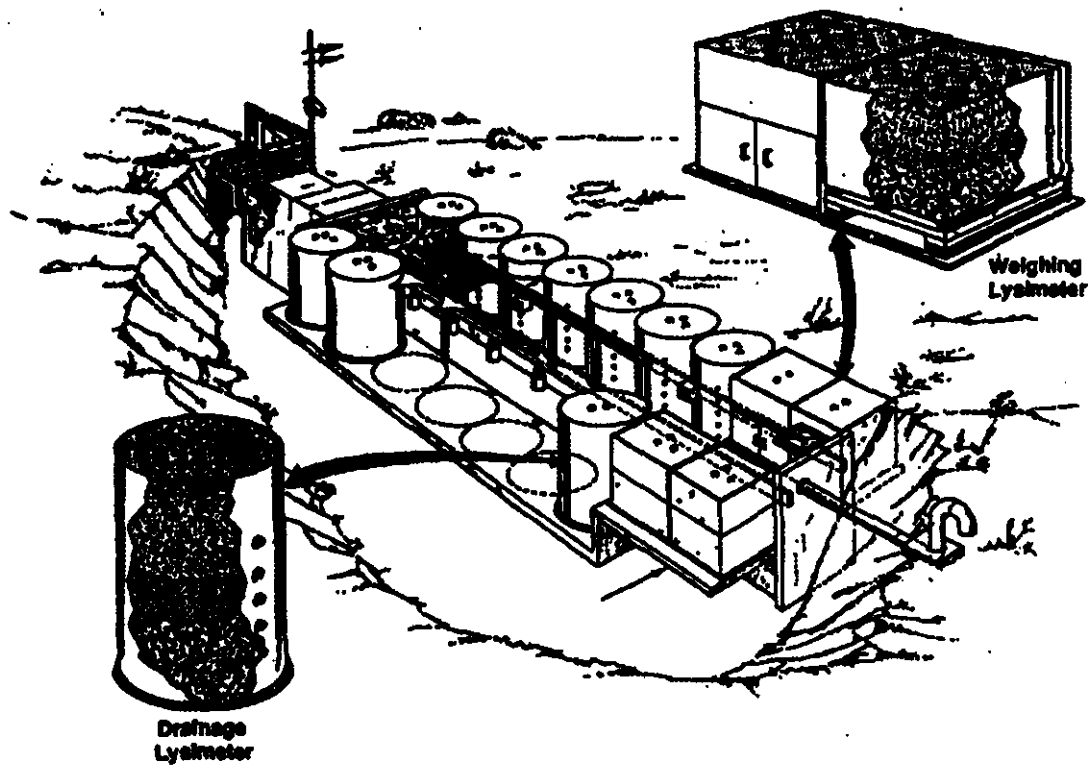


Figure A.2. Artist's Rendering of the FLTF

A.3 Methods

When the FLTF was constructed in 1987, three tests (and seven treatments) were being conducted. When testing was completed for some of the lysimeters, those lysimeters were converted to new tests and treatments. As of March 31, 1999, the number of tests had expanded to 11 and the number of treatments had expanded to 24, reflecting various combinations of soil type and layering, vegetation, and precipitation. The 11 tests and associated data collection activities and frequencies are described below.

A.3.1 Test Descriptions

Gee et al. (1989), Campbell et al. (1990), Campbell and Gee (1990), and Gee et al. (1993a) provided descriptions of the first five tests. More detail is provided below for the tests initiated in FY 1998 and 1999. Table A.1 summarizes all of the tests and treatments.

Hanford Barrier. The objective of this test was to collect data on the performance of a Hanford Barrier. The general configuration consisted of 1.5 m of silt loam that rested on a sequence of materials grading

Table A.1. Summary of Treatments and Applicable Dates at the FLTF as of March 31, 1999 ("a" indicates irrigation was accelerated till drainage commenced; "g" indicates sagebrush planted but died, leaving only grasses; treatment 7 lysimeters received special precipitation and evaporation conditions after March 14, 1988; dates in bold italics indicate current configurations).

Test Description	Treatment ID No.	Precipitation			Vegetation			Lysimeter ID	Monitoring Period	
		1x	2 to 3x	3x	NV	SRV	DRV		Start	End
Hanford Barrier	1	X					X	D4	4 Nov 1987	22 Apr 1994
		X					X	D7	4 Nov 1987	22 Apr 1994
		X					X	W1	4 Nov 1987	***31 Mar 1999***
		X					X[g]	C3	9 Nov 1988	***31 Mar 1999***
	2	X			X			D1	4 Nov 1987	***31 Mar 1999***
		X			X			D8	4 Nov 1987	27 Feb 1998
		X			X			W2	4 Nov 1987	26 Nov 1997
	3		X				X	D13	4 Nov 1987	27 Feb 1998
			X				X	D14	4 Nov 1987	22 Apr 1994
			X				X	W3	4 Nov 1987	***31 Mar 1999***
			X				X	C6	9 Nov 1988	***31 Mar 1999***
	4		X		X			D10	4 Nov 1987	***31 Mar 1999***
			X		X			D12	4 Nov 1987	26 Nov 1997
			X		X			W4	4 Nov 1987	26 Nov 1997
	7		X[a]		X			D9	4 Nov 1987	22 Apr 1994
			X[a]		X			D11	4 Nov 1987	22 Apr 1994
Hanford Barrier w/Gravel Admix	5	X					X	D2	4 Nov 1987	22 Apr 1994
		X					X[g]	D5	4 Nov 1987	26 Nov 1997
Eroded Hanford Barrier	6	X					X	D3	4 Nov 1987	***31 Mar 1999***
		X					X	D6	4 Nov 1987	27 Feb 1998
	18			X			X	D13	27 May 1998	***31 Mar 1999***
Gravel Mulch	8	X			X			C1	17 Nov 1989	***31 Mar 1999***
	10		X		X			C4	17 Nov 1989	***31 Mar 1999***
Pitrun Sand	9	X					X[g]	C2	17 Nov 1989	***31 Mar 1999***
	11		X				X	C5	17 Nov 1989	***31 Mar 1999***
Basalt Sideslope	12	X			X			D2	Nov 1994	***31 Mar 1999***
	13			X	X			D9	Nov 1994	Nov 1998
Sandy Gravel Sideslope	14	X			X			D4	Nov 1994	***31 Mar 1999***
	15			X	X			D11	Nov 1994	***31 Mar 1999***
Hanford Prototype Barrier	16	X					X	D7	Nov 1994	Nov 1998
	17			X			X	D14	Nov 1994	***31 Mar 1999***
Hanford Barrier Erosion/Dune Sand Deposition	19	X				X		D5	15 Nov 1997	***31 Mar 1999***
		X				X		W2	15 Nov 1997	***31 Mar 1999***
	20			X		X		D12	15 Nov 1997	***31 Mar 1999***
				X		X		W4	15 Nov 1997	***31 Mar 1999***
Sand Dune Migration	21	X				X		D6	22 Jul 1998	***31 Mar 1999***
	22			X		X		D8	22 Jul 1998	***31 Mar 1999***
Modified RCRA Subtitle C Cover	23	X					X	D7	23 Feb 1999	***31 Mar 1999***
	24			X			X	D9	23 Feb 1999	***31 Mar 1999***
Vegetation Symbols are: NV = no vegetation, SRV = shallow rooted vegetation, and DRV = deep rooted vegetation										

from sand to gravel filter layers and finally resting on basalt riprap. This test included shrub-steppe vegetation and no vegetation comparisons (treatment numbers 1 through 4, and 7 in Gee et al. 1993a).

Hanford Barrier with Gravel Admix. The objective of this test was to collect data on the impact of a gravel admix on the performance of a Hanford Barrier. The basic configuration was a Hanford Barrier, with the exception that the top 0.2 m of silt loam was amended with pea gravel. The gravel content was 15% by weight. This test included shrub-steppe vegetation but addressed only ambient precipitation (treatment number 5 in Gee et al. 1993a).

Eroded Hanford Barrier. The objective of this test was to collect data on the performance of an eroded Hanford Barrier. The basic configuration was a Hanford Barrier, with the exception that the silt loam layer thickness was reduced from 1.5 to 1.0 m. This test included shrub-steppe vegetation (treatment number 6 in Gee et al. 1993a and 18 in this appendix).

Gravel Mulch. The objective of this test was to collect drainage data on the performance of a gravel mulch layer above Hanford formation sand. The basic configuration was 0.15 m of coarse gravel above 1.35 m of screened pitrun sand (to remove the gravel), on top of unscreened pitrun sand (described below). This test did not include vegetation (treatment numbers 8 and 10 in Gee et al. 1993a). Although not its primary purpose, this test may be useful for characterizing deep drainage rates at the high-level waste tank farms at Hanford.

Pitrun Sand. The objective of this test was to collect drainage data on the performance of a coarse gravelly sand taken from a nearby borrow pit (hence "pitrun" sand). The basic configuration was 1.5 m of screened pitrun sand (to remove the gravel), on top of unscreened pitrun sand. This test included shrub-steppe vegetation (treatment numbers 9 and 11 in Gee et al. 1993a).

Basalt Sideslope. The objective of this test was to collect drainage data on the performance of basalt riprap that could be used to construct sideslopes for surface covers. The basic configuration was 1.5 m of unscreened basalt riprap. This material is being tested for sideslope use on a larger scale at the Hanford Prototype Barrier in the 200-BP-1 Operable Unit (Ward et al. 1997). Beneath the basalt layer was a 0.15-m thick asphaltic concrete layer that was underlain by gravel and more basalt riprap. Resting on top of the asphaltic concrete was about 2 to 3 cm of silt loam, within which was embedded a 2.54-cm outside diameter fiberglass wick. The wick was splayed out within the silt loam to maximize contact, but exited through the drain outlet as one piece. This test did not include vegetation (treatment numbers 12 and 13 in Gee et al. 1993a).

Sandy Gravel Sideslope. The objective of this test was to collect drainage data on the performance of unprocessed local sandy gravel that could be used to construct sideslopes for surface covers. The basic configuration was 1.5 m of sandy gravel resting on an asphaltic concrete layer in a manner similar to the basalt sideslope test. The sandy gravel material was tested for sideslope use on a larger scale at the Hanford Prototype Barrier in the 200-BP-1 Operable Unit (Ward et al. 1997). This test did not include vegetation (treatment numbers 14 and 15 in Gee et al. 1993a). Although not its primary purpose, this test may be useful for characterizing deep drainage rates at the high-level waste tank farms at Hanford.

Hanford Prototype Barrier. The objective of this test was to collect data on the performance of the Hanford Prototype Barrier design. The basic configuration was 1.0 m of silt loam amended with pea gravel (15% by weight) above 1.0 m of silt loam, which gave a combined thickness of 2.0 m. Beneath the silt layer were sand and gravel filter layers, then the asphaltic concrete layer described in the basalt sideslope test description. A full-scale cover of the same design was built in the 200-BP-1 Operable Unit (Ward et al. 1997). The test at the FLTF included shrub-steppe vegetation (treatment numbers 16 and 17 in Gee et al. 1993a).

Hanford Barrier Erosion/Dune Sand Deposition. The objective of this test was to collect data on the performance of the Hanford Barrier after experiencing some erosion of the silt loam layer and subsequent deposition of dune sand. The top 20-cm of silt loam was removed from four lysimeters containing a Hanford Barrier. The excavated silt loam was replaced with dune sand to study the effect of sand deposition. The dune sand was obtained from the dune that is aligned along the southern edge of the ILAW Disposal Site (Reidel et al. 1998). All instruments remained as before. This test included shallow-rooted vegetation, primarily cheatgrass (treatment numbers were 19 and 20).

Sand Dune Migration. The objective of this test was to collect data on the performance of a sand dune that might migrate onto the surface cover. Two lysimeters were completely filled with dune sand. These lysimeters will provide data on the impact of a dune forming on a barrier, as well as provide data on the behavior of dunes that might form around a barrier and elsewhere at the Hanford Site. The dune sand was obtained from the dune that is aligned along the southern edge of the ILAW Disposal Site (Reidel et al. 1998). Tensiometers were installed to measure matric potential at three depths: 100, 150, and 210 cm. An aluminum access tube was inserted vertically for neutron probe measurements of water content. Time-domain-reflectometry probes were installed horizontally to measure water content at nine depths (5, 30, 60, 90, 120, 150, 180, 210, and 240 cm). A tenth time-domain-reflectometry probe was installed vertically from 5 to 35 cm. An array of thermocouples was installed to measure temperature variations. This test included shallow-rooted vegetation, primarily cheatgrass (treatment numbers were 21 and 22).

Modified RCRA Subtitle C Cover. The objective of this test was to collect data on the performance of a modified RCRA Subtitle C barrier that was proposed by DOE/RL (1996). This barrier design meets the requirements for a RCRA Subtitle C barrier but uses a thinner silt loam soil than the Hanford Prototype Barrier (1.0 rather than 2.0 m). In addition, the silt layer has two modifications. The first is that the upper 0.5 m of silt loam is amended with pea gravel at the rate of 15% by weight. The second feature is that the lower 0.5 m of silt is compacted. The rationale for the compacted layer was to create a low-conductivity layer to impede downward drainage (DOE/RL 1996). We expect the compacted layer will initially hinder root growth and make it difficult to establish and maintain shrubs. However, we expect roots will eventually penetrate the compacted layer, reduce its density, and thus no other treatment in the FLTF has a layer that has been compacted. Table A.2 describes the materials and the depth intervals within the lysimeters.

The configuration in the lysimeters differs from the modified RCRA Subtitle C design in three ways. First, we discovered that one sand filter layer was not enough to prevent sand movement into the gravel filter. We added a coarser sand layer (No. 8 sand) between the 20/30 sand and the gravel filter. This

Table A.2. Material Configuration for the Test of the Modified RCRA Subtitle C Cover

Material	Depth Intervals (m)	
	D7	D9
Warden Silt Loam with 15% gravel	0-0.5	0-0.5
Warden Silt Loam (compacted to 1.6 g/cm^3)	0.5-1.0	0.5-1.0
#2030 Granusil #4075 Silica	1.0-1.10	1.0-1.10
#8 Mesh Granusil #2095 Silica	1.10-1.15	1.10-1.15
1.9 cm (0.75 in.) Chips (gravel filter)	1.15-1.3	1.15-1.3
3.18 cm (1.25 in.) Chips (lateral drainage)	1.3.-1.7	1.3.-1.5

arrangement is the same filter sequence used in the other lysimeters. The overall sand layer thickness remained unchanged at 0.15 m.

The second change involved the lateral drainage layer. The specified material (3.18 cm minus) met the particle size requirements, but the conductivity was much less than 1 cm/s. We replaced this material with 3.18-cm chips, which had conductivity in excess of 1 cm/s.

The final change involved the density of the lower silt loam layer. We had an extremely difficult time trying to compact it to the specified density of 1.76 g/cm^3. We tried a tamping bar, a gas-powered plate compactor, a gas-powered upright compactor, and a hydraulic hole compactor. The tamping bar and plate compactor were unable to give us densities above 1.5 g/cm^3. The upright compactor was better (about 1.6 g/cm^3), but was still not near the target of 1.76 g/cm^3. We expected the hydraulic compactor to be the most compactive of all. However, Northwest Testing, using a commercial density meter, determined that the effort of the hydraulic system was not exceeding the densities achieved with the upright compactor.

The square design of the hydraulic compactor made it difficult to be effective in a round lysimeter with a neutron probe access tube in the center. Also, its end plate was large (roughly 28 cm^2); a smaller end plate may have enabled the hydraulic compactor to be more successful. After trying several methods, we completed compacting the silt loam layer with the gas-powered upright compactor. A single soil core from D9 (43.18-cm long, 2.54-cm diameter) yielded a density of 1.6 g/cm^3.

Both lysimeters contain a tensiometer to measure matric potential at the 100-cm depth, a neutron probe access tube to measure water content, and a series of thermocouples to measure soil temperature distributions. This test included shrub-steppe vegetation (treatment numbers were 23 and 24).

A.3.2 Data Collection Methods and Frequency

The types of data needed to estimate recharge and test models include water contents and storage, matric suction, temperature, drainage, and vegetation characteristics. Some measurements were conducted manually, while others are made automatically using the facility data logger system. Each lysimeter has a unique combination of sensors, sensor placement, and measurement frequency. Most details are provided by Gee et al. (1989); any variations are explained below.

Weather. Weather data were collected at the Hanford Meteorological Station (HMS), which is located at the same elevation about 0.5 km west of the FLTF (Hoitink et al. 1999). The HMS is a complete weather station, providing hourly measurements of all variables, including air temperature, dewpoint temperature, solar radiation, wind speed, cloud cover, and precipitation. The station is operated by another project.

Irrigation. A subset of lysimeters received irrigation to mimic an increased precipitation regime. Untreated water from the Columbia River was applied in increments ranging from 3 to 35 mm per application. The rate was typically 4 mm/h. During several years, up to 73 mm of water were applied in a single irrigation event to simulate a 1,000-year storm. The total quantity and frequency of application were determined by the target amount, which was either two or three times the monthly average. The water was delivered through six nozzles spaced 0.41 m apart along a 2.4-m boom that was connected to the water source. The boom was 0.5 m above the ground surface and was moved automatically down the length of the facility at the rate of about 0.7 m/min. Four rain gauges were positioned within the irrigation path and monitored during each application. The weight resolution of the weighing lysimeters was better than the rain gauges, so lysimeter W4 was used to check the application rate.

Water Content. Water content was measured primarily with a neutron probe. The measurement frequency was bi-weekly in the first 6 years and sporadic thereafter. The measurement depths were every 15 cm, starting at the 15-cm depth. In lysimeters containing silt loam layers, measurements were not made below the silt loam-sand interface. In FY 1999, the two lysimeters containing dune sand were instrumented with time-domain-reflectometry probes that coincided with neutron probe measurement depths. Water contents were not measured in the sideslope treatments or in the clear tube lysimeters.

Water Storage. Water storage was measured directly in the weighing lysimeters. In the other lysimeters, water storage was calculated by integrating the water content measurements for the entire profile. Water storage was not measured in the sideslope treatments or the clear tube lysimeters.

Matric Potential. Matric potential was measured intermittently with tensiometers and a pressure transducer. In most lysimeters, two depths were monitored: 100 and 150 cm. In the dune sand treatment, an additional tensiometer was placed at the 210-cm depth. Thermocouple psychrometers were placed in several lysimeters and read independently of the regular data logger program. Matric potential was not measured in the sideslope treatments or the clear tube lysimeters.

Soil Temperature. Soil temperature was measured with copper-constantan thermocouples placed at various depths and lateral positions within the lysimeters. The temperatures were measured hourly in some cases, but mostly daily, all by the data logger system. Soil temperature was not measured in the sideslope treatments or the clear tube lysimeters.

Drainage. Drainage was measured by collecting free water from the outlet located at the base of each lysimeter. The collected water was weighed immediately at the facility. The nominal collection frequency was bi-weekly. Drainage was measured in all lysimeters.

Vegetation. Field observations were used to characterize the phenology of species during the spring of 1988, which was the first growing season. In 1989 and 1992, the height, width, and areal coverage of plants were measured. Minirhizotrons were installed in several lysimeters to monitor root growth. The minirhizotrons, which were 5-cm inside diameter glass cylinders, permitted video camera observations of root activity and location. Monthly observations of plant activity were initiated in November 1998. Each lysimeter is surveyed to identify the species present and their areal coverage, and the height of shrubs.

A.4 Results

The FLTF has been operated for more than 11 years and, in that time, yielded significant quantities of data. Examples are presented below that illustrate the type of data collected since it was constructed in 1987. Following the data examples is a synthesis of observations relative to the potential for drainage in each of the eleven tests described in Section 2. Finally, the results are discussed relative to unresolved issues and future activities.

A.4.1 Data Examples

A.4.1.1 Weather

Figure A.3 shows that monthly average air temperatures for the period of FLTF operation (defined as November 1987 to March 1999) have been consistently higher than the temperatures for the period from 1961 to 1990. The averages for the period of FLTF operation were warmer by amounts ranging from

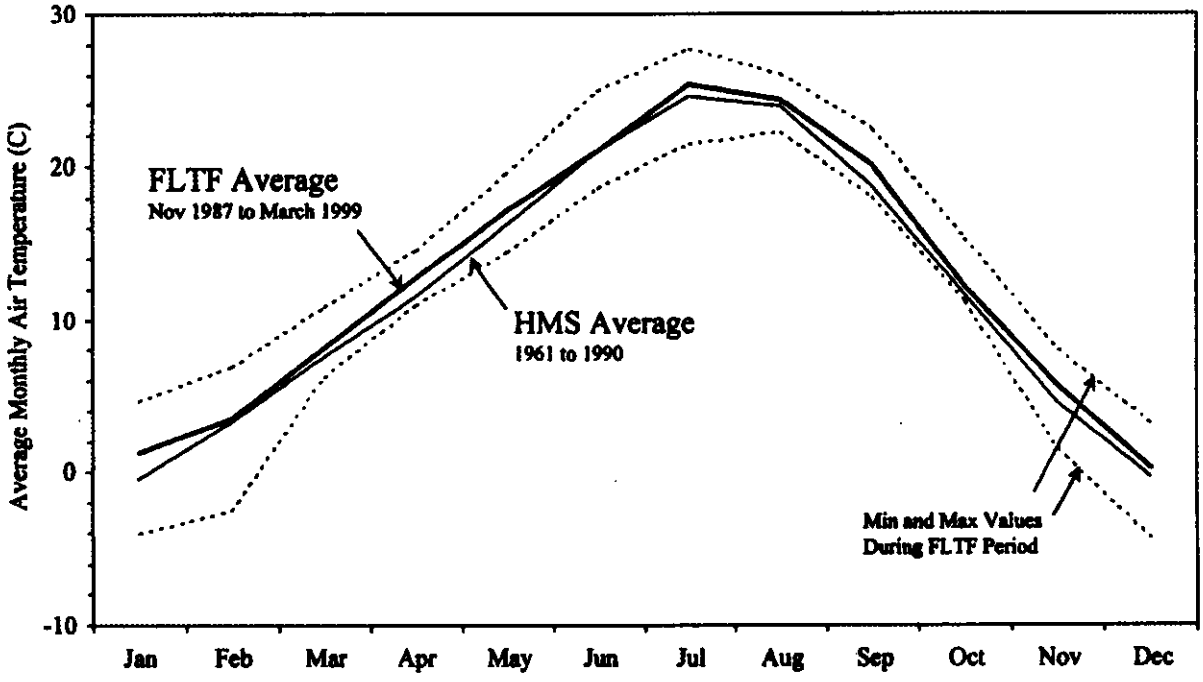


Figure A.3. Monthly Air Temperatures Measured at the HMS

0.1 to 1.7°C. Six monthly records for maximum temperature were either set or tied (one monthly minimum record was also set). Overall, average annual air temperature was 0.8°C warmer than the average temperature from 1961 to 1990.

Figure A.4 shows that monthly precipitation amounts were mostly higher than normal amounts. During the FLTF period of operation, monthly amounts ranged from 2.7 mm less than normal to 6.8 mm greater. Four maximum monthly precipitation records were set. The maximum annual precipitation record of 313 mm was set in 1995. This record was nearly broken in the following year when annual precipitation totaled 310 mm. During the FLTF period, two records for maximum monthly snowfall were set: 57.4 cm in December 1996 and 43.2 cm in February 1989. The annual snowfall record of 142.5 cm was set during the winter of 1992-1993. During the FLTF period, the annual average precipitation was 191 mm, which was 30 mm greater than the 1961 through 1990 average of 161 mm.

A.4.1.2 Irrigation

Figure A.5 shows that the irrigation applications were sufficient to maintain the target rate in most years. Deviations occurred during lysimeter modifications, when it was not possible to run the system because of open lysimeters and construction material.

A.4.1.3 Water Content

Figure A.6 shows how water content varied annually in the Hanford Barrier for the driest condition (lysimeter D4, with ambient precipitation and vegetation) and the wettest condition (lysimeter D10, with irrigation but without vegetation). Water content in D4 was initially high (between 0.15 and 0.2 cm^3/cm^3)

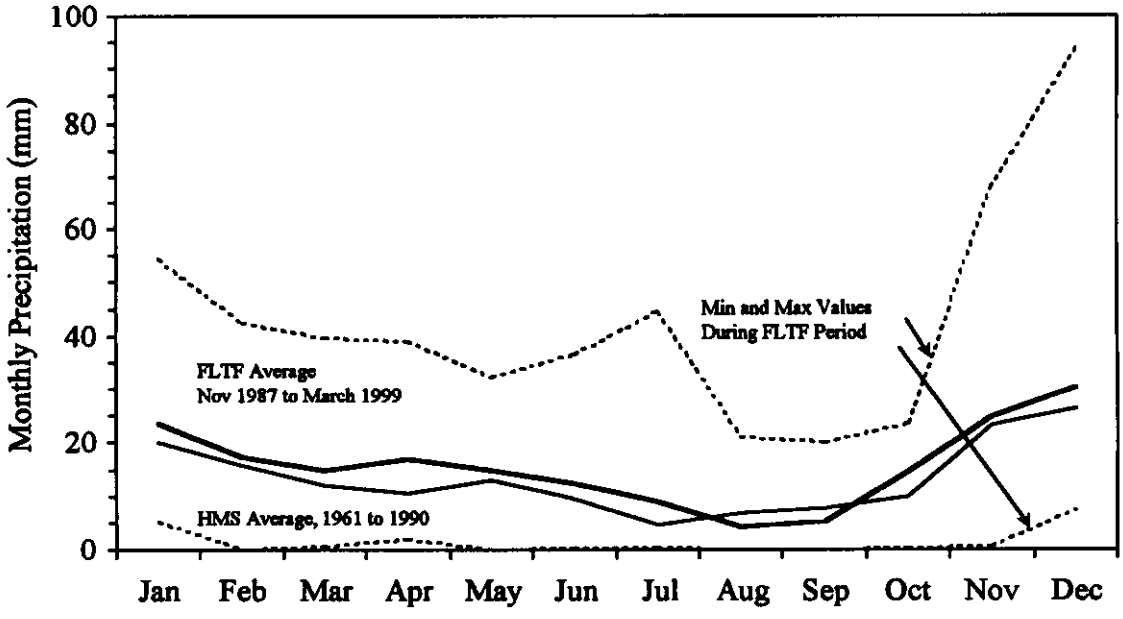


Figure A.4. Monthly Precipitation Measured at the HMS

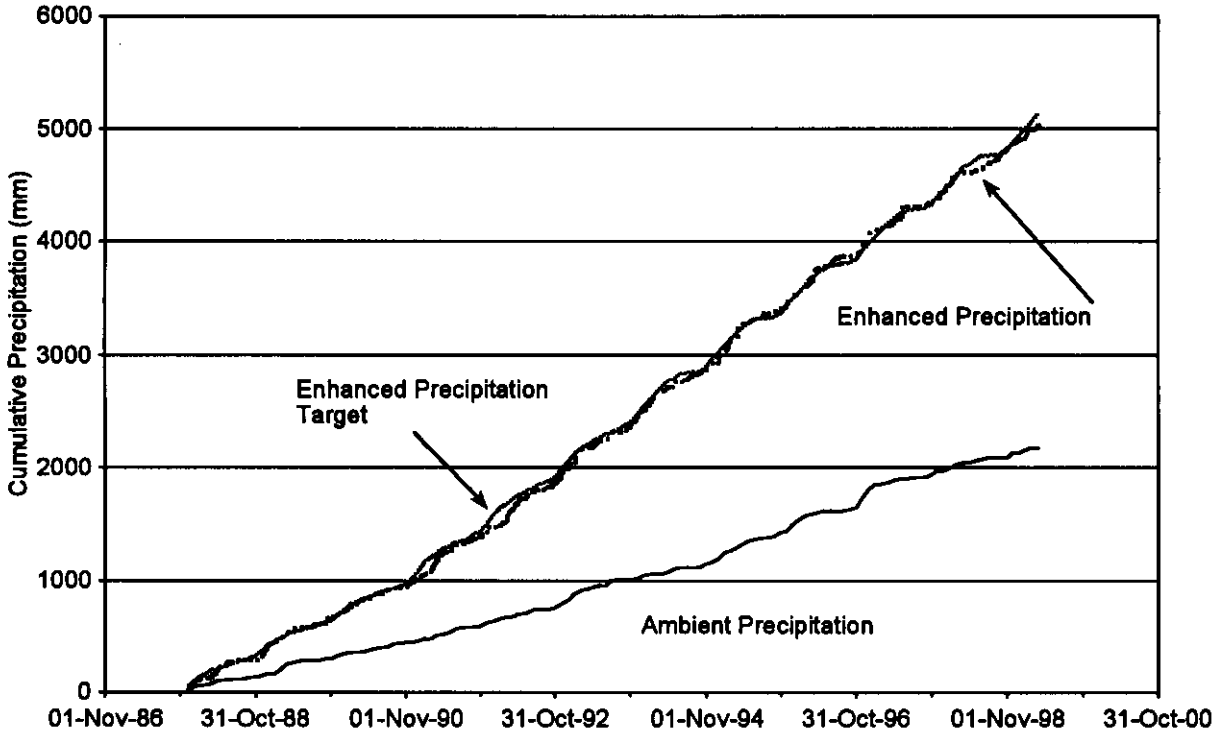


Figure A.5. Precipitation Treatments and the Enhanced Precipitation Target

but quickly dropped to 0.05 to 0.07 cm^3/cm^3 at all depths in the first summer. This rapid drop in water content at all depths demonstrates the ability of plants to extend roots deep into the profile quickly and extract existing water. In subsequent winters, water content increased in the 30- to 60-cm depth range, but hardly changed at all at deeper depths. The winter increases at 30 cm varied year-to-year, giving some indication of the impact of weather variations. In summers, water content always dropped to the same range, about 0.05 to 0.07 cm^3/cm^3 at all depths. This minimum range appears to be the limit to which plants can extract water.

Water content in D10 was much higher than in D4. During the first 3 years, when irrigation raised the water application to 2x normal precipitation, the high water content in winter ranged from 0.22 to 0.33 cm^3/cm^3. When irrigation was increased to achieve 3x normal precipitation, the high water content in winter ranged from 0.25 to 0.42 cm^3/cm^3. Theoretically, the distribution of water received in each year was the same. However, water content in D10 shows distinct differences from year to year. These differences may be related to several factors, including variations in weather (e.g., warm versus cool spring) changes in vegetation, and responses to irrigation (for some months, ambient precipitation was high and obviated the need for irrigation). Another factor could be the irrigation schedule. Our goal was to apply water each month so that the total amount of water received was consistent with the target (either 2 or 3x the normal monthly precipitation). As mentioned earlier, we were not able to do so consistently.

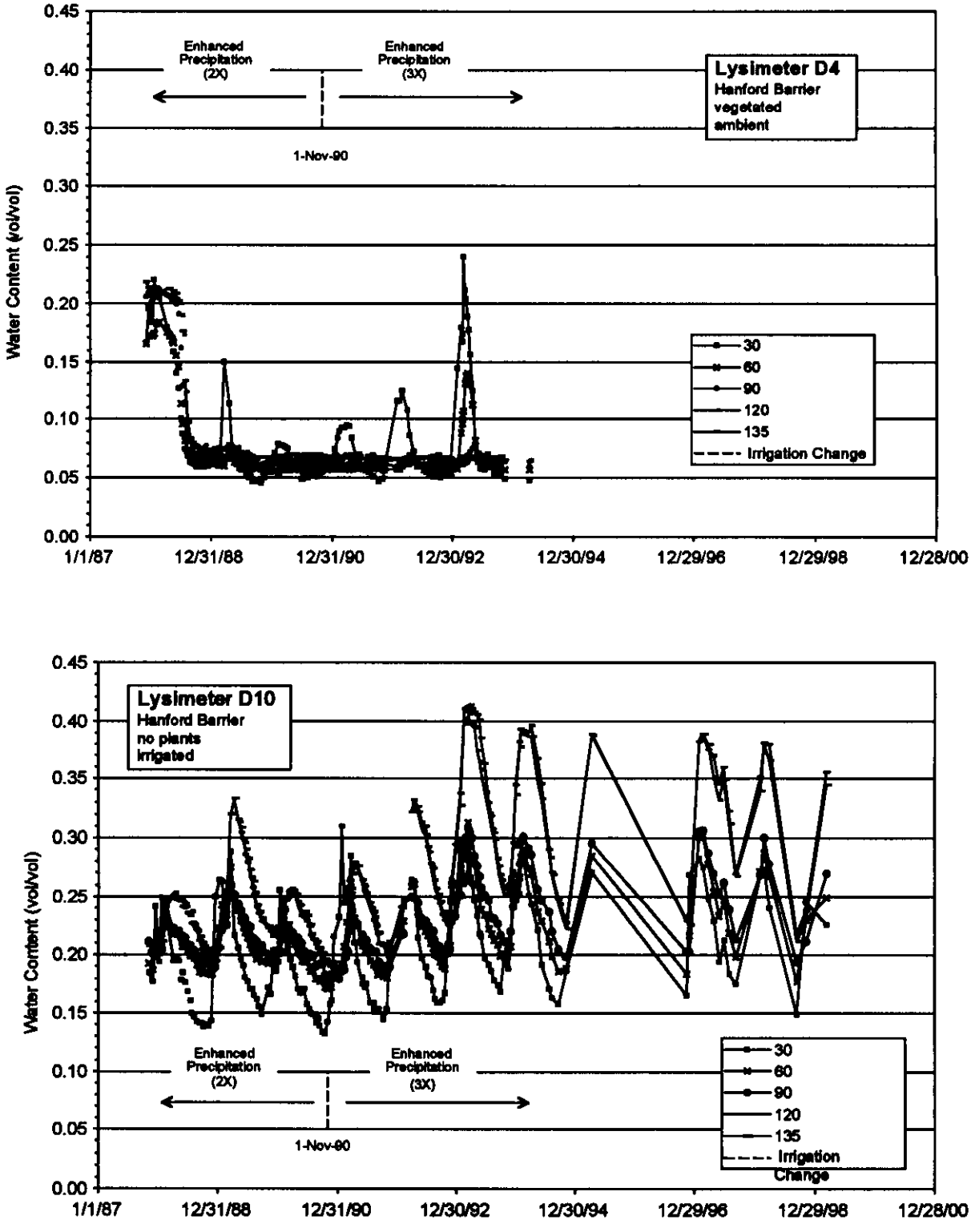


Figure A.6. Annual Water Content Variations for Several Depths Within the Hanford Barrier

Water content in D10 during the summer months was as low as 0.14 cm^3/cm^3 at the shallower depths. In the first three summers, the water content appeared to persist for a month or two before rising in the fall. This low water content may represent a minimum value that the evaporation process can accomplish under the enhanced precipitation regime. At the deeper depths, water content rarely dropped below 0.2 cm^3/cm^3 in the summer.

A.4.1.4 Water Storage

Figure A.7 shows how water storage varied annually in the Hanford Barrier for the driest condition (lysimeter W1, with ambient precipitation and vegetation) and the wettest condition (lysimeter W4, with irrigation but without vegetation). More than 200 mm of water was removed in the first year, which reduced storage to a minimum of about 100 mm. After the first year, winter water storage was never as high as the initial storage, indicating that W1 started much wetter than could be sustained by ambient conditions. In the summers, storage always returned to a consistent minimum of about 80 mm.

In contrast to W1, much more water was stored in W4. Under 2x precipitation, the peak water storage was 450 mm, and under 3x precipitation, the peak was 590 mm. Despite attempts to replicate the same precipitation regime each year, water storage in W4 showed distinct year-to-year differences, probably for the same reasons outlined above for water content. In summers, water storage never reached a recognizable minimum value, indicating that the lysimeter continued to lose water all summer.

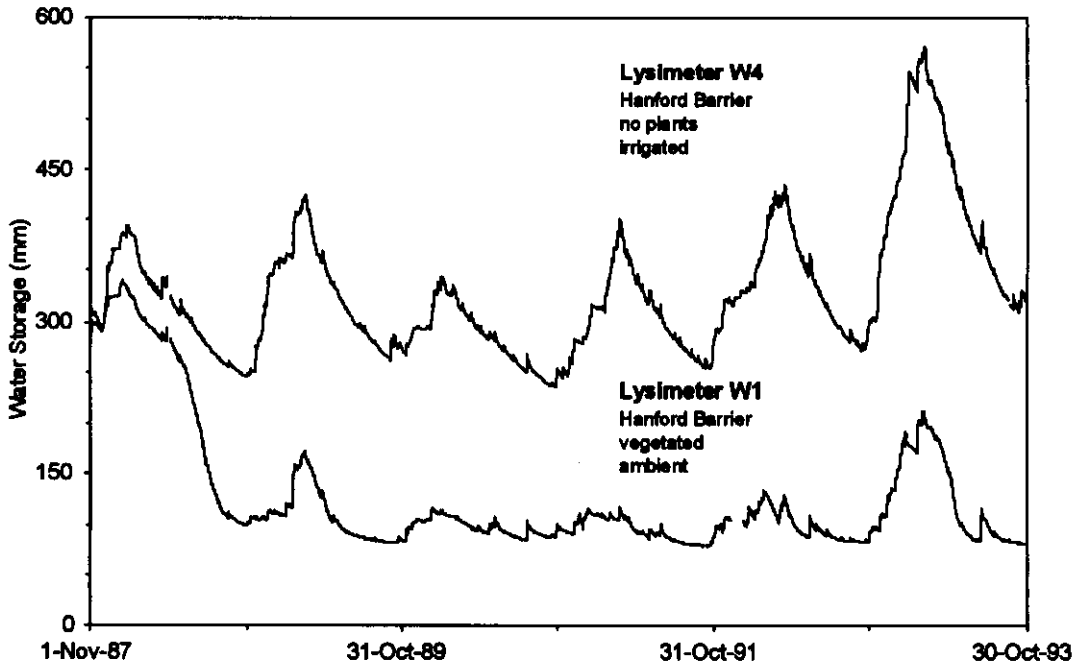


Figure A.7. Daily Water Storage for the Hanford Barrier

A.4.1.5 Matric Potential

Only a few lysimeters had matric potentials high enough to measure with a tensiometer. For these, Figure A.8 shows that potentials at the 150-cm depth were quite consistent from 1995 through 1997. In November 1997, D12 and W4 were modified: 20 cm of silt loam was removed and replaced with 20 cm of dune sand (treatment No. 20). In the following summer, potentials in D10 dropped as in previous years, but potentials in D12 and W4 remained above -100 cm. All three lysimeters were mostly unvegetated, so the contrast in potentials is due primarily to the impact of the surface soil. The dune sand is much less able than the silt loam to store water near, and/or transmit water to, the evaporation surface. These lysimeters were intended to be unvegetated in 1998, but tumbleweeds invaded all three lysimeters and grew to a height of 30 cm in a 1-month period before being removed in May. The results can be seen in Figure A.8 as the rapid drop in matric potentials in the spring of 1998.

Thermocouple psychrometers were placed in several lysimeters, but data from only five of these sensors were reported for a single date, October 22, 1989 (Campbell and Gee 1990). For one of the three psychrometers at the 150-cm depth in W2 and W4, the matric potentials were -0.6 and -0.9 MPa, respectively. For the three psychrometers at the 150-cm depth in W3, the matric potentials were -2.1, -2.5, and -3.1 MPa. These data clearly show the ability of plants in W3 to extract water and reduce the soil water matric potential. Differences among the three potentials in W3 also give an indication of the variability that is possible over a very short distance (< 1.2 m).

In addition to tensiometers and psychrometers, some soil samples were collected and analyzed for matric potential using the filter paper method (Gee et al. 1993a). Samples were collected from six depths

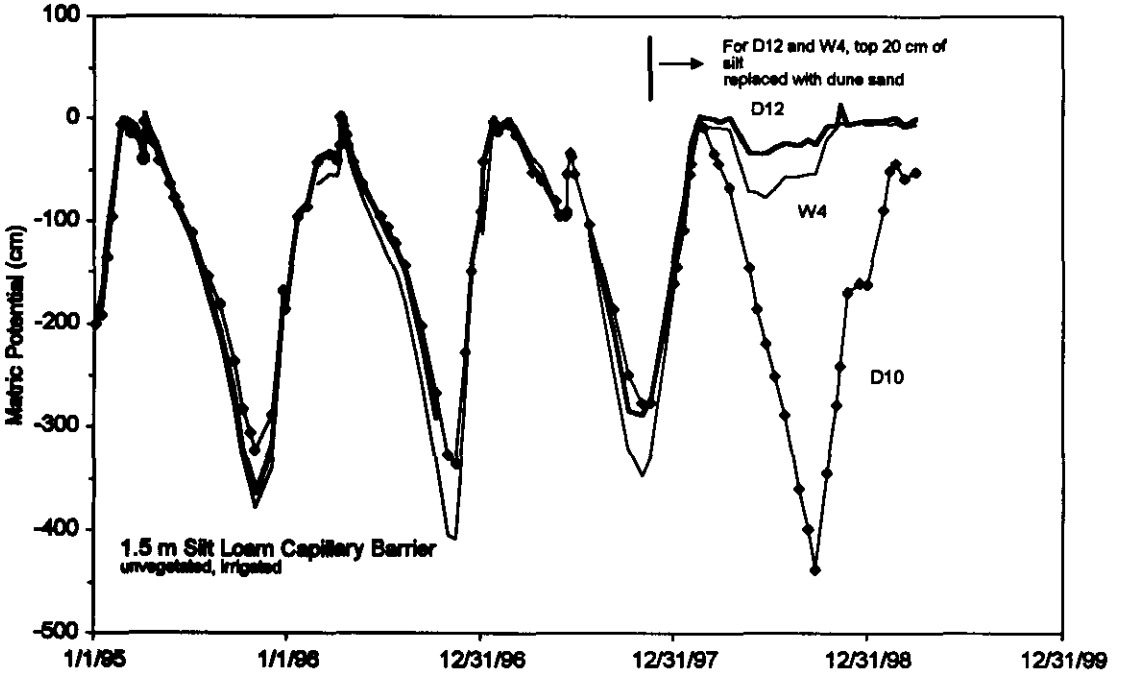


Figure A.8. Matric Potentials at the 150-cm Depth in the Irrigated Hanford Barrier with No Plants

(0.5, 1, 5, 10, 15, and 20 cm) in six lysimeters on three dates in October 1991 and two dates in July 1992. The results showed that matric potentials at the soil surface were lower than -100 MPa in all treatments examined; the absolute minimum potential observed was -210 MPa. At the 20-cm depth, the matric potentials in the unvegetated lysimeters were nearly all less than -1.4 MPa, regardless of precipitation treatment. Potentials in the vegetated lysimeters ranged from -1.8 to -48.8 MPa under ambient precipitation and -5.7 to -14.7 MPa under enhanced precipitation.

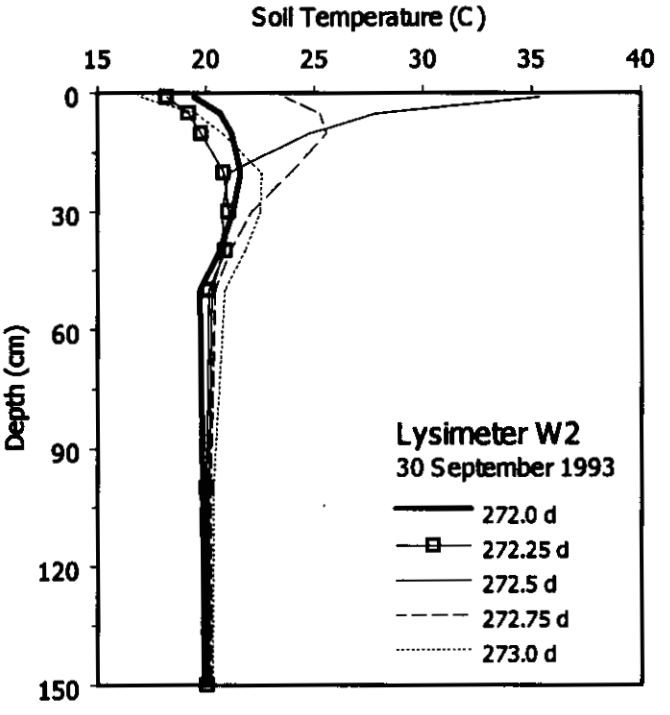
A.4.1.6 Temperature

Hourly soil temperatures were recorded for the thermocouples in the weighing lysimeters and in some of the drainage lysimeters. Figure A.9 shows how temperature varied with depth and time in W2 on September 30, 1993. The response in Figure A.9 is typical of soil temperatures. Near-surface temperatures exhibit the largest temperature range whereas deep temperatures barely change in a day. The progression of the temperature pulse through the soil is delayed and the peak is damped relative to the pulse at the soil surface. The result of the delay and damping is that temperature at the 150-cm depth has a seasonal rather than daily cycle.

A.4.1.7 Drainage

Since the fall of 1989, all of the lysimeters containing vegetated Hanford Barrier treatments had no drainage, even under the 3x precipitation treatment. We did not include 1987 and 1988 because of the leak tests (Campbell and Gee 1990), which we could not separate from actual drainage. Through September 1989, two of the vegetated lysimeters drained less than 0.1 kg in 1989, but we suspect this was residual water from leak testing conducted in 1988. In the 10 years since then, no water has drained from vegetated Hanford Barrier lysimeters. The drainage design specification for the Hanford Barrier was to limit drainage to less than 0.5 mm/yr. The FLTF observations are strong evidence that the Hanford Barrier design functions much better than designed.

Between 1989 and 1999, the two drainage caissons (D1 and D8) containing the unvegetated Hanford Barrier test that received ambient precipitation drained an average of 0.05 and 0.2 mm/yr. The drainage always occurred in mid to late summer and was attributed to vapor flow (Campbell and Gee 1990). Figure A.10 shows how the annual drainage amounts for lysimeters D1 and D8 varied. A similar seasonal drainage pattern was observed prior to 1993 in the two drainage caissons containing the unvegetated Hanford Barrier that received enhanced precipitation. Results from these lysimeters are also included in Figure A.10. Two questions arise from these results. First, does the drainage water originate from the basalt riprap and gravel (i.e., residual water from construction and leak testing) or from the silt loam layer above? Second, if seasonal temperature changes are affecting drainage, is the design of the lysimeter facility in any way responsible? Ward et al. (1997) reported "small seasonal discharges" from the Hanford Prototype Barrier test plots. These vegetated test plots were in a full-scale surface cover; thus avoiding any complications such as might be possible in the FLTF. Their data set covered 3 years of monitoring following construction. If they continue to occur during the next several years, the seasonal discharges will provide strong evidence that temperature cycles in the silt loam layer induce water movement into the underlying gravel.



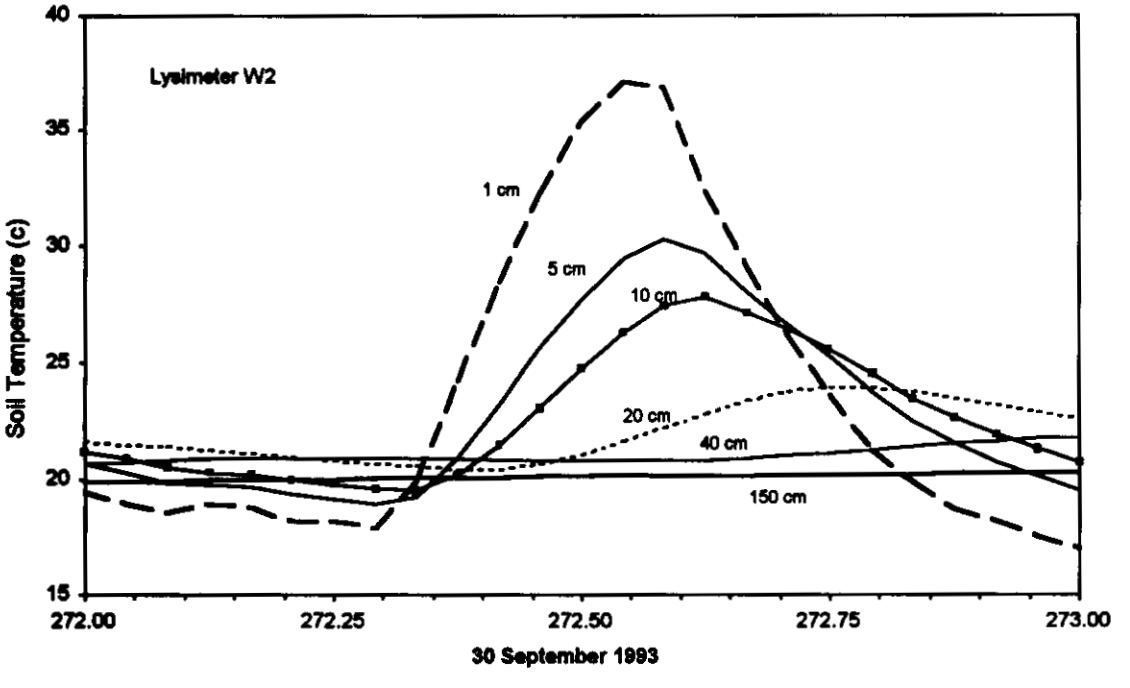


Figure A.9. Soil Temperatures

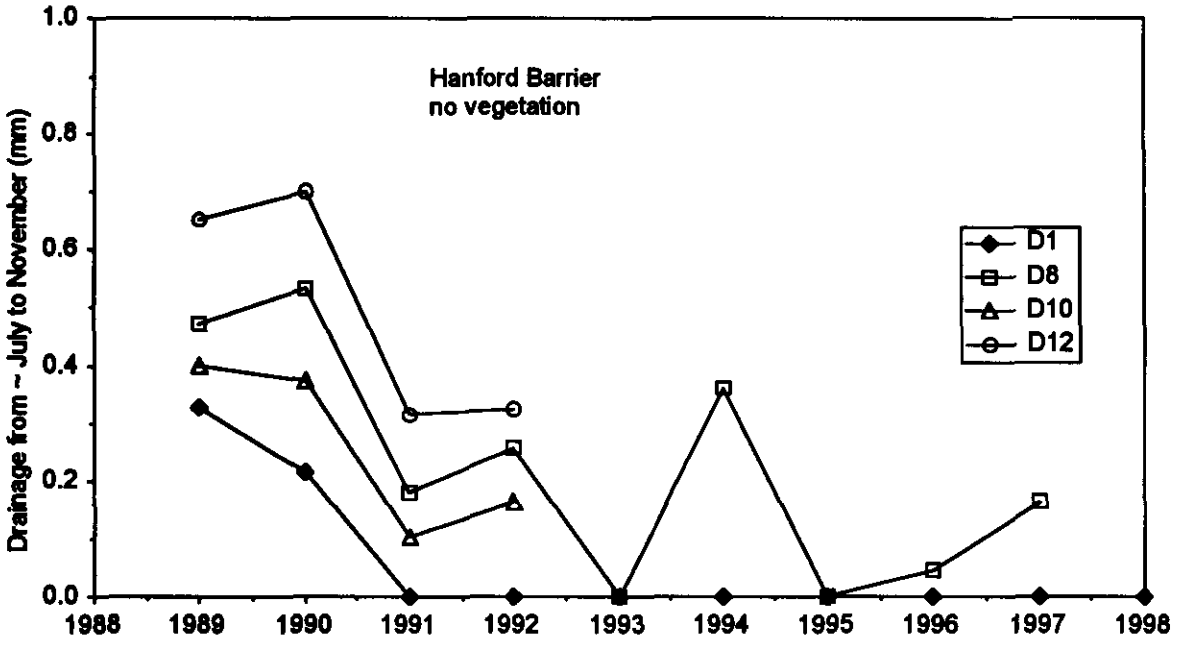


Figure A.10. Annual Drainage from the Lysimeters Containing the Unvegetated Hanford Barrier

The four weighing lysimeters, containing the Hanford Barrier test, had zero drainage. In these lysimeters, there is no coarse gravel or basalt layer within which vapor could move downward and condense at greater depths. A complicating factor is that these lysimeters are susceptible to unusual temperature changes. They have an air gap along the sides (to allow free movement up and down on the scale) and their bottoms are somewhat "de-coupled" from the ground temperature because of the scale.

The only condition that led to significant drainage from a Hanford Barrier treatment was 3x precipitation and no vegetation. Figure A.11 shows that, for the first 3 years (under 2x precipitation), the three lysimeters containing an unvegetated Hanford Barrier had no significant drainage. Three years after increasing to 3x precipitation, these lysimeters had significant drainage. The onset of drainage coincided with the melting of a large snowpack in February 1993. In early 1997, a similar event occurred that also resulted in significant drainage from these lysimeters. In the intervening years, and in 1998, individual lysimeters had small amounts of drainage, but there was no consistency in amount. Such differences indicate the drainage variability that could be expected in a real cover.

After D12 and W4 were modified in November 1998, the drainage pattern of the three lysimeters diverged. D10 continued to have very little drainage, while D12 and W4 began to have more drainage than was collected in all of the previous years combined. The increase in drainage resulted from the replacement of 20 cm of silt loam with dune sand on the surface. This result is consistent with the observed increase in matric potential in D12 and W4.

Figure A.12 shows that drainage from the sideslope treatments was consistently significant in every year. The sandy gravel lysimeters drained 536 mm under ambient precipitation (992 mm) and 1424 mm

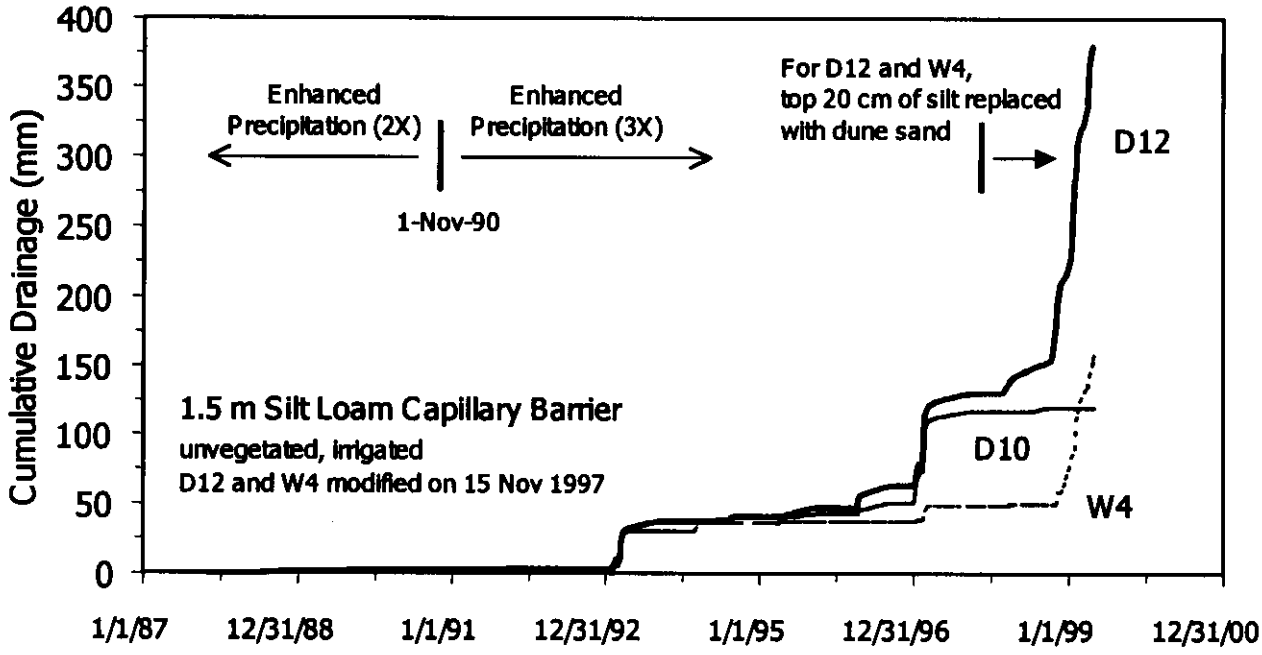


Figure A.11. Cumulative Drainage from Irrigated Lysimeters Containing the Unvegetated Hanford Barrier

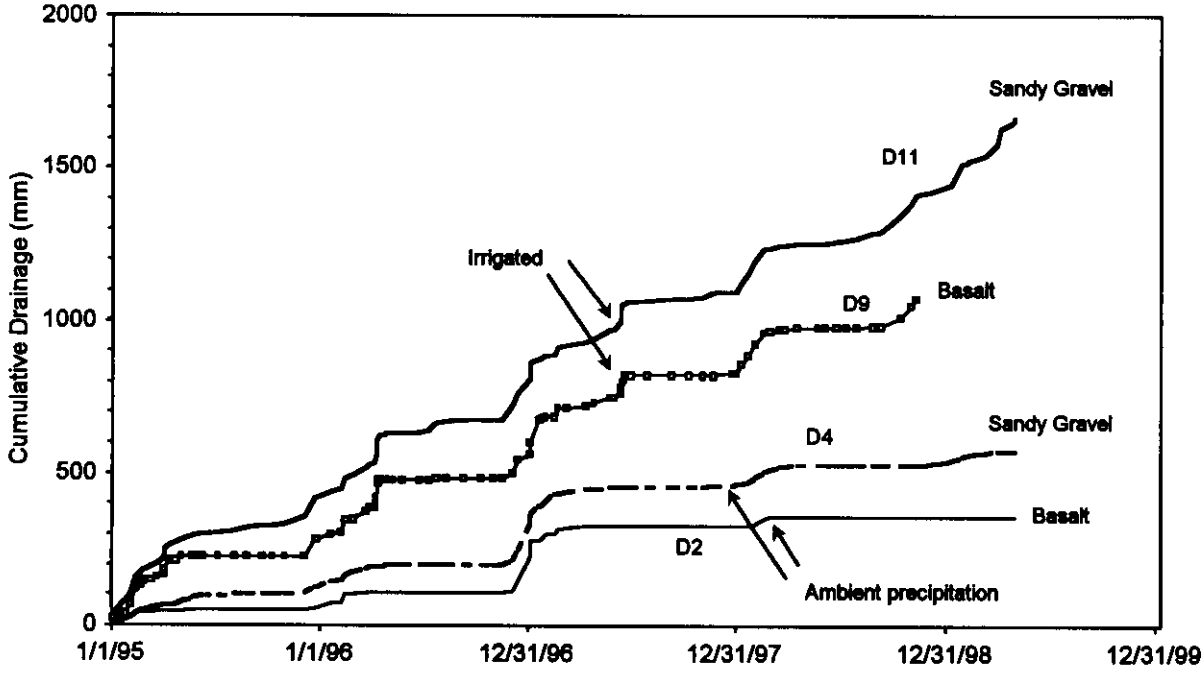


Figure A.12. Cumulative Drainage from the Lysimeters Containing Sideslope Tests

under enhanced precipitation (1978 mm) from mid-November 1994 through 1998. For the 4.1-year period, the average drainage rates were 130 and 345 mm/yr, respectively. These rates represent 54% of the amount of water received under ambient conditions and 72% under enhanced precipitation. The level of ambient precipitation received during this time was 48% higher than normal. It may be that, if precipitation rates subside to more-normal levels, the percentage that becomes drainage may fall to something less than 54%. If the percentage remained the same, then the drainage rate associated with the normal precipitation (160 mm/yr) would be 86.4 mm/yr. This rate could also be applied to conditions at the tank farms in the 200 Areas. The precise value for each tank farm would depend on the distribution of sand and gravel on the surface. In addition, this rate does not account for any effects caused by the increased temperature around the tanks.

The higher percentage (of precipitation becoming drainage) for the enhanced precipitation treatment may truly reflect what could happen under wetter regimes. It may also be related to the method of applying irrigation water. With this method, 10 to 20 mm of irrigation water were applied in a single event rather than as more numerous smaller events. Large events may penetrate the profile more deeply, where the water would be less susceptible to evaporation.

Under both precipitation regimes, the basalt sideslope had less drainage and, in some years, had no drainage. These lysimeters drained 357 mm under ambient precipitation and 1051 mm under enhanced precipitation from mid-November 1994 through 1998. For the 4.1-year period, the average drainage rates were 87.1 and 256 mm/yr, respectively. These rates represent 36% of the amount of water received under ambient conditions and 53% under enhanced precipitation. For the long-term average precipitation rate of 160 mm/yr, the basalt drainage data translate to a long-term drainage rate of 57.6 mm/yr.

One theory why drainage rates through basalt riprap are lower than those through sandy gravel is that the voids between the basalt fragments are so large. Significant amounts of air can move in and out of these large voids and thus effectively extend the drying region deeper into the profile than is normal for soil (Ward et al. 1997). Another factor at the FLTF is the design of the test. The lysimeters containing the sideslope treatments have an asphaltic concrete layer at 1.5 m. On top of this layer is about 2 to 3 cm of silt loam within which was embedded a 2.54-cm outside diameter fiberglass wick. The wick was splayed out within the silt loam to maximize contact, but exited through the drain outlet as one piece. We had some difficulty with this arrangement. First, the wick was jammed as it passed through the outlet and we believe this restricted drainage from the lysimeter. By delaying drainage, water was left standing in the caisson and susceptible to evaporation. Second, the silt loam has a fair amount of storage capacity. Water stored in this layer would not have drained through the wick when potentials dropped below -20 cm. This stored water would also be susceptible to evaporation.

Figure A.13 shows that there was significant drainage from four of the clear tube lysimeters, the two with pitrun sand and the two with gravel mulch. The clear tube lysimeters containing the Hanford Barrier configuration (C3 and C6) never had drainage. The pitrun sand lysimeters had drainage in some but not all years. Although the lysimeters are vegetated, the plants were unable to prevent drainage. From February 8, 1990, through February 11, 1998, drainage rates averaged 23.6 and 52.4 mm/yr for the ambient (C2) and enhanced precipitation (C5) treatments, respectively. These drainage rates represented 12 and 11%, respectively, of the total amount of precipitation and irrigation received from 1990 to 1998.

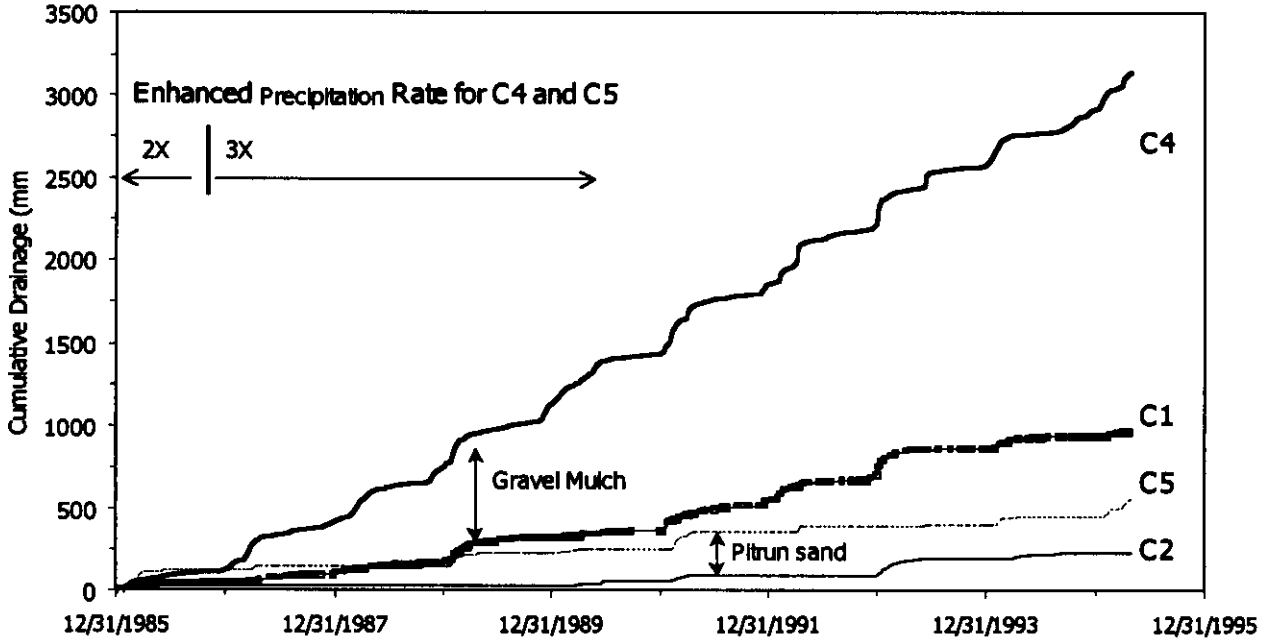


Figure A.13. Cumulative Drainage from the Clear Tube Lysimeters

Figure A.13 shows that the gravel mulch lysimeters had much more drainage than the pitrun sand lysimeters. From February 8, 1990, through February 11, 1998, drainage rates averaged 104 and 332 mm/yr for the ambient (C1) and enhanced precipitation (C4) treatments, respectively. These drainage rates represented 52 and 72%, respectively, of the total amount of precipitation and irrigation received from 1990 to 1998. Two factors that explain the higher drainage relative to the pitrun sand test are the lack of vegetation and the suppression of evaporation by the gravel mulch. The suppression occurs because water that infiltrates into the sand beneath the gravel can only evaporate by the slow process of diffusion up through the gravel mulch layer. The other mechanism for water to move upward is for water to flow directly in the liquid phase up through the gravel. Such flow is essentially negligible because of the extremely low hydraulic conductivity of unsaturated gravel.

A.4.1.8 Vegetation

Vegetation was planted on the lysimeters in November 1987 for the first three tests. Bunchgrasses and sagebrush seedlings were dug at McGee Ranch, which has a shrub-steppe plant community growing on silt loam (Gee et al. 1989). McGee Ranch was the borrow area for the silt loam that was placed in the lysimeters. Species included *Poa sandbergii* (Sandberg's bluegrass), *Oryzopsis hymenoides* (Indian rice grass), and *Artemisia tridentata* (sagebrush). Although *Bromus tectorum* (cheatgrass) was present at McGee Ranch, no attempt was made to transplant it. Gee et al. (1989) assumed that cheatgrass seed was present in the transplant soil masses as well as in the plant community surrounding the FLTF and that cheatgrass would have no difficulty occupying the lysimeter surfaces.

The record of vegetation measurements and observations is sparse. Phenology observations were made in the spring of 1988 only. Phenological stages were delayed about 1 month relative to stages observed in natural settings, possibly because of the wet initial conditions in the lysimeters (Gee et al. 1989).

In May 1989 and the spring of 1992, individual plant height, width, areal coverage, and location within the lysimeters were measured. The main observation was that irrigation caused significant increases (by a factor of 2 to 3) in total plant biomass. Indian rice grass decreased in all lysimeters between 1989 and 1992 but the cause was never determined (Gee et al. 1993a).

Root behavior was observed with the minirhizotrons and reported only once (Campbell et al. 1990). The data, in the form of root counts, suggested higher root density under the enhanced precipitation treatment.

Root observations were also made using the clear tube lysimeters. Sagebrush roots grew downward through the silt loam in lysimeter C6 at an average rate of 2 cm/d, and sometimes at rates as high as 5 cm/d (Campbell and Gee 1990; Campbell et al. 1990). The downward growth rate may have been a function of the constrained rooting volume because the lysimeter diameter was only 0.3 m. When the roots reached the sand filter layer, they penetrated no more than 1 cm presumably because the sand held very little water. In the sandy soil of lysimeters C2 and C5, the downward root growth rate averaged 1.4 and 0.9 cm/d, respectively. All of these lysimeters were moist prior to transplanting. In lysimeter C3, which was not irrigated, roots grew down to the existing wetting front within the silt loam layer and stopped. The sagebrush on this lysimeter died in 1989 and was not replaced. The hypothesis is that the water available in this small lysimeter was insufficient to support the plant.

The sagebrush on C6 died in 1991, despite receiving the enhanced precipitation treatment. Although cheatgrass remained, lysimeter C6 became noticeably wetter in the next two years. By early 1993, the filter layers and basalt riprap were visibly wet. In March 1993, a sagebrush seedling was planted on C6. By late May, a few roots had penetrated the sand filter layer and entered the gravel filter layers. By late July, a few roots appeared to be at the 2-m depth. These observations indicated that gravel layers are not root impediments, or barriers, as long as water is available (Gee et al. 1993a). Between 1993 and 1998, the sagebrush in C6 died and no attempt was made to plant a replacement.

On four dates in late 1998 and early 1999, the FLTF was surveyed to identify the existing plant species and monitor changes in areal coverage. Sagebrush and Sandberg's bluegrass still remained. Indian rice grass was no longer present. A new species was observed on several lysimeters: *Agropyron cristatum* (crested wheatgrass). Cheatgrass was present on most of the vegetated lysimeters. Individuals of eight other species were present. The most notable of this group was *Salsola kali* (tumbleweed), which has a deeply penetrating taproot that allows the plant to extract water stored deep within the profile.

Since 1987, one of the most difficult tasks in operating the FLTF is maintaining the no-vegetation status of those lysimeters that were supposed to be bare. Our experience has been that these lysimeters must be weeded every two weeks in the spring and monthly during the remainder of the year. On several occasions, a one-month hiatus in weeding during the spring resulted in an extensive crop of plants,

usually tumbleweeds but also sagebrush seedlings, cheatgrass, and other species. The implication is that a non-vegetated condition (e.g., due to fire, disturbance, etc.) will probably not persist for silt loam surface barriers for more than a couple of months, and certainly not for more than 1 year.

A.4.2 Results of the Eleven Tests

We used the FLTF data (primarily the drainage data) to draw conclusions for each of the eleven tests. For the barrier tests, we compared the drainage data to the design standard of 0.5 mm/yr (Wing 1994). For our evaluations, we assumed natural conditions, with no disturbance by humans.

Hanford Barrier. For periods ranging from 6.5 to 11 years, there has been no drainage from the lysimeters containing the Hanford Barrier configuration (1.5 m of silt loam above sand and gravel layers) with plants. For Hanford Barrier lysimeters without plants, there has been no significant drainage (i.e., greater than 0.5 mm/yr) under ambient precipitation and under 3 years of 2x normal precipitation. Drainage from these non-vegetated lysimeters eventually occurred, but only after 3 years of 3x normal precipitation. Based on our experience of keeping these lysimeters plant-free, we predict that Hanford Barriers receiving 3x normal precipitation will not remain plant-free for more than a few months at most. Based on all of the data collected to date, we expect that the Hanford Barrier will perform as designed for the conditions envisioned for the ILAW Disposal Site.

Hanford Barrier with Gravel Admix. The two lysimeters containing this configuration with plants and receiving the ambient precipitation treatment showed no drainage after 6.5 and 10 years, respectively. The gravel admix did not appear to impair the ability of the Hanford Barrier to prevent drainage. We did not see any recognizable differences in plant community compared to the tests without gravel admix. Although there were no treatments involving enhanced precipitation, we expect that a Hanford Barrier with gravel admix and receiving enhanced precipitation will prevent drainage as designed.

Eroded Hanford Barrier. The two lysimeters (containing 1.0 m of silt loam above sand and gravel), with plants, and receiving the ambient precipitation treatment showed no drainage after 10 years. This configuration is similar to the modified RCRA Subtitle C cover. The results suggest that the modified RCRA cover will perform as well. A test of the actual design has been initiated (see below). The single lysimeter receiving the enhanced precipitation treatment was set up and started in May 1998. With a data record less than 1 year long, this test is not complete. However, we expect that it will be just as successful as the ambient treatment in preventing drainage.

Gravel Mulch. The two small lysimeters used for this test generated a significant amount of drainage in 8 years: 104 mm/yr (52% of received water) for the ambient treatment and 332 mm/yr (72% of received water) for the enhanced precipitation treatment. These results may be useful for describing an upper limit to deep drainage in tank farms. The gravel mulch used at the FLTF contains very few finer particles (except what the wind deposits). Tank farms, in contrast, have 50% or more sand particles (Figure 3 of Smoot et al. 1989). Of all the tests, the clean gravel mulch without plants resulted in the highest deep drainage rates.

Pitrun Sand. The two small lysimeters used for this test generated a measurable amount of drainage, although not consistently in every year. In an 8-year period, drainage rates averaged 23.6 mm/yr (12% of received water) for the ambient precipitation treatment and 52.4 mm/yr (11% of received water) for the enhanced precipitation treatment. These lysimeters are vegetated, mostly with grasses. Several attempts were made to establish sagebrush, but the plants did not survive for more than a few years. Thus, these deep drainage results are probably higher than for a similar sand with a shrub-steppe plant community.

Basalt Sideslope. The two lysimeters used for this test generated a significant amount of drainage in 4 years: 87.1 mm/yr (36% of received water) for the ambient treatment and 256 mm/yr (53% of received water) for the enhanced precipitation treatment. As a percentage of total water input, drainage was 36 and 53% for the ambient and enhanced precipitation treatments. These lysimeters had no vegetation, so the drainage rates should be viewed as upper limits. A field-scale test of this sideslope with no vegetation is occurring at the Hanford Prototype. The results after 3 years indicated drainage rates of 22 to 34% of the precipitation (Ward et al. 1997).

Sandy Gravel Sideslope. The two lysimeters used for this test generated a significant amount of drainage in 4 years: 130 mm/yr (54% of received water) for the ambient treatment and 345 mm/yr (72% of received water) for the enhanced precipitation treatment. As a percentage of total water input, drainage was 54 and 72% for the ambient and enhanced precipitation treatments. These lysimeters had no vegetation, so the drainage rates should be viewed as upper limits. A field-scale test of this sideslope, with vegetation (albeit limited), is occurring at the Hanford Prototype. The results after 3 years indicated drainage rates of 20 to 30% of the precipitation (Ward et al. 1997). The lysimeter and Hanford Prototype results may be useful for describing deep drainage in tank farms. However, we have no measure of the particle size distribution of the sandy gravel used in the tests.

Hanford Prototype Barrier. The two lysimeters used for this test had no drainage in 4.5 years, even under 3x normal precipitation. In addition, matric potentials were always below the tensiometer range, indicating dry soil. We expect that the Hanford Prototype Barrier will perform as designed for the conditions envisioned for the ILAW Disposal Site.

Hanford Barrier Erosion/Dune Sand Deposition. The four lysimeters used for this test have been monitored for 1.5 years. The matric potential data indicate that the silt loam is wetting under both precipitation treatments. Drainage has not occurred for the ambient precipitation, but has been significant for the 3x normal precipitation treatment. After 1 to 2 more years, we suspect that drainage may begin from the ambient treatment. Vegetation on the lysimeters is limited to shallow-rooted species, primarily cheatgrass. The combination of dune sand and cheatgrass was intended to mimic a serious but plausible degradation of the cover. In the first year, the cheatgrass cover was not measured because it was sparse to non-existent. By November 6, 1998, one year after the test began, there was no live cheatgrass on D5 and 25% coverage on D12. Because of the limited cheatgrass cover during the first year, the drainage results may more accurately be said to reflect an unvegetated state. Cheatgrass was much more prevalent in spring 1999. It may be that several years are required for vegetation to establish itself in the lysimeters of this test. Till then, we make no predictions except to say that sand deposition on a surface cover has the potential to degrade performance relative to preventing drainage.

Sand Dune Migration. The two lysimeters used for this test were started in July 1998, so the length of record is short. By March 31, 1999, no drainage had occurred from the lysimeter receiving ambient precipitation. However, the lysimeter receiving 3x normal precipitation already generated significant drainage. Like the erosion/deposition test above, vegetation is supposed to be shallow-rooted species like cheatgrass. However, plant activity was marginal, so the results are more nearly like an unvegetated test. It may be that several years are required for shallow-rooted vegetation to establish itself. Till then, we make no predictions except to say that a sand dune on a surface cover has the potential to degrade surface cover performance (relative to preventing drainage) and to increase recharge rates in the immediate vicinity of the cover.

Modified RCRA Subtitle C Cover. The two lysimeters used for this test were started in February 1999. It will take several years of data to reach conclusions, but we expect that this cover will perform as designed for the conditions envisioned for the ILAW Disposal Site.

A.5 Conclusions

The data collected at the FLTF have shown how soil type, barrier design, vegetation, and precipitation can impact deep drainage rates. One of the significant results from the FLTF is that the Hanford Barrier described by Wing (1994) worked much more successfully than expected. In concert with vegetation, the barrier reduced drainage to zero (compared to the design goal of 0.5 mm/yr). This performance occurred under ambient and 2x precipitation, with or without plants. Even under 3x precipitation, the vegetated Hanford Barrier prevented drainage. The only condition that resulted in drainage through a Hanford Barrier was when plants were purposefully kept off for three consecutive years under 3x precipitation. All indications are that plants will never be absent for more than a few months and that precipitation will not exceed 128% of modern levels, which is far below the 3x precipitation rate that caused drainage.

A second barrier design, the Hanford Prototype Barrier, also reduced drainage to zero. Data are just starting to be collected for a third design, the Modified RCRA Subtitle C barrier. Two lysimeters with a similar design (i.e., 1 m of silt loam) had zero drainage in 10 years under ambient precipitation conditions. Therefore, we expect the modified RCRA Subtitle C design will work just as well at preventing drainage.

The addition of gravel admix to the surface silt loam layer of the Hanford Barrier did not impact barrier performance, nor did the loss of 0.5 m of silt to erosion. In both cases, there was no drainage. The dune sand test is beginning to show an increase in water storage. Although the length of record is short and there is already measurable drainage under the 3x precipitation treatment. The lysimeters in this test had a sparse cover of shallow-rooted cheatgrass and none of the deep-rooted plants of a shrub-steppe community that might reduce drainage considerably. Without a deep-rooted shrub-steppe plant community, deposition of wind-blown sand on the cover is a concern.

The sideslope tests showed how poorly these materials prevented drainage. The sandy gravel material drained 54% of the ambient precipitation, while the basalt drained 36%. These tests were not vegetated, so the results represent an upper limit to drainage through such sideslopes.

Because the cover systems performed much better than the design goal of 0.5 mm/yr, we propose using a rate of 0.1 mm/yr for the 2001 ILAW PA. The data clearly support this lower rate. We would have proposed a lower rate if we understood the seasonal drainage observations more fully. The possibility of seasonal water vapor movement downward from the surface cover indicates a need to understand the temperature effects.

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Appendix B

Recharge Estimates Using Environmental Tracers at the Immobilized Low-Activity Waste (ILAW) Disposal Site

E. Murphy and J. Phillips

Appendix B

Recharge Estimates Using Environmental Tracers at the Immobilized Low-Activity Waste (ILAW) Disposal Site

B.1 Introduction

This appendix summarizes the analyses of sediments collected from boreholes located in the 200 East Area of the Hanford Site for tracer measurements. This area is a proposed location for the burial of low-level waste encapsulated in glass and is referred to as the Immobilized Low-Activity Waste (ILAW) Site (Figure B.1). In this area, vegetation and, to a lesser degree, heterogeneity in the stratigraphy control the downward movement of water.

Naturally deposited atmospheric tracers were used to determine the rate of water movement through the vadose zone. The natural tracer method based on chloride mass balance (CMB) is one of the simplest, least expensive, and most useful for determining long-term recharge in arid climates (Allison et al. 1994). Recharge is often used interchangeably with deep drainage flux. Technically, recharge is the amount of water over time reaching the water table. Deep drainage flux is the water flux below the evapotranspiration zone, or alternatively, the water flux at a point where the chloride concentration is measured (Phillips 1994). Using the CMB method, recharge is determined by applying a mass balance argument on the

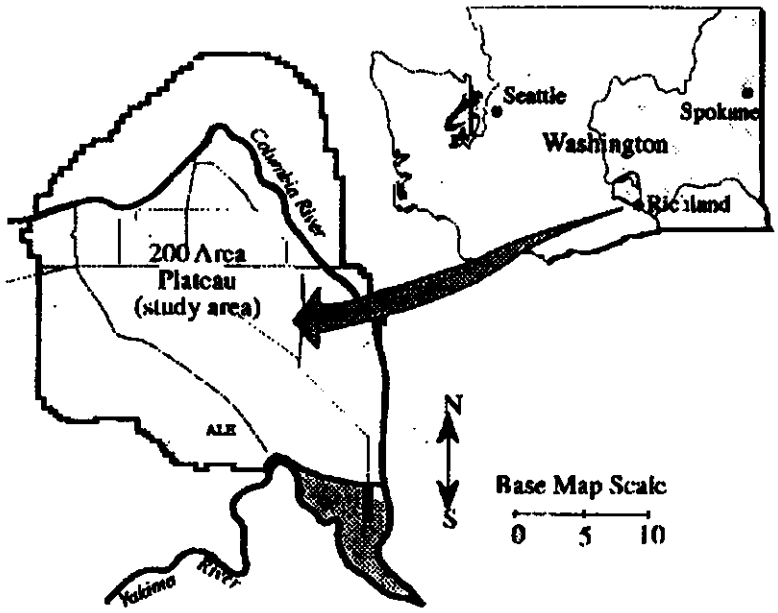


Figure B.1. Washington State Map and Location of Study Area at the Hanford Site

chloride ion in which the difference between the chloride concentration in the soil water and the atmospheric input concentration is due to evapotranspirative enrichment.

Environmental tracers give site-specific estimates of deep drainage flux below the evapotranspiration zone. Therefore, this technique is ideal for investigating the effect of spatial variations in vegetation and stratigraphy on recharge. At the proposed ILAW Disposal Site, spatial variations in vegetation and stratigraphy can occur at distances ranging from a meter to tens of meters. Interpretation of chloride profiles at the proposed ILAW Disposal Site suggests that prior to the establishment of a dense sagebrush community, atmospheric tracers such as chloride did not accumulate in the sediment profiles. This indicates rapid water flux through these medium sand sediments. The impact of vegetation and its absence have been demonstrated elsewhere (e.g., Allison 1988). Stratigraphy, in particular the occurrence of silt lenses, impacted the spatial distribution of moisture content across the proposed ILAW Disposal Site. Variations in peak concentrations of chloride in the different boreholes suggest differences in the history of vegetative establishment during the Holocene.

In this appendix we compare information from two exploratory boreholes drilled in 1995, a trench dug in 1995, and four boreholes (B8500 series) drilled in 1998. The objectives of the exploratory drilling in 1995 were to demonstrate the feasibility of collecting continuous cores in these largely sandy sediments and to determine the location of the chloride profiles for recharge estimates. Large volume samples were collected from the trench to develop a profile for the bomb-pulse tracer ^{36}Cl. An additional objective of the sampling at the B8500 boreholes in 1998 was to provide estimates of natural recharge using tracer methods and to assess the variability in recharge rates across the proposed ILAW Disposal Site.

The application of tracer methods ideally requires the collection and analysis of continuous cores from the surface to below the root zone (approximately to a depth of 15 m at the proposed ILAW Disposal Site). Nearly continuous cores were collected at two previously undisturbed sites in March 1995 using a hollow stem auger with split-tube wire-line sampling. In September 1995, a trench was dug south of the exploratory boreholes to a maximum depth of approximately 5 m. In the spring of 1998, one deep borehole (B8500, also designated 299-E17-21) and two shallow boreholes (B8501 and B8502) were drilled near the proposed ILAW Disposal Site. Unlike previous exploratory drilling in 1995, the drilling for the B8500 series boreholes was not controlled by the researchers who were collecting the data. As a result, many of the standard drilling procedures at the Hanford Site conflicted with or negated the research goals. This impact was most severe on the investigation into recharge mechanisms that are largely controlled by near-surface processes.

Core sediments were not collected above 3 m at B8500, which precludes this borehole being used to estimate recharge with atmospheric tracers. Near-continuous sediment cores were collected from B8501 and B8502. Preliminary results indicate that the near-surface recharge processes at B8501 may have been affected by disturbances associated with the construction of a drilling pad and the standard practice of drilling *through* the gravel pad (as opposed to drilling off the side of the pad in undisturbed sediments). In addition, some of the sediment cores from B8502 were affected at the drill site by storage in ice chests containing standing water. In some cases a wetting front was observed in the core sediment. In other cases, droplets of water were found between the Lexan liner and the duct tape that was used to seal the

ends of the cores. It cannot be determined whether the highly variable moisture profiles at the shallow holes are 1) natural, 2) an artifact of the drilling pad, or 3) lack of end caps and blue ice for sealing and storing the cores. However, in some profiles there is a distinct correlation between increased moisture content and the spatial distribution of silt lenses.

The problems associated with drilling the B8500 boreholes limit the information that can be used from these cores. Except for borehole B8503, which was drilled in undisturbed sediments, the moisture profiles, sediment characterization, and bulk densities should be disregarded in the upper 2 to 3 m of the B8500 boreholes.

B.2 Site Description

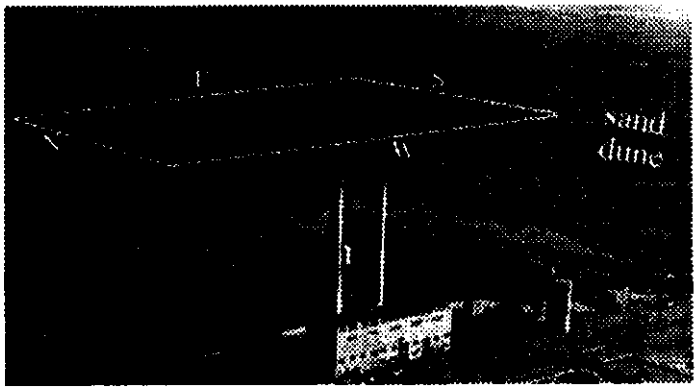
The proposed ILAW Disposal Site is located on the south side of the Cold Creek bar, a depositional bar left in the lee of the Umtanum Ridge during Pleistocene cataclysmic flooding. This bar is dominated by gravel on the north side (closest to the main flood channels) grading to fine sand on the south side.

The proposed ILAW Disposal Site lies along the northern margin of a giant dune field (Appendix D). A long, stabilized dune lying in an east-west direction can be seen along the southern portion of the proposed ILAW Disposal Site in the photograph at the top of Figure B.2. The existence of the dune field appears to be controlled by wind moving from west to east, down the adjacent Dry Creek and Cold Creek valleys and across the expansive Hanford plains toward the Columbia River. Most dunes are stabilized by vegetation and are not actively growing or migrating. The closest point of active dune formation to the proposed ILAW Disposal Site is approximately 3 km south of this area (Gaylord and Stetler 1994). The presence of a dune at the proposed ILAW Disposal Site indicates a history of sand dune development in this area since the last cataclysmic flood (~13,000 years yBP). Appendix D discusses this eolian activity in more detail.

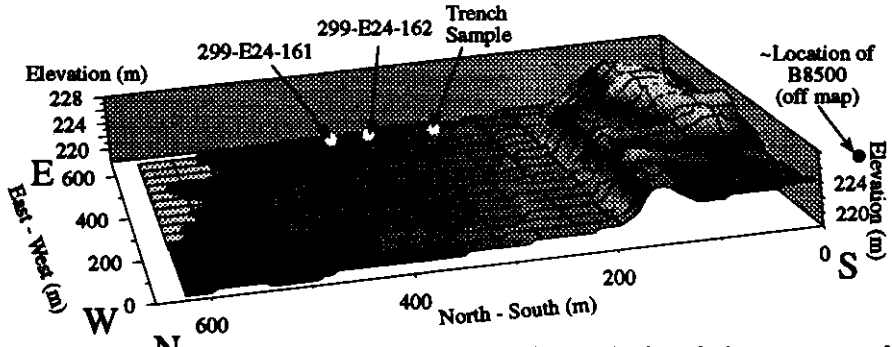
B.3 Borehole Descriptions

Table B.1 summarizes the six boreholes that have been drilled and used to collect sediment samples for tracer analyses. Two boreholes (designated 299-E24-161 and 299-E24-162) were drilled in 1995 to a depth of approximately 18 m. The stratigraphy consisted of a thin layer of sand, 0.3 to 0.6 m thick, resting on top of the Hanford formation. From 0.6 m to about 4.3 m are gravelly sands, reflecting the strength of the flood currents carrying gravel across the bar. The remainder of the sediments encountered (from 4.3 to 18.0 m) are sands with occasional minor gravel. To minimize surface disturbance, drilling pads were not constructed at these boreholes.

The sand-dominated layers of the Hanford formation were deposited during the late Pleistocene cataclysmic flooding (13,000 to 30,000 years ago). Pedogenic calcium carbonate (Stage 1) forms a partial rind on the underside of some gravel clasts in sediments from 0.3 to 1.2 m deep. No other calcic zones were encountered. Sand grain size is primarily coarse to medium (1 to 0.25 mm in diameter), with more than 70% of the sand consisting of those sizes. This reflects a calmer depositional environment than the north side of the bar, where boulders are up to 0.3 m in diameter. A thin sand layer, formed from reworking of flood deposits, overlies the Hanford formation.



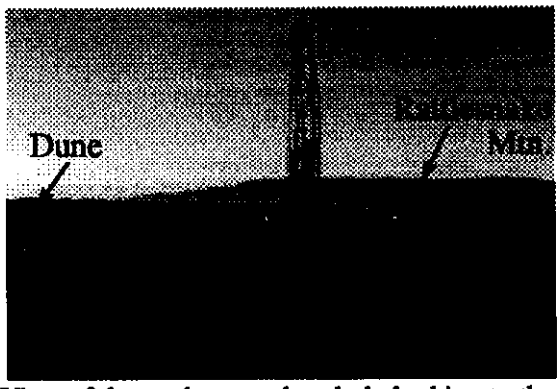
View of ILAW site from north-east. Power plant is in the foreground. The rectangle represents the approximate location of the surface plot below.



Surface plot of ILAW area. The vertical scale is exaggerated to show relief of the dune at the south end of the site. The locations of exploratory boreholes, trench, and relationship to B8500 borehole are noted.



Hollow-stem auger used in exploratory boreholes.



View of the exploratory borehole looking to the south. The dune and Rattlesnake Mtn are visible in the background.

Figure B.2. ILAW Site in the 200E Area of the Hanford Site

Table B.1. Drilling Locations and Dates for ILAW Tracer Studies

Borehole ID	Local ID	Northing	Easting	Drilling Start Date
299-E24-161	NA	N135378	E574651	March 1995
299-E24-162	NA	N135344	E574651	March 1995
299-E17-21	B8500	N134894.21	E574107.02	April 6, 1998
NA	B8501	N134924.68	E574107.02	April 24, 1998
NA	B8502	N134894.21	E574137.48	April 27, 1998
NA	B8503	N134909	E574127	~May 1998

The drill pad for the B8500 boreholes was on the western end of the windward side of a dune oriented in an east-west direction. The near surface sediment (apart from the imported sediment fill and drill pad) is primarily the sediment composing the sand dune. Below this dune material the sediments are coarse to medium sands characteristic of the Hanford formation (Reidel and Reynolds 1998).

Many tracer methods rely on accurately measuring the depth below surface of the tracer profiles. To ensure this accuracy, the surface elevations were surveyed using a ground-positioning satellite (GPS) system before the gravel drilling pad was constructed and after the drilling was completed (Table B.2). The natural surface sediments were graded in preparation for the gravel layer as indicated by the large mounds of natural sediments along the northeast edges of the gravel pad. Without GPS readings after grading and prior to application of gravel, it would be difficult to determine the amount of natural sediment that was removed under the existing drilling pad. The sediments under the pad were compacted and visibly wetter than the undisturbed sediments.

Table B.2. Pre- and Post-Pad Elevations by Ground-Positioning Satellite

Well ID	Pre-Pad Elevation ft (m)	Post-Pad Elevation ft (m)	Difference ft (m)
B8500 (2-E17-21)	734.9 (223.39)	735.7 (224.24)	+0.8 (+0.85)
B8501	739.5 (225.40)	741.1 (224.88)	+1.6 (+1.49)
B8502	734.9	737.8	+2.9

B.4 Results

The analyses of the borehole samples followed procedures outlined by Murphy et al. (1991) and Murphy et al. (1996). Tables B.3 to B.9 contain the results for every sample analyzed. These results are discussed below.

Table B.3. Exploratory Borehole 299-E24-161 Drilled in 1995

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions				Sand Sizes		
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Coarse (%)	Medium (%)	Fine (%)
0.08	0.032	1.700	106.1									
0.38	0.063	1.538	37.4	1.485	25	0.3	82.2	14.9	2.5	8.8	13.3	60.1
0.76	0.059	1.434	41.9	0.816	51							
1.07	0.107	1.400	31.0	2.288	14							
1.37	0.085	1.450	41.9	1.768	24							
1.68	0.084	1.536	46.1	0.979	47	10.3	64.6	23.3	1.8	12.9	11.9	39.7
2.60	0.020	1.582	4129.5	15.274	270							
3.15	0.014	1.524	1173.2	5.437	216							
3.45	0.014	1.456	1143.8	3.068	373							
3.76	0.015	1.549	584.1	1.910	306	6.6	90.6	2.8	0.0	59.7	23.2	7.7
4.05	0.014	1.416	483.0									
4.36	0.016	1.494	301.4	1.586	190							
4.69	0.016	1.428	273.6									
5.03	0.016	1.490	244.3									
5.37	0.017	1.479	213.1									
6.93	0.013	1.469	232.2			0.7	98.3	0.0	1.0	70.5	25.1	2.7
7.59	0.013	1.405	251.7									
7.90	0.013	1.412	286.8									
8.23	0.015	1.584	281.0									
8.53	0.015	1.449	254.1									
8.89	0.016	1.458	274.3									
9.19	0.017	1.458	229.7									
9.58	0.016	1.411	273.1	1.471	186							
10.08	0.016	1.417	206.4			4.9	92.2	1.9	1.0	66.9	20.6	4.6
10.62	0.015	1.383	225.6	1.851	122							
11.32	0.014	1.415	250.7									
11.53	0.016	1.454	272.2									
12.07	0.016	1.484	230.2									
12.62	0.016	1.422	234.9									
12.93	0.019	1.399	201.5									
13.51	0.015	1.410	234.5									
13.82	0.015	1.469	240.0			3.0	94.1	1.9	1.0	56.1	33.4	4.7
14.20	0.014	1.603	236.8									
14.50	0.016	1.427	213.6									
14.83	0.016	1.411	215.1	1.859	116							
15.14	0.025	1.398	208.8	1.506	139							

Table B.4. Exploratory Borehole 299-E24-162 Drilled in 1995

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Depth (m)	Particle Size Distributions				Sand Sizes		
							Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Coarse (%)	Medium (%)	Fine (%)
0.10	0.060	1.502	12.6	BD									
0.53	0.057	1.534	26.6	0.659	40	0.64	0.6	84.5	14.9	0.0	14.6	18.9	51.0
0.95	0.094	1.572	14.7	1.342	11								
1.30	0.078	1.564	17.5	1.357	13								
1.68	0.035	1.668	1382.8	7.299	189								
2.04	0.032	1.572	3688.5	15.003	246								
2.48	0.020	1.554	3350.4	14.805	226	2.52	26.0	71.8	0.7	1.5	55.4	7.3	9.1
3.18	0.017	1.481	716.5	3.002	239								
3.53	0.018	1.565	292.8	1.285	228								
3.97	0.018	1.529	184.7	1.356	136								
4.64	0.015	1.453	93.0			4.72	1.2	95.8	0.0	3.0	37.0	47.6	11.3
4.99	0.016	1.465	93.0	2.293	41								
5.34	0.017	1.434	78.4	1.628	48								
5.69	0.016	1.373	70.4	2.492	28								
6.04	0.018	1.365	50.8	1.354	38								
6.39	0.016	1.395	74.7	1.533	49								
6.74	0.012	1.375	74.7			6.74	0.4	96.6	1.0	2.0	72.8	20.0	3.8
7.54	0.013	1.426	69.4										
7.89	0.013	1.392	77.7	1.905	41								
8.27	0.017	1.403	81.6	BD									
8.62	0.016	1.453	73.2	BD									
9.64	0.013	1.521	71.3	BD									
10.34	0.014	1.460	50.0	BD									
11.07	0.015	1.398	21.8	BD									
12.51	0.016	1.378	51.5	BD									
12.86	0.018	1.400	46.8	BD									
13.24	0.016	1.440	51.4	BD									
13.59	0.016	1.437	53.1	BD									
13.97	0.017	1.456	51.3	BD									
14.32	0.020	1.442	57.8	BD									
14.76	0.018	1.398	56.5	BD		14.84	2.2	94.9	1.0	2.0	57.1	31.9	5.8
15.11	0.018	1.423	53.9	BD									
15.52	0.022	1.401	74.4	BD									
15.87	0.021	1.394	59.4	BD									
16.65	0.021	1.416	50.5	BD									
17.02	0.019	1.393	58.8	BD									
17.37	0.011	1.431	76.1	BD		17.45	3.1	93.0	1.9	1.9	62.4	25.6	5.0

Note: BD = below detection.

Table B.5. Trench Data (1995)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density ($g/>cm^3$)	$^{36}Cl/Cl$ Bkgd-Corrected[a]	Error[b]
0.30	0.0248	1.4999	8.69E-12	9.60E-14
0.40	0.0266	1.4812	6.14E-12	9.10E-14
0.55	0.0258	1.4380	3.91E-12	5.20E-14
0.85	0.0379	1.4260	8.13E-12	1.40E-13
1.01	0.0366	1.4965	9.48E-12	1.50E-13
1.43	0.0465	1.8074	1.38E-11	2.30E-13
1.62	0.0241	1.7119	5.31E-12	1.80E-13
1.62	0.0241	1.7119	5.41E-12	1.30E-13
1.92	0.0368	1.6377	1.52E-12	4.10E-14
2.01	0.0332	1.6528	1.41E-12	2.40E-14
2.29	0.0357	1.6652	1.10E-12	2.70E-14
2.29	0.0357	1.6652	8.85E-13	2.80E-14
2.41	0.0252	1.5774	9.80E-13	2.10E-14
2.68	0.0202	1.6721	9.26E-13	2.30E-14
2.93	0.0156	1.5963	8.72E-13	2.30E-14
3.26	0.0175	1.6484	8.90E-13	2.90E-14
3.32	0.0198	1.5939	8.31E-13	2.10E-14
3.69	0.0194	1.6394	9.55E-13	4.80E-14
3.75	0.0138	1.6540	8.87E-13	2.20E-14
3.81	0.0161	1.6300	1.16E-12	2.90E-14
4.02	0.0150	1.5596	8.29E-13	2.30E-14
4.51	0.0132	1.5517	8.10E-13	2.00E-14
4.79			8.85E-13	2.80E-14

(a) Background-corrected ratios are calculated using the measured ratio for a blank sample.

(b) Uncertainty in the $^{36}Cl/Cl$ is the combined uncertainties in the sample measurement and in the standard measurements used for normalization. The final value reported is the weighted mean of the individual measurements of the sample. Two uncertainties are calculated from this weighted mean: 1) the internal error is the propagated uncertainty in the weighted mean, where the weighting factors are the uncertainties in the individual measurements calculated as stated above; and 2) the external error is the population standard deviation of the individual measurements of the weighted mean. The reported error is the larger of the internal and external error and represents the uncertainty in the final measurement.

Table B.6. B8500 (299-E17-21) Drilled in 1998

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
2.71	0.0349	1.581	2331.6	13.449	173	1.0	70.3	21.3	7.4
2.90	0.0334	1.555	2120.4	12.591	168				
2.99	0.0254	1.661	2062.3	12.988	159				
3.08	0.0353	1.545	2409.3	14.491	166				
3.17	0.0270	1.501	1846.2	10.399	178				
3.35	0.0278	1.489	1714.5	11.145	154	14.3	76.7	4.7	4.3
3.44	0.0214	1.512	1997.0	13.101	152				
3.54	0.0187	1.439	1884.8	10.721	176				
3.66	0.0430	1.458	1723.0	10.920	158	0.0	65.5	27.0	7.5
3.75	0.0246	1.609	1414.7	8.119	174				
3.84	0.0202	1.474	1032.1	6.913	149				
3.93	0.0271	1.403	798.7	4.789	167	0.0	89.0	6.5	4.5
4.05	0.0195	1.516	619.5	3.587	173				
4.15	0.0370	1.661	601.8	3.516	171	0.9	61.5	30.7	6.9
5.52	0.0261	1.433	137.2	1.921	71	0.0	93.0	4.0	3.0
5.61	0.0285	1.400	110.2	0.702	157				
5.70	0.0454	1.383	108.9	0.882	124				
5.82	0.0329	1.346	102.1	0.914	112				
5.91	0.0275	1.474	97.6	1.821	54				
6.02	0.0228	1.391	92.8	1.320	70				
6.13	0.0463	1.414	67.2	0.431	156	2.6	69.1	20.9	7.3
6.22	0.0215	1.646	70.0	0.928	76				
6.31	0.0250	1.484	76.8	0.795	97				
8.38	0.0119	1.493	21.1	BD		4.2	89.1	2.9	3.8
8.53	0.0117	1.573	18.9	BD					
8.63	0.0119	1.558	23.4	BD					
8.72	0.0126	1.717	31.7	BD					
8.81	0.0116	1.576	31.8	BD					
8.90	0.0142	1.572	30.4	BD		6.3	82.4	6.6	4.7
8.99	0.0167	1.554	27.4	BD					
9.42	0.0111	1.486	27.8	BD					
9.48	0.0110	1.469	29.2	BD					
9.57	0.0123	1.566	41.4	BD					
9.66	0.0123	1.622	63.4	BD		4.1	77.2	12.5	6.2

Table B.6. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
10.67	0.0116	1.567	40.4	BD		3.2	88.1	3.9	4.8
10.73	0.0122	1.584	22.2	1.646	14				
10.79	0.0138	1.552	38.6	BD					
10.88	0.0125	1.568	35.2	BD					
10.97	0.0155	1.574	53.0	BD					
11.43	0.0135	1.565	30.4	BD					
11.52	0.0172	1.373	19.2	1.744	11				
11.61	0.0156	1.440	20.5	BD					
11.70	0.0154	1.453	25.4	BD					
11.80	0.0161	1.347	19.2	BD					
11.89	0.0154	1.529	42.4	BD		1.1	90.0	4.0	4.9
14.30	0.0182	1.513	34.1	1.102	31	0.0	81.5	11.5	7.0
15.09	0.0096	1.291	87.6	BD		1.5	69.0	20.7	8.9
15.70	0.0117	1.578	25.6	BD					
17.01	0.0097	1.466	37.2	BD					
17.92	0.0123	1.669	32.5	1.625	20				
18.17	0.0118	1.570	45.0	BD					
18.93	0.0106	1.598	44.6	BD					
21.31	0.0140	1.702	22.1	1.428	16				
22.83	0.0128	1.483	20.3	BD					
23.59	0.0136	1.561	28.6	BD					
24.17	0.0140	1.462	19.3	BD					
24.93	0.0148	1.596	33.3	1.358	25				
28.04	0.0138	1.457	21.7	BD					
27.28	0.0115	1.553	25.1	BD					
30.33	0.0123	1.471	25.1	BD					
31.09	0.0127	1.497	31.5	BD					
33.16	0.0156	1.426	24.4	BD					
33.89	0.0182	1.452	26.4	BD					
35.17	0.0171	1.506	18.8	BD					
35.94	0.0117	1.519	25.6	BD					
36.58	0.0158	1.482	19.6	BD					
37.31	0.0166	1.424	25.2	BD					
39.23	0.0116	1.455	44.9	BD					

Table B.6. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
39.99	0.0239	1.464	23.9	BD					
43.59	0.0227	1.487	15.0	BD					
42.82	0.0165	1.503	33.4	BD					
46.76	0.0122	1.468	32.7	BD					
45.99	0.0234	1.507	10.7	BD					
48.59	0.0152	1.535	42.9	BD					
49.35	0.0158	1.539	53.3	BD					
54.77	0.0205	1.459	18.6	BD					
55.38	0.0182	1.540	19.2	BD					
58.13	0.0169	1.522	20.1	BD					
60.05	0.0155	1.511	18.1	BD					
61.05	0.0178	1.548	17.4	BD					
63.09	0.0190	1.534	16.3	BD					
64.13	0.0173	1.547	20.2	BD					
66.17	0.0170	1.591	14.7	BD					
67.24	0.0376	1.402	15.2	BD					
69.22	0.0226	1.508	15.5	BD					
72.27	0.0148	1.530	30.5	BD					
73.30	0.0175	1.638	29.1	BD					
82.02	0.0191	1.729	49.3	BD					
106.56	0.0446		13.5	BD					
116.04	0.3029	1.346	4.4	BD					

Note: BD = below detection.

Table B.7. B8501 Borehole Drilled in 1998

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
0.06	0.06433	1.579	13.4	BD					
0.15	0.05966	1.529	7.4	BD					
0.27	0.06475	1.513	6.3	BD		3.17	85.69	4.84	6.29
0.40	0.04861	1.528	7.4	BD					
0.52	0.05679	1.396	3.5	BD					
0.64	0.06346		3.6	0.040	91				
0.82	0.01858	1.595	1030.0	5.387	191				
0.98	0.01270	1.502	175.5	BD					
1.10	0.06043	1.572	6.9	BD					
1.22	0.04747	1.502	4.4	BD					
1.34	0.03507	1.414	3.7	BD					
1.46	0.03896	1.317	2.3	BD					
1.58	0.03864	1.479	4.1	BD					
1.77	0.04350	1.839	450.8	1.609	280	62.04	25.43	9.49	3.04
1.89	0.04137	1.891	441.4	1.691	261				
2.32	0.03944	1.645	288.1	1.015	284				
2.44	0.04958	1.666	217.0	1.008	215				
2.56	0.08187	1.599	9.5	BD					
2.68	0.10820	1.454	5.1	BD					
2.80	0.12394	1.456	4.8	BD					
2.93	0.08326	1.597	0.6	BD					
3.05	0.04134		12.1	BD					
3.17	0.02761	1.667	55.1	BD		47.82	43.31	4.96	3.91
3.69	0.03394	1.479	2055.1	17.079	120				
4.57	0.03598	1.603	1584.5	12.503	127				
4.69	0.03071	1.624	1684.2	14.005	120				
4.82	0.04739	1.506	2067.1	17.077	121	0.11	67.92	23.47	8.49
4.97	0.02245	1.515	1082.5	9.343	116				
5.09	0.02106	1.493	976.3	7.594	129				
5.21	0.00654	1.524	2869.9	24.464	117				
5.33	0.01923	1.421	868.5	7.276	119				
5.46	0.01764	1.506	879.6	8.507	103				
5.58	0.04455	1.540	920.5	7.630	121				
5.70	0.02864	1.659	699.8	5.936	118	0.03	73.48	18.49	8
5.82	0.02326	1.697	777.0	7.310	106				
5.94	0.02770	1.451	492.9	4.350	113				
6.07	0.02095	1.546	765.5	6.204	123				

Table B.7. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density ($g/>cm^3$)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
6.07	0.01906	1.590	693.0	6.295	110	0.94	87.67	4.46	6.93
6.19	0.02337	1.598	666.8	6.852	97				
6.31	0.02852	1.423	641.7	5.260	122	0.17	86.85	6.99	5.99
6.43	0.02079	1.527	662.5	5.773	115				
6.55	0.02898	1.586	668.7	6.211	108				
6.77	0.02988	1.567	566.1	5.354	106				
6.89	0.03073	1.513	585.7	5.209	112	0.01	88.49	4	7.5
7.01	0.03205	1.457	564.6	4.996	113				
7.13	0.03054	1.206	614.9	5.563	111				
7.25	0.02242	1.497	614.0	5.351	115				
7.41	0.02176	1.625	706.7	6.892	103				
7.53	0.02104	1.531	620.2	5.703	109				
7.65	0.02361	1.503	555.4	5.507	101				
7.77	0.03059	1.533	574.1	4.904	117				
7.89	0.03688	1.563	574.5	5.151	112				
8.53	0.01434	1.460	270.6	BD					
8.66	0.01549	1.493	250.5	BD					
8.78	0.01556	1.532	221.9	BD					
8.90	0.01581	1.495	194.2	BD					
9.02	0.02026	1.459	137.7	BD					
9.14	0.03292	1.586	96.2	BD		1.13	83.05	9.39	6.43
9.27	0.02093	1.570	246.0	BD					
9.39	0.01253	1.556	272.8	BD					
9.51	0.01214	1.518	142.5	BD					
9.63	0.01296	1.520	120.4	BD					
9.81	0.01250	1.556	119.8	BD					
9.94	0.01252	1.504	91.9	BD		0.72	84.38	9.93	4.96
10.06	0.01290	1.479	69.0	BD					
10.18	0.01279	1.488	64.9	BD					
10.30	0.01373	1.530	55.3	BD					
10.42	0.01355	1.525	52.4	BD					
10.55	0.01520	1.523	46.7	BD		0.29	88.74	6.98	3.99
10.67	0.01920	1.565	36.9	BD					
10.79	0.01315	1.564	63.1	BD					
10.91	0.01148	1.454	53.2	BD					
11.00	0.01169	1.481	45.3	BD					
11.13	0.01370	1.453	40.1	BD					

Table B.7. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density ($g/>cm^3$)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
11.25	0.01563	1.474	32.0	BD					
11.37	0.01246	1.452	41.0	BD					
11.49	0.01271	1.447	30.7	BD					
11.61	0.01574	1.471	26.0	BD					
11.73	0.01469	1.444	30.6	BD					
11.86	0.01597	1.408	22.5	BD		0.18	87.84	7.99	3.99
11.98	0.01474	1.438	25.1	BD					
12.10	0.01523	1.472	23.0	BD					
12.22	0.01371	1.477	27.0	BD					
12.34	0.01519	1.507	22.4	BD					
12.47	0.01431	1.459	27.3	BD					
12.59	0.01397	1.532	23.6	BD					
12.71	0.03086	1.405	11.0	BD					
13.81	0.01249	1.572	68.0	BD					
14.08	0.01607	1.473	23.0	BD					
14.20	0.01367	1.540	16.1	BD					
14.33	0.01412	1.509	15.6	BD					
14.45	0.01367	1.480	16.8	BD		0.01	93.99	2	4
14.57	0.01459	1.526	14.4	BD					
14.69	0.01324	1.447	14.4	BD					
Note: BD = below detection.									

Table B.8. B8502 Borehole Drilled in 1998

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
0.00	0.0545	1.645	67.8	BD		25.0	55.1	14.6	5.2
0.15	0.0525	1.634	60.4	BD					
0.27	0.0476	1.747	85.8	BD					
0.43	0.0567	1.454	3.0	BD					
0.55	0.0402	1.501	2.2	BD		1.0	87.2	6.9	5.0
0.67	0.0670	1.497	1.3	BD					
0.79	0.1043	1.469	1.2	BD		3.5	33.8	55.0	7.7
0.94	0.1302	1.467	1.0	BD					
1.13	0.0413	1.725	100.0	BD					
1.25	0.0972	1.602	4.1	BD					
1.37	0.0752	1.677	8.6	BD		21.4	48.8	24.4	5.5
1.49	0.0843	1.706	14.5	BD					
1.62	0.0698	1.732	11.9	BD					
1.74	0.0673	1.730	12.8	BD					
1.86	0.0448	1.832	25.4	BD					
2.23	0.0425	1.640	74.1	BD		43.2	44.1	9.1	3.7
2.35	0.0242	1.521	108.0	BD					
2.47	0.0587	1.540	108.5	1.363	80				
2.59	0.0339	1.503	133.8	1.182	113				
2.71	0.0249	1.551	192.7	BD		13.4	80.5	1.7	4.3
2.83	0.0284	1.548	111.7	BD					
2.96	0.0235	1.525	178.7	BD					
3.35	0.0333	1.506	454.2	3.905	116	4.7	90.5	1.4	3.3
3.47	0.0619	1.411	515.1	3.717	139				
3.47	0.0297	1.515	425.8	2.690	158				
3.72	0.0259	1.201	983.0	6.189	159				
3.84	0.0246	1.521	1180.5	8.136	145				
3.96	0.0269	1.424	1125.7	7.440	151				
4.08	0.0373	1.506	1228.5	8.299	148				
4.27	0.0477	1.432	1227.5	7.746	158				
4.39	0.0474	1.391	1125.6	6.974	161	0.0	86.0	8.0	6.0
4.51	0.0357	1.610	1174.3	7.574	155				
4.63	0.0262	1.582	1058.9	7.255	146				
4.75	0.0235	1.460	984.8	6.378	154				
4.88	0.0345	1.611	1148.0	7.238	159	1.1	77.2	15.8	5.9
5.00	0.0241	1.427	854.6	5.814	147				
5.12	0.0242	1.475	645.3	4.126	156				

Table B.8. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density ($g/>cm^3$)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
5.18	0.0212	1.677	910.0	5.896	154				
5.24	0.0255	1.446	361.7	2.549	142				
5.30	0.0217	1.596	694.7	5.174	134				
5.36	0.0432	1.478	1083.4	7.834	138				
5.43	0.0224	1.679	588.2	4.020	146				
5.55	0.0244	1.502	419.7	3.276	128	0.3	93.2	2.5	4.0
5.67	0.0284	1.589	458.0	3.521	130				
5.79	0.0288	1.594	391.8	2.432	161				
5.91	0.0260	1.601	332.2	1.923	173				
6.04	0.0301	1.395	290.6	1.663	175				
6.16	0.0352	1.408	255.5	1.705	150				
6.28	0.0330	1.713	245.3	2.120	116				
6.46	0.0563	1.427	123.0	1.065	116				
6.58	0.0361	1.720	223.2	1.938	115	11.9	73.1	9.3	5.7
6.71	0.0170	1.601	218.6	BD					
6.83	0.0348	1.586	81.2	BD					
6.95	0.0137	1.581	156.7	BD					
7.04	0.0281	1.551	30.3	BD					
7.16	0.0321	1.600	31.2	BD		1.8	89.9	4.4	3.9
7.28	0.0275	1.541	102.0	BD					
8.08	0.0193	1.487	30.6	BD					
8.14	0.0143	No bulk density	25.8	BD					
8.20	0.0159	1.587	47.2	BD					
8.26	0.0125	1.503	28.2	BD					
8.26	0.0133	No bulk density	26.0	BD					
8.38	0.0138	1.507	27.3	BD					
8.38	0.0140	No bulk density	29.3	BD					
8.50	0.0154	1.493	37.8	BD					
8.50	0.0134	No bulk density	32.0	BD					
8.63	0.0134	No bulk density	39.5	BD					
8.75	0.0114	1.567	23.7	BD		1.8	90.4	3.9	3.9
8.87	0.0115	1.539	26.0	BD					

Table B.8. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density ($g/>cm^3$)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
8.99	0.0121	1.532	18.9	BD					
9.11	0.0174	1.622	16.1	BD					
9.24	0.0155	1.589	18.7	BD					
9.39	0.0329	1.442	16.4	BD					
9.51	0.0140	1.558	15.0	BD		1.3	91.8	2.5	4.4
9.63	0.0259	1.504	10.4	BD					
9.75	0.0187	1.465	15.5	BD					
9.88	0.0314	1.433	8.6	BD					
10.24	0.0145	1.526	16.5	BD					
10.79	0.0189	1.581	13.8	BD					
11.16	0.0109	1.504	25.6	BD					
11.31	0.0110	1.423	21.9	BD					
11.43	0.0111	1.510	18.1	BD		0.0	93.5	3.0	3.5
11.55	0.0118	1.397	18.7	BD					
11.67	0.0111	1.462	19.9	BD					
11.80	0.0128	1.484	20.3	BD					
11.92	0.0136	1.420	19.9	BD					
12.04	0.0139	1.437	20.1	BD					
12.16	0.0164	1.384	19.5	BD					
12.28	0.0133	1.547	20.4	BD					
12.47	0.0159	1.566	21.4	BD					
12.53	0.0150	1.524	21.4	BD					
12.62	0.0174	1.551	20.7	BD					
12.80	0.0154	1.537	20.8	BD					
12.92	0.0151	1.506	17.8	BD					
13.05	0.0143	1.502	17.5	BD					
13.17	0.0161	1.509	18.0	BD		1.3	92.3	1.5	4.9
13.29	0.0164	1.477	17.7	BD					

Note: BD = below detection.

Table B.9. B8503 Borehole Drilled in 1998

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
0.09	0.0284	1.280	14.7	BD					
0.15	0.0222	1.515	16.2	BD					
0.21	0.0290	1.462	11.3	BD					
0.30	0.0284	1.502	11.9	BD		0.055	84.953	9.995	4.997
0.37	0.0317	1.477	7.6	BD					
0.46	0.0320	1.450	5.9	BD					
0.67	0.0253	1.464	11.4	BD					
0.76	0.0274	1.463	10.5	BD					
0.85	0.0323	1.483	9.6	BD					
0.93	0.0397	1.424	3.0	BD					
1.01	0.0405	1.433	2.7	BD					
1.08	0.0460	1.379	1.7	BD					
1.26	0.0393	1.449	18.8	BD					
1.34	0.0397	1.336	14.1	BD					
1.43	0.0379	1.404	25.6	BD					
1.52	0.0360	1.439	33.1	BD		0.019	91.483	3.499	4.999
1.60	0.0351	1.406	37.6	BD					
1.69	0.0360	1.400	40.3	BD					
1.83	0.0348	1.352	50.0	BD					
1.89	0.0290	1.436	48.3	BD					
1.98	0.0277	1.531	55.7	BD					
2.06	0.0368	1.545	49.2	BD					
2.13	0.0398	1.545	38.5	BD					
2.19	0.0337	1.523	38.0	BD					
2.29	0.0350	1.561	38.9	BD		0.185	85.841	9.981	3.993
2.50	0.0410	1.506	31.4	BD					
2.58	0.0555	1.500	37.2	BD					
2.65	0.0745	1.464	33.1	BD					
2.74	0.0867	1.372	39.3	BD		0.494	32.837	56.718	9.951
2.85	0.1010	1.369	50.5	BD					
2.93	0.1155	1.391	69.8	BD					
3.11	0.0959	1.425	72.1	BD					
3.20	0.1347	1.503	188.3	0.817	230				
3.29	0.1346	1.548	227.7	1.189	192				
3.41	0.0583	1.759	125.0	BD					
3.51	0.0240	1.687	235.3	BD		51.869	37.542	7.220	3.369
3.69	0.0364	1.684	432.9	3.571	121				
3.78	0.0422	1.441	601.5	4.262	141				
3.89	0.0386	1.547	490.7	3.891	126				
3.96	0.0314	1.655	423.1	3.502	121				
4.16	0.0336	1.707	388.6	3.276	119				

Table B.9. (contd)

Depth (m)	Moisture Content ($g_{H2O}/g_{dry\ soil}$)	Bulk Density (g/cm^3)	Soil Water Chloride ($\mu g_{Cl}/g_{H2O}$)	Soil Water Bromide ($\mu g_{Br}/g_{H2O}$)	Cl/Br	Particle Size Distributions			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)
4.22	0.0338	1.704	400.3	3.254	123	6.004	62.507	24.439	7.050
4.88	0.0240	1.604	590.3	5.404	109				
4.97	0.0216	1.563	685.7	5.564	123				
5.06	0.0202	1.603	909.5	7.930	115	0.029	86.974	9.997	2.999
5.09	0.0226	1.614	990.8	7.536	131				
5.14	0.0214	1.578	1152.3	9.334	123				
5.18	0.0222	1.581	1127.4	8.565	132				
5.24	0.0217	1.608	1152.4	9.684	119				
5.67	0.0233	1.606	776.8	6.434	121				
5.79	0.0227	1.589	759.0	6.178	123	0.332	76.744	16.944	5.980
5.91	0.0307	1.612	807.7	6.524	124				
6.02	0.0285	1.711	756.2	5.971	127				
6.10	0.0259	1.700	704.4	6.951	101	0.126	75.904	17.977	5.992
6.19	0.0291	1.447	803.2	7.211	111				
6.28	0.0333	1.640	786.1	6.613	119				
6.37	0.0268	1.607	646.5	5.226	124				
6.60	0.0319	1.634	783.1	6.592	119				
6.69	0.0229	1.639	663.9	5.682	117				
6.77	0.0344	1.536	694.0	5.813	119				
6.86	0.0289	1.581	634.4	5.534	115				
6.96	0.0427	1.411	814.0	7.023	116	0.126	70.411	21.972	7.491
7.13	0.0235	1.595	636.5	5.965	107				
7.24	0.0248	1.616	639.3	6.058	106				
7.32	0.0224	1.526	706.1	5.806	122				
7.42	0.0287	1.468	698.3	5.923	118				
7.53	0.0281	1.497	685.3						
7.62	0.0282	1.669	684.1						
7.62	0.0273	1.638	683.0						
7.68	0.0268	1.571	681.9						
7.77	0.0250	1.605	680.7						
7.85	0.0248	1.593	679.6						
7.92	0.0237	1.649	678.4						
8.14	0.0271	1.567	677.3						
8.18	0.0373	1.540	676.1			4.342	84.179	6.696	4.783
8.23	0.0315	1.638	675.0						
8.31	0.0188	1.614	673.8			13.252	75.471	6.940	4.337
8.35	0.0176	1.657	672.7						
8.41	0.0154	1.668	671.5			6.284	79.190	7.966	6.560

Note: BD = below detection.

Sun River Electric and Watts Construction started construction of the drilling pad on February 12 and completed work on February 17, 1998. The site is extremely sandy and a bulldozer was used initially to clear the vegetation and level the area. Gravelly sediments were taken from a borrow pit in the 200 West Area that was used to burn sagebrush. Approximately 15 cm of this material was laid down, and then a large vibratory roller was used to compact the material. This compaction can easily affect the first two feet of sediment. Approximately 7.5 cm of crushed gravel was then laid down and the vibratory roller compaction was repeated. Drilling began on April 6, 1998, at B8500, April 24, 1998, at B8501, and April 27, 1998, at B8502. The gravel drill pad is a very effective structure for reducing evaporation, which increases the movement of water deeper into the profile. Precipitation totaled 22.1 mm between construction and drilling. Our concern is that some of this water may have affected the upper samples.

B.4.1 Physical Properties

B.4.1.1 Stratigraphy

Stratigraphic columns were constructed from available geologic information (Figure B.3). In 1995, the columns were reconstructed from geologic notes taken at the drill site. A more thorough analysis was done in 1998 when the split cores were examined in detail in the laboratory.

Distinct layering was evident from the exposed trench wall. This layering was primarily gravels, medium to fine sands, and silts. The structured horizontal layering (seen in the lower portion of the trench photograph in Figure B.3) results from layers of fine and coarse sands and silts, usually on the order of a few centimeters thick. These layers are part of the upper flow regime of the plane-laminated sand facies of the Hanford formation.

B.4.1.2 Grain Size Analyses

Grain size distributions were determined by sieving according to the Wentworth scale; the amount of silt and clay was determined by sedimentation using a hydrometer (Figure B.4). There is a striking difference between the grain size distributions of the boreholes north of the east-west sand dune compared with the B8500 series boreholes that were located just outside the southern boundary of the proposed ILAW Disposal Site. The exploratory boreholes (299-E24-161 & -162) show less clay and silt and much less layering than the B8500 boreholes. In general, the exploratory boreholes had more uniform grain sizes with depth.

Among the B8500 series of boreholes, borehole B8503, which was drilled in undisturbed sediment, provided the most accurate grain-size distribution in the upper 2 m. The grain-size distributions in the upper 3 m of B8501 and B8502 were likely impacted by the fill sediment and gravel that was used to construct the drill pad.

Although the sediments are predominantly sand, some gravel and silt layering is evident in B8503, similar to what was observed at the exposed face of the trench dug in 1995. At some depths a high gravimetric moisture content correlates well with silt layers as shown in Figure B.5 for borehole B8502. This is in contrast to the labeling on the stratigraphy column of areas of clay-rich silt to silty sand. The

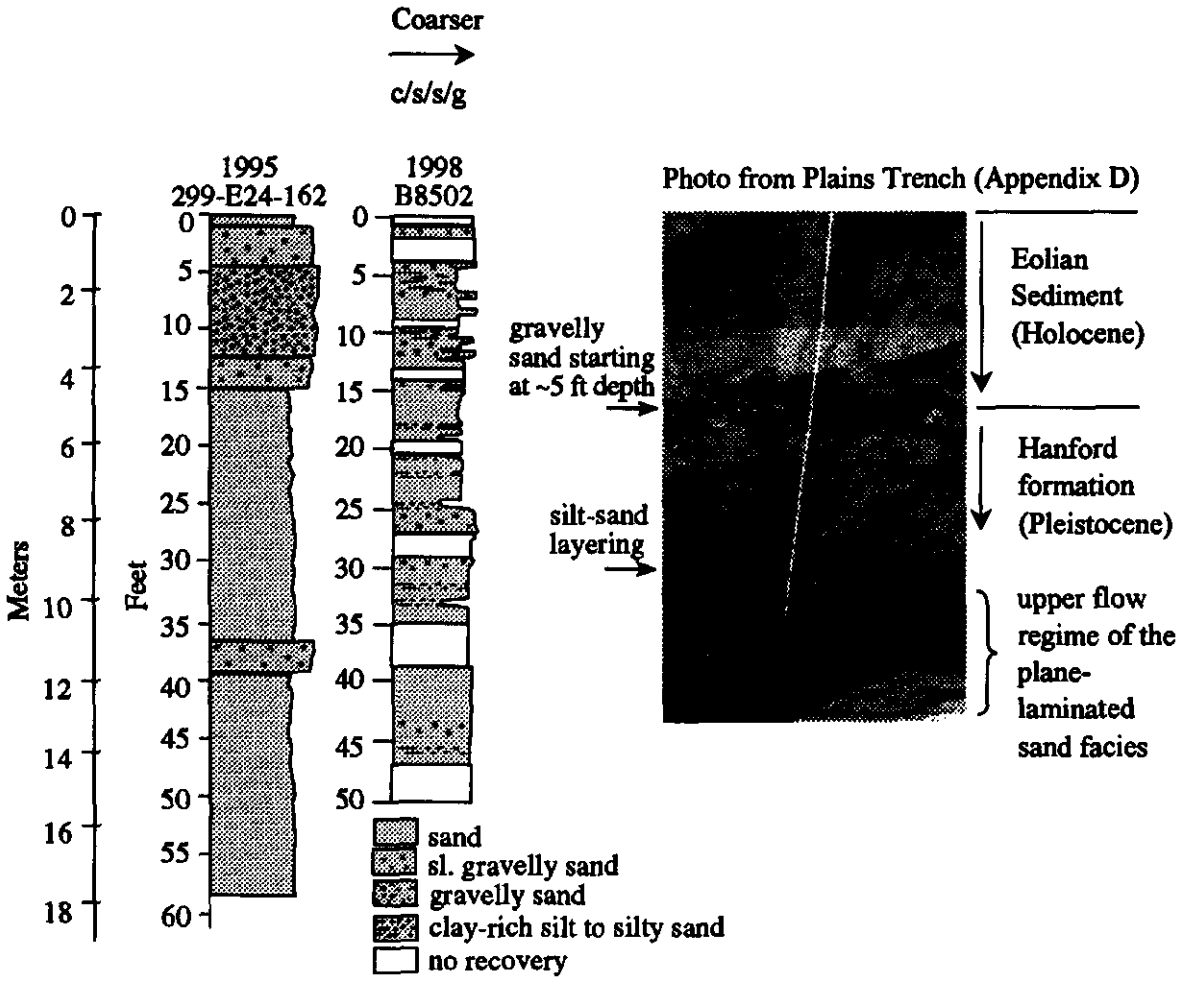


Figure B.3. Stratigraphic Columns Constructed from Drill-Site Geologic Logs and a Photograph Taken from the Trench Excavation in 1995

hydrometer methods indicated a fairly uniform low concentration of clay, ranging between ~5 to 10%. Sieve analyses indicated highly variable concentrations of silt in the sediment column. Therefore, the correlation of moisture with specific layers in the profile is likely due to the concentration of silt and not a clay-rich region in the profile.

B.4.1.3 Gravimetric Moisture Content

Gravimetric moisture contents varied between ~0.01 to 0.13 g/g with the higher values generally in the top 3 m of sediment. The moisture contents of sediments collected from two exploratory boreholes drilled in March 1995 are shown in Figure B.6a along with moisture contents from the B8500 series boreholes (April 1998, Figure B.6b). The 1995 exploratory boreholes (161 and 162) were 35 m apart and were drilled during the same week. The B8500 series boreholes were all within ~22 m and were drilled

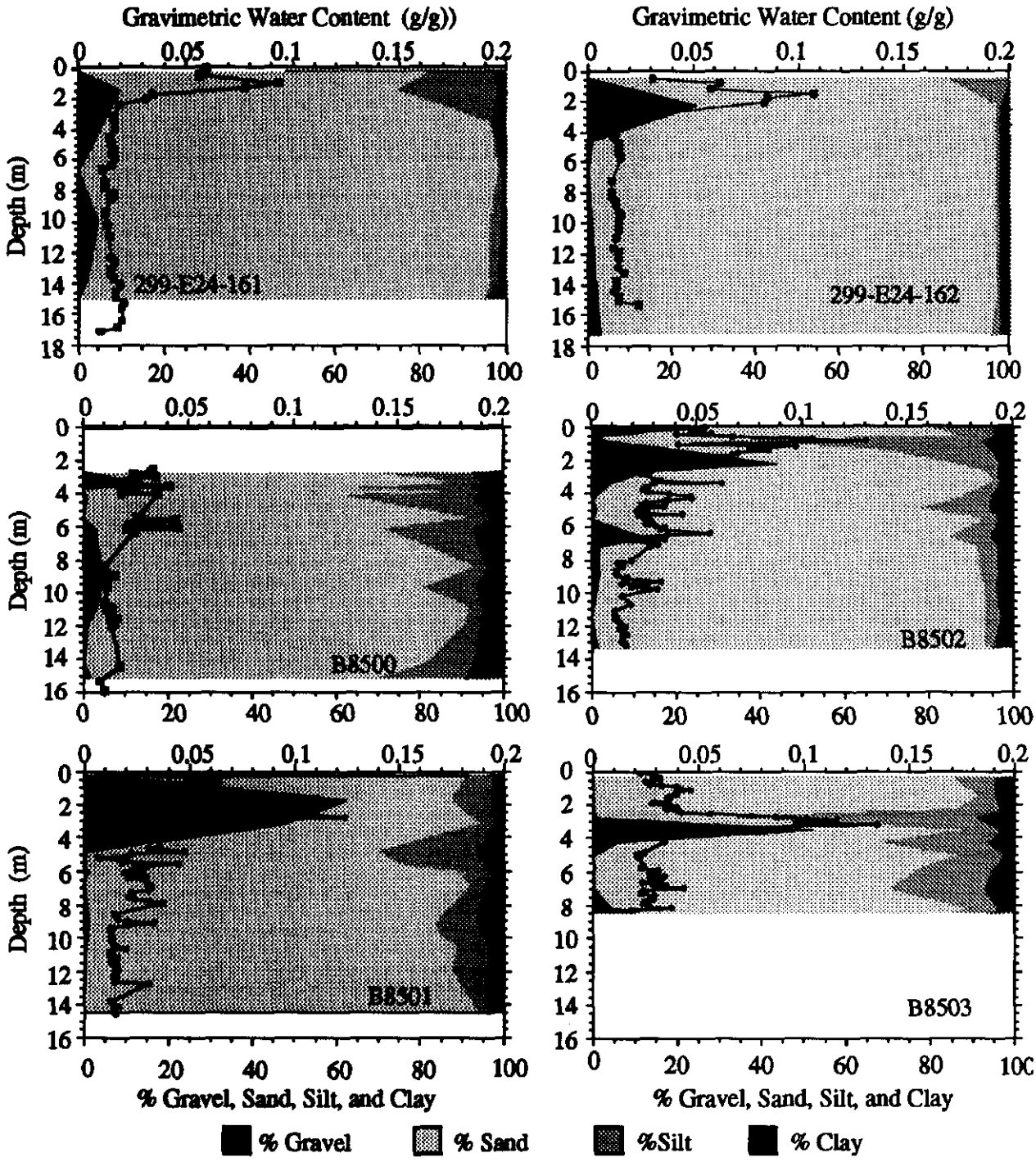


Figure B.4. Gravel, Sand, Silt, and Clay Percentages in the B8500 Series Boreholes. The data points show the corresponding gravimetric water content with depth. The lower x-axis of each graph is the percentage for the grain size distribution, while the upper x-axis of each graph is the gravimetric water contents (g/g).

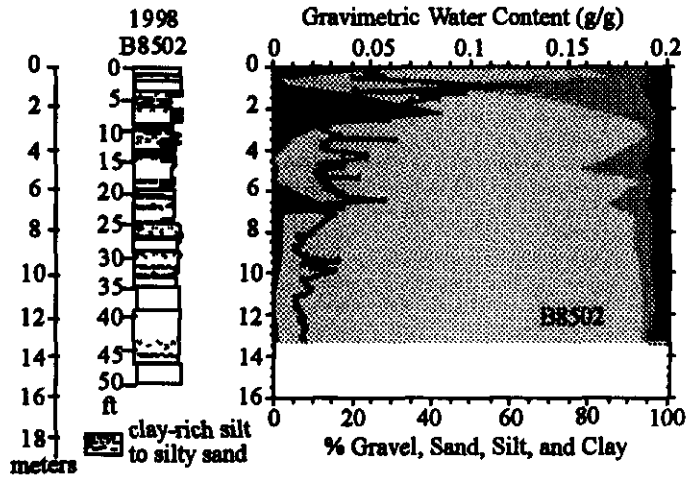


Figure B.5. Comparison of Stratigraphy with Particle Size Distribution for Borehole B8502

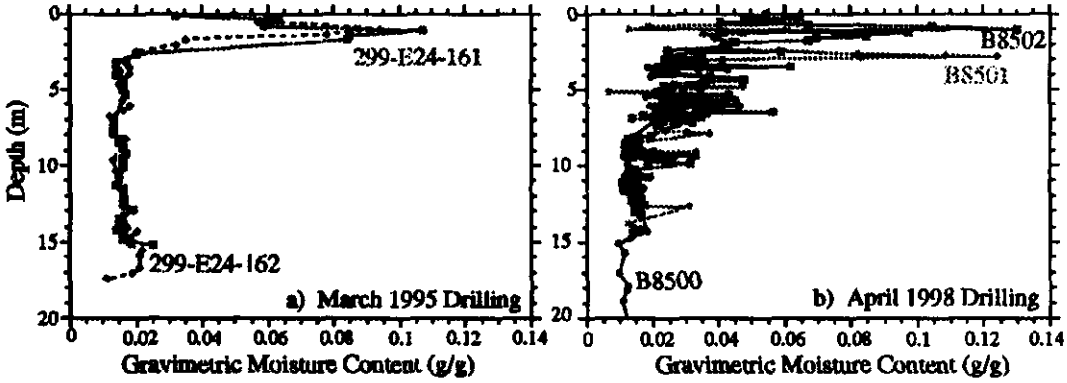


Figure B.6. Gravimetric Moisture Content Profiles from 1995 Exploratory Drilling (a) and Profiles from B8500, B8501, and B8502 (b)

The 1995 exploratory holes showed greater consistency in moisture content, which may be due to greater uniformity in the stratigraphy and surface vegetation compared to the B8500 site or handling problems associated with the B8500 sampling. When there was an obvious wetting front in the core sample (due to improper handling), the sediment was not sampled. The resulting moisture profile for the B8500 boreholes show greater variability than the wells drilled in 1995; however, the moisture contents were within the range typically found for Hanford sediments. Although we cannot assess the impact of the drilling pad construction and fill material on the moisture profiles, we can suggest that the more pronounced silt layering in the B8500 boreholes has a direct impact on the moisture variability with spikes in the moisture content generally associated with silt layers (see Figure B.4).

The other primary difference between the exploratory borehole site and the B8500 site is the surface vegetation. The exploratory boreholes were located on the lee side of the sand dune in a dense stand of mature sagebrush. In contrast, the B8500 boreholes are located on the windward side of the sand dune. The vegetation here was much smaller and sparse. The dense, mature vegetative cover at the exploratory

boreholes may promote the greater uniformity seen in the moisture contents. In these profiles, the predominant moisture was confined to the root zone. Below the root zone, the sediments were extremely dry, ranging from 0.01 to 0.02 g/g gravimetric water content. The B8500 moisture profiles showed greater variability and somewhat higher moisture contents at depths below the root zone.

B.4.1.4 Dry Bulk Density

Dry bulk density measurements were performed on all samples that were used for tracer analysis. The chloride mass balance approach uses this measurement to estimate recharge. Similar to the moisture content, the dry bulk densities were more variable in the B8500 series boreholes when compared to the 1995 exploratory holes (Figure B.7). A correlation was not evident when moisture content was plotted against dry bulk density.

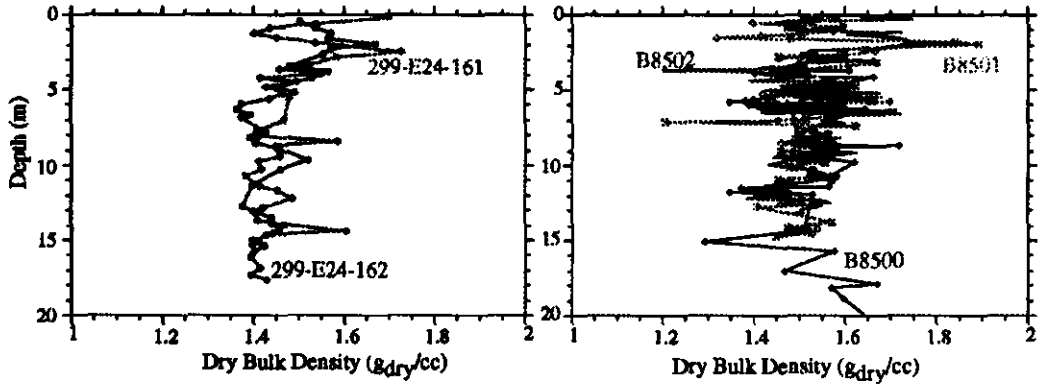


Figure B.7. Dry Bulk Density Comparison Between 1995 Exploratory Boreholes (a) and B8500 Series Boreholes (b)

B.4.2 Tracer Results and Discussion

Unsaturated flow processes have been investigated using indirect physical measurements (e.g., water balance and Darcy flux measurements), direct physical measurements (e.g., lysimetry), and environmental tracers (e.g., Cl, ^{3}H, and ^{36}Cl). Allison and others (Allison 1988; Allison et al. 1994) concluded that the indirect physical measurements were the least successful in arid regions and the tracer methods were the most successful. However, Phillips (1995) cautioned that "unless considered in the context of a thorough evaluation of the physical hydrogeology, tracer results are of generally limited value. Conversely, isotopic and environmental tracers can usually provide very useful constraints on interpretations of subsurface flow regimens."

The application of environmental tracers generally yields a site-specific, long-term recharge estimate (where recharge is defined as the net deep drainage flux when measured below the root zone). This section details the results of the environmental tracers, ^{36}Cl, chloride, and Cl/Br ratios.

B.4.2.1 Bomb-Pulse ^{36}Cl

^{36}Cl (half life approximately 301,000 years) was produced indirectly during atmospheric nuclear weapons testing by thermal neutron irradiation of chloride in sea water. Thus, only the explosions carried out by the United States in the South Pacific between late 1952 and mid-1958 activated chloride in sea-water and produced the worldwide ^{36}Cl signal (Bentley et al. 1986). The peak in the ^{36}Cl fallout occurred in 1955 (Phillips et al. 1988). Water fluxes are estimated for bomb-pulse ^{36}Cl from the depth of the center of mass of the ^{36}Cl profile. The amount of water in the profile above the center of mass is equal to the water flux over the time period since the ^{36}Cl was deposited on the soil surface.

Archived samples were processed for ^{36}Cl. These samples had been collected in 1995 at the ILAW Disposal Site (previously known as the Low Level Glass Site) in the 200 East Area. Large quantity samples were collected from a trench with a backhoe. Depth measurements were made before each sample was collected. The samples were sealed in plastic buckets and processed for leachable chloride in late 1997 to early 1998. The samples were analyzed for $^{36}Cl/Cl$ by tandem accelerator mass spectrometry (TAMS) at Lawrence Livermore National Laboratory. Blind sample splits were included to determine TAMS measurement variability. The results with measurement error bars are plotted against sample depth in Figure B.8. The samples and sample-splits were processed in two different runs approximately a month apart. The sample splits showed little variability considering the TAMS runs were a month apart.

A sharp $^{36}Cl/Cl$ peak occurs in the trench profile (see Figure B.8) with a center of mass at approximately 1.5 m. The peak is still well within the root zone at this site. When the bomb-pulse $^{36}Cl/Cl$ is located in the root zone, one can infer that the water flux at this site is extremely low (Scanlon et al. 1997). Much of the water in the root zone is eventually removed by evapotranspiration; therefore, estimates of water fluxes by tracers in the root zone will overestimate the amount of net deep drainage flux below the root zone by several orders of magnitude (Tyler and Walker 1994). These types of estimates would also be affected by seasonal moisture variations in the root zone. Recharge is defined as the net deep drainage flux *below* the root zone (e.g., that water that has escaped evapotranspiration processes and can therefore contribute to recharge of the unconfined aquifer).

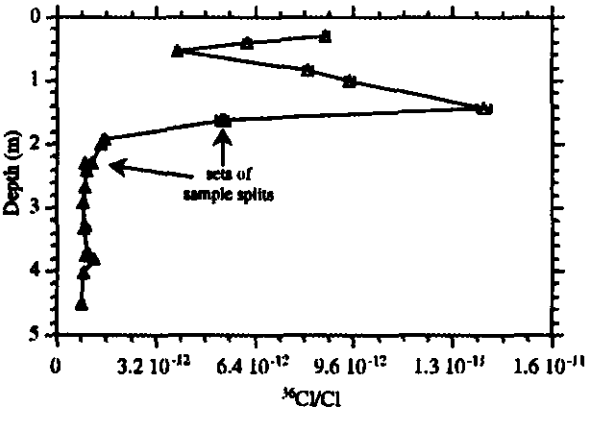


Figure B.8. Bomb-Pulse ^{36}Cl Profile from Samples Collected in the Plains Trench at the ILAW Disposal Site

The shape of the $^{36}Cl/Cl$ pulse in Figure B.8 is significant because it suggests that the center of tracer mass is moving by piston flow through the root zone. Piston-type flow is an underlying assumption in most unsaturated flow models and in methods used to estimate recharge by atmospheric tracers. Deviations from piston flow can occur when there is preferential flow through root channels and macropores created by natural soil activities. Although there is no evidence to indicate that this piston-type flow can persist below the root zone, absence of a strong preferential flow component in the root zone suggests that this mechanism may dominate in these sandy sediments. The ratio $^{36}Cl/Cl$ may not indicate preferential flow if chloride concentrations are high because small variations in ^{36}Cl can be overwhelmed by the high chloride. We did not measure the chloride concentrations of these samples, but nearby boreholes indicated the chloride concentrations could be as high as 4000 mg/L.

B.4.2.2 Chloride Mass Balance

The natural tracer method based on CMB is one of the simplest, least expensive, and most useful for determining recharge in arid climates (Allison et al. 1994). In this mass balance approach, water entering the soil column contains meteoric chloride that is treated as an inert tracer. As water percolates downward through the root zone, evapotranspiration removes water, thus enriching the chloride concentration with depth through the root zone. This increase in chloride concentration quantitatively reflects the corresponding reduction in water flux from the infiltration flux to the deep drainage flux beneath the evapotranspiration zone. The CMB method is especially applicable to arid and semiarid regions where evapotranspirative enrichment of the pore water produces a distinct chloride profile in the unsaturated zone.

Application of the CMB method typically involves the following simplifying assumptions regarding transport: 1) flow is vertically downward of piston type at constant water content and 2) the precipitation and the accumulation rate of atmospheric chloride are steady over the relevant period. An additional assumption of steady state water flux throughout the column is often invoked, but as shown by Ginn and Murphy (1997) this assumption is not required in application of CMB. Recharge or net deep drainage flux is determined by the relationship

$$J_R = \left(\frac{Cl_o}{Cl_{sw}}\right) P \qquad \text{(B.1)}$$

where J_R = net downward deep drainage flux (mm/yr)
Cl_o = average atmospheric chloride concentration in local precipitation and dry fallout (mg/L or equivalent units of g/m^3)
Cl_{sw} = average chloride concentration in the soil water (mg/L)
P = average annual precipitation (mm/yr).

Cl_o can be expressed as the total chloride mass deposited at ground surface q_{Cl} (q_{Cl} - units of mg $m^{-2}yr^{-1}$) divided by the precipitation (160 mm/yr at Hanford). Values for q_{Cl} can be measured,

calculated, or obtained from the literature. For the ILAW site, q_{Cl} was determined using the approach outlined by Phillips et al. (1988) and Scanlon et al. (1990):

$$q_{Cl} = \frac{{}^{36}Cl_o \left(atoms\, m^{-2} s^{-1}\right)\left(31.56 \times 10^6\, s/yr\right)\left(35.5 \times 10^3\, mg/mol\right)}{\left({}^{36}Cl/Cl\right)_m \left(6.023 \times 10^{23}\, atoms/mol\right)} \quad \text{(B.2)}$$

where ${}^{36}Cl_o$ = calculated natural fallout of 18.8 atoms $m^{-2}s^{-1}$ for 46°N geographic latitude (Andrews and Fontes 1992)

$({}^{36}Cl/Cl)_m$ = ${}^{36}Cl/Cl$ ratio in the soil water excluding the anthropogenic ${}^{36}Cl$ peak.

Over the Holocene the geographic latitude represents a long-term average of the frequent fluctuations in the geomagnetic latitude (Merrill and McElhinny 1983). Below the bomb pulse, the average ${}^{36}Cl/Cl$ ratio between depths 2.4 and 4.8 m was 911 x 10^{-15}. The values ranged from 810 x 10^{-15} to 1160 10^{-15} and had a median value of 887 x 10^{-15}. Ratios at other sites at Hanford fall within this range (Murphy et al. 1996; Prych 1998). Using the average ratio of 911 x 10^{-15} in Eq. B.2, we calculated a q_{Cl} value of 38.4 mg/m^2/yr. This value is consistent with previously reported values for the 200 area plateau, which range from 32.7 to 49.4 mg/m^2/yr (Murphy et al. 1996).

Figure B.9 shows the chloride profiles (concentration of chloride in the pore waters) for the two exploratory boreholes in 1995 and the four B8500 boreholes drilled in 1998. The exploratory boreholes both show a peak in chloride starting at approximately 1.5-m depth and ending at approximately 4-m depth (center of mass is approximately 2.5 to 3 m). As can be seen in Figure B.9b, only the bottom portion of the chloride pulse was recovered from borehole B8500. The drilling contractor was not prepared to collect continuous core and did not attempt to collect core above approximately 3 m. The depth of the bottom of the B8500 profile was consistent with the location of the chloride profiles in 1995. By 5 to 6 m the chloride concentration in the porewater has returned to background levels.

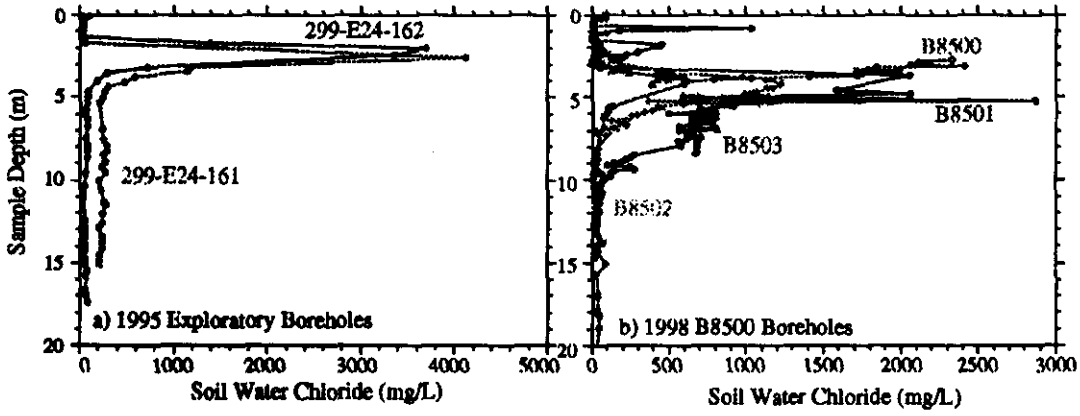


Figure B.9. Comparison of Chloride Profiles from B8500, B8501, and Exploratory Boreholes Drilled in 1995

The chloride profile for B8501 is more complete, but much more irregular than what we typically find at undisturbed sites (Figure B.9b). The chloride peaks near the surface (0 to 3 m) are most likely artifacts of the fill dirt/gravels that were deposited at this location and therefore should be disregarded. For example, B8503 is located directly adjacent to B8501, a meter off of the drill pad where the surface was undisturbed. There are no significant peaks in the chloride in the top 3 m of the B8503 profile. The secondary peak of chloride in the B8501 borehole between a depth of 6 to 9 m suggests a past period of lower recharge rates, possibly due to changes in the surface vegetation. It is possible that the B8503 profile may have mimicked the chloride profile in B8501; however a critical portion of the B8503 core, where the peak chloride concentration would likely occur, was not recovered between 4 and 5 m. The chloride profile from the B8502 borehole is deeper than the peaks detailed in the 1995 exploratory boreholes and has a broader peak, suggesting higher recharge rates at this location.

The CMB method for estimating recharge relies on an accurate accounting of the mass of this tracer. If chloride mass is removed by grading or added by applying gravel/fill to the surface, then the mass balance approach will be compromised. So little of the chloride pulse is defined in B8500, that we are unable to determine the peak concentration and cannot estimate recharge using the chloride mass balance method for this particular borehole. In addition, incomplete recovery of the B8503 chloride profile precludes using this profile for estimating recharge rates.

The net downward deep drainage flux can be estimated with the conventional CMB method (Equation B.1). A value for Cl_{pw} is determined by plotting cumulative chloride content with depth against cumulative water content at the same depth (Figure B.10). The slopes of the straight-line segments represent a period over which the precipitation and atmospheric chloride deposition conditions were approximately constant. The recharge rates ranged from 0.013 to 0.016 mm/yr at the 1995 exploratory boreholes (Figure B.10a). Somewhat higher rates were found at the B8500 site, ranging from 0.03 to 0.065 mm/yr; however, these estimated rates are still quite low. The recharge rates are consistent with the differences in surface vegetation at the two locations. Two recharge rates are calculated for B8501, one corresponding to the initial chloride peak and the other corresponding to the secondary bulge in chloride below the initial peak (Figure B.10b).

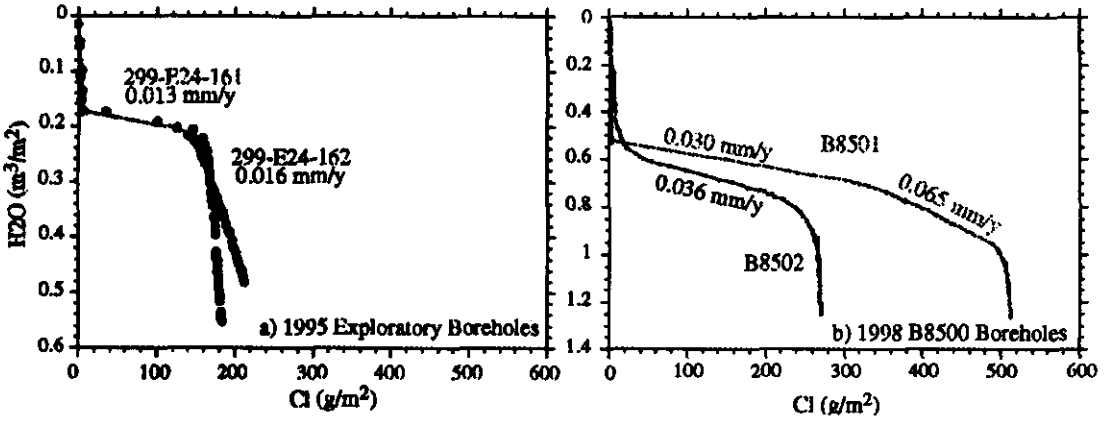


Figure B.10. Cumulative Water Versus Cumulative Chloride in the Sediment Profiles

The cumulative masses of chloride are different for the boreholes shown in Figure B.10. In particular, borehole B8501 had more total chloride than the other boreholes. If we assume that the large peak starting at approximately 3 m was not contaminated by fill material, then there are two possible processes that could lead to the differences in total chloride mass: 1) spatial and temporal differences in the extraction rate of water over time, and 2) variable input of chloride at the soil surface.

The variable total masses of the chloride in the different boreholes is most likely caused by spatial and temporal variations in the extraction rate of water over time. The extraction rate is a function of the type and density of the vegetation at a particular location and also is affected by the seasonal timing of precipitation. The two borehole locations were both subjected to repeated flooding during the late Pleistocene, which would have erased the pre-Holocene chloride signal (Murphy et al. 1996). The post-flood depositional history at the two ILAW drilling locations, however, is quite different as evidenced by their stratigraphy. The B8500 boreholes were located on the tail of a long dune lying in an east-west direction, while the 1995 exploratory boreholes were located approximately 300 m north of the dune. At the exploratory boreholes the eolian sands represent the top 0.5 m of the profile followed by the flood deposits of the Hanford formation. Using the accumulation of chloride mass at the exploratory boreholes as a measure of the time of evapotranspirative enrichment, vegetation capable of extracting pore water such that chloride is accumulated was likely established around 5,000 yBP at this site. This timing is consistent with the end of a period of maximum aridity that occurred between 8,000 and 5,500 yBP (Chatters and Hoover 1992; Gaylord et al. 1991) and transition to higher precipitation rates that would have been conducive to the establishment of vegetation.

The stratigraphy at the B8500 location is much more complex. The occurrence of a paleosol at 3 m in B8501 and 1.5 m in B8502 (Reidel et al. 1998) may reflect a time period early in the Holocene (approximately 8,000 to 10,000 yBP) when a grass-steppe vegetation dominated (Chatters and Hoover 1992; Mehringer 1985). This paleosol was also encountered at a backhoe trench that was attempted on the north (leeward) side of the dune in 1995 (the Dune Trench in Appendix D). The entire sequence exposed to approximately 4 m in this trench consisted of eolian sand. The flood deposits of the Hanford formation were not encountered before the trench collapsed at 4 m. However, a dark yellowish brown silty fine sand was found just below 3 m in the trench. Several peat-like clasts consisting of dense, partially decomposed mats of root hairs were located at this depth indicating past establishment of vegetation at this location. The dune lying in an east-west direction at the southern end of the proposed ILAW Disposal Site overlies this paleosol and may have been deposited during a period of maximum aridity, between 8,000 and 5,500 yBP. Therefore, it is possible that the lower chloride bulge in B8501 contains chloride accumulated in the early Holocene (10,000 to 8,000 yBP), followed by an arid period of dune formation (8,000 to 5,500 yBP), followed by establishment of vegetation again in the late Holocene (approximately 5,000 yBP to present). The more recent period is represented by the sharp chloride peak at 4 to 5 m.

In addition to a variable history in extraction rate, spatially variable atmospheric deposition of chloride could lead to differences in the total mass of chloride in the sediment profiles. It is highly unlikely that the atmospheric deposition of chloride would be spatially variable over such a small area (22 m horizontal separation between B8501 and B8502). Non-meteoric sources of chloride, such as

chloride leaching from basalt grains or anthropogenic sources of chloride, may lead to spatially varying masses of chloride in the sediment profile and will be discussed in more detail in the next section.

B.4.2.3 Cl/Br Ratios

Ratios of ions are often used as tracers in hydrologic studies to determine the origin or evolution of waters or to quantitatively evaluate the mixing of different sources of water. If the two ions used have similar properties, then their ratio should remain relatively constant. In a recent article, Davis et al. (1998) reviewed information on the chemistry, characteristics, and concentrations of chlorine and bromine in nature. We have adopted the terminology of Davis et al. (1998) and have expressed Cl/Br as a ratio of the mass of each element.

Ratios of Cl/Br were analyzed to evaluate non-meteoric sources of chloride (Figure B.11). At the proposed ILAW Disposal Site, non-meteoric sources might include chloride leaching from basalt sand grains and chloride deposited from anthropogenic sources such as fly ash from a nearby power plant or other processing facilities within the 200 East Area. The ratios of potential sources of chloride were either measured or extracted from published reports. The basalt sands in the Hanford formation originate from the Columbia River basalt, which consists of multiple basalt flows that include the Grande Ronde, Saddle Mountain, and Wanapum flows. Flanagan (1973) measured a Cl/Br ratio of 333 for the Grande Ronde basalt. Ratios of Cl/Br in an additional 14 basalt samples ranged from 184 to 500 (Yoshida et al. 1971). The meteoric ratio of Cl/Br is somewhat more difficult to evaluate because approximately 60% of the chloride deposition occurs in dry fallout, while the remaining 40% is associated with precipitation events. The anion ratios may be quite different for wet and dry deposition. However, to evaluate the meteoric source, we need the combined ratio of wet and dry atmospheric deposition. In an extensive survey, Davis et al. (1998) found that most Cl/Br ratios in precipitation were less than 200. They suggested that Cl/Br ratios in precipitation vary geographically between 130 and 180 near the coast, to

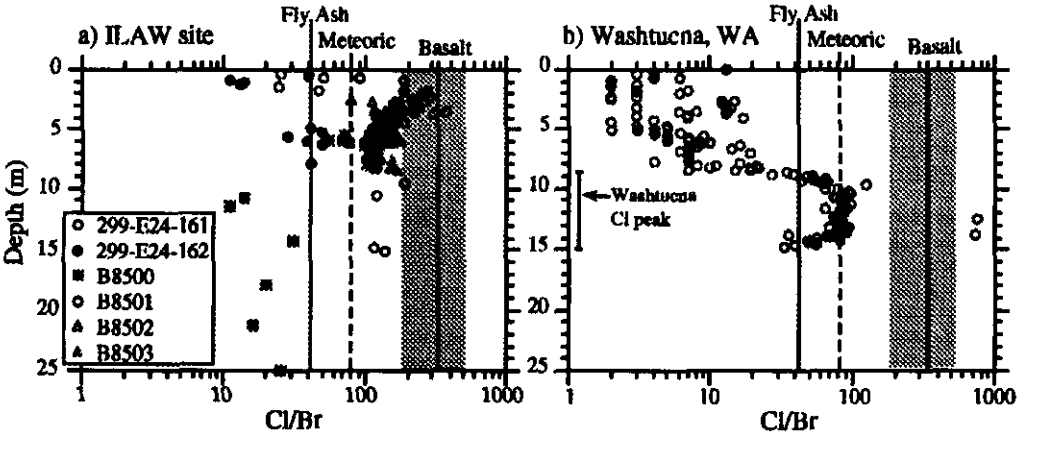


Figure B.11. Cl/Br Ratios of Pore Water Extracts from the ILAW Site (a) and the Washtucna Site in the Palouse Region of Eastern Washington State (b). The dashed line represents the meteoric Cl/Br ratio. The solid line represents the Cl/Br ratio of Grand Ronde basalt.

between 75 and 120 several tens to a few hundred kilometers inland, to as low as 50 several hundred kilometers inland. Berg et al. (1980) measured a Cl/Br ratio of 80 in the lower stratosphere at northern latitudes, which represents the total concentration of these anions in air. In the absence of specific measurements of meteoric Cl/Br in the Pasco Basin, shallow porewater ratios should reflect the combined wet/dry fallout ratio of meteoric Cl/Br. As can be seen, however, at the proposed ILAW Disposal Site (Figure B.11a) the Cl/Br ratios in the first few meters of the profile were the most variable, ranging from 10 to over 100. Surface evaporation alone should not affect this ratio.

In all of the boreholes examined to date, the Cl/Br ratio was low in the shallow portion of the borehole, increased to a maximum at the depth of the chloride peak, and then declined again below the chloride peak in the lower regions of the profile (Figure B.11). The increase in Cl/Br shifts the ratio closer to the ratio found in basalt. However, the increase in the ratio is not correlated with the basalt composition of the sediments (Murphy et al. 1996) nor is there sufficient chloride in basalt to impact the mass of this peak. The increase in the ratio also is not consistent with fly ash from the power plant located next to the proposed ILAW Disposal Site. Leaching of an 11-cm-deep sample of fly ash yielded a Cl/Br ratio of 41 (Table E.3, Appendix E), somewhat lower than the meteoric signature of 80 reported by Berg et al. (1980). In contrast to the shallow fly ash sample, a deeper sample (61 cm) yielded a Cl/Br ratio of 382. Although based on only two samples, the wide range of Cl/Br ratios in the fly ash may make it difficult to demonstrate a correlation with the ratios observed in the boreholes.

Finally, the ratios from the proposed ILAW Disposal Site are compared to the ratios collected from a borehole in the Palouse region of eastern Washington State (Figure B.11b, Washtucna, Washington). This site is not located near a power plant and is in a region of eolian deposition of fine sand and silt. The precipitation and recharge rates are much higher at the Washtucna site (Ginn and Murphy 1997). The Cl/Br ratios above the chloride peak are much lower than values at the proposed ILAW Disposal Site. It is not known whether these lower Cl/Br ratios reflect the relative distances of the sites from the ocean (approximately 350 kilometers for ILAW versus approximately 450 km for Washtucna) or other atmospheric patterns which might affect the meteoric ratio (Davis et al. 1998). The maximum Cl/Br ratios occurred concurrent with the depth of the chloride peak and then declined below this zone of evapotranspirative enrichment. Plotting the Cl/Br ratio against the chloride concentration in the pore water showed the relationship of an increasing ratio with increasing concentration of chloride (Figure B.12). The chloride and bromide peaks in the ion chromatograph were sufficiently separated that this relationship was not due to analytical interference at high chloride concentrations. We were also unable to find any bias in the ratios with low bromide measurements.

Davis et al. (1998) found a similar relationship of increasing Cl/Br with increasing concentration of chloride in precipitation samples and in groundwater samples. These authors also provide insight into a possible mechanism that leads to higher Cl/Br ratios in the zone of evapotranspirative enrichment of chloride. Chlorine is generally 40 to 8000 times more abundant than bromine. Therefore, a relatively small change in the total mass of bromine will give rise to a large change in the Cl/Br ratio. Additionally, bromide is much more soluble than chloride. McCaffrey et al. (1987) noted that during the evaporation of seawater, the residual brine is enriched in bromide due to bromide's higher solubility. Finally, some researchers have suggested that surface vegetation may concentrate bromine (Gerritse and George 1988; Shotyk 1997).

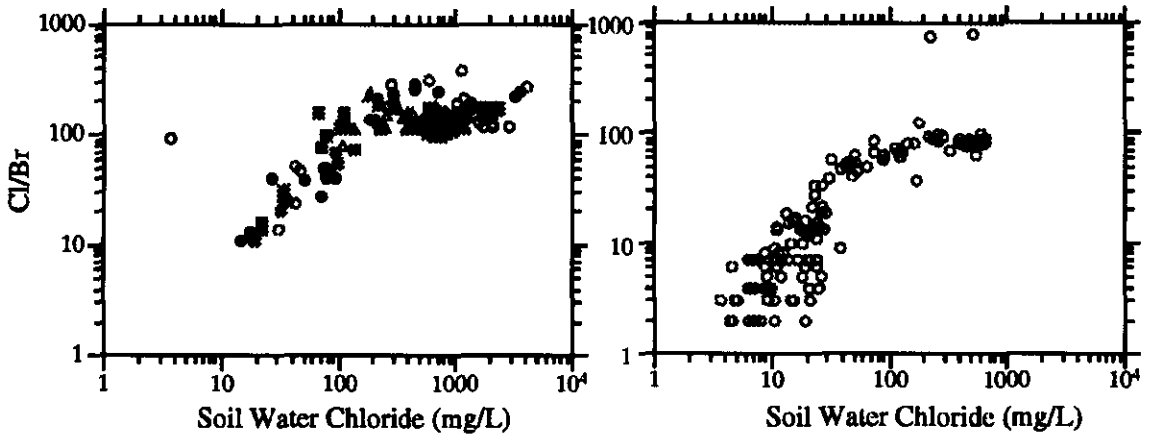


Figure B.12. Relationship Between the Soil Water Chloride Concentration and the Cl/Br Ratios at the ILAW Site (a) and the Washtucna Site in Eastern Washington State (b)

Two possible mechanisms could result in greater Cl/Br ratios in the zone of evapotranspirative enrichment: differential solubility and selective plant uptake. The highest soil water chloride concentrations generally range from 1000 to 4000 mg/L at gravimetric moisture contents as low as 0.02 g/g. Theoretically, plants could reduce the water content in the sediment. Under this condition, chloride is more likely than bromide to precipitate out of solution, leaving the soil solution enriched in bromide. As the plants take up soil water, the more soluble bromide will be removed in quantities greater than chloride, because a higher proportion of bromide mass will be in solution. When sediments are processed with distilled water to extract dissolved species, both the precipitated and solution chloride are recovered. Because bromide concentrations are so much lower than chloride to start with, any removal of the more soluble bromide by the plants will produce lower total bromide mass in the evapotranspiration zone. This precipitation mechanism is not likely, however, because the solubility concentration limit of chloride salts is ~220,000 mg/L. In the example above, the plants would have to reduce the water content from 0.02 g/g to the unrealistically low value of 0.0004 g/g for precipitation to occur. The selective plant uptake of bromide relative to chloride remains a viable mechanism.

This process could be tested by 1) extracting the pore water directly from the sediments without adding distilled water, and/or 2) by measuring the ratios of Cl/Br in the plant biomass for direct comparison with the ratios in the zone of evapotranspirative enrichment. Rickard and Vaughan (1988) measured chloride and bromide in two samples of sagebrush leaves, which yielded Cl/Br ratios of 100 and 196. These values bound the limits found in the zone of evapotranspirative enrichment at the proposed ILAW Disposal Site. Ideally, a direct comparison of the Cl/Br ratios in the sediment profile should be made with the plant biomass at the same site.

If the Cl/Br ratios are altered in the zone of evapotranspirative enrichment, then the Cl/Br ratios may be much more useful in tracer studies than just identifying non-meteoric sources of chloride. The Cl/Br ratios may provide an understanding of the recharge mechanisms taking place in the Hanford vadose zone. For example, all of the profiles at the proposed ILAW Disposal Site show the characteristic

increase in the Cl/Br ratio in the zone of evapotranspirative enrichment (Figure B.11a). Most of the profiles show a decline in the Cl/Br ratio below this zone, suggesting that little water is escaping the root zone. In one of the 1995 exploratory boreholes, 299-E24-161, high Cl/Br ratios persist at depth and somewhat higher total chloride mass. On a mass basis, approximately 5% of the chloride may be displaced below the chloride peak. There are two possible mechanisms that may lead to this displacement of chloride from the peak: 1) preferential flow, or 2) displacement of sands during drilling. Although preferential flow cannot be ruled out, we might expect to see some indication of chloride mass displacement in the shape of the chloride peak (e.g., multiple peaks). The chloride peak at this site is extremely sharp. In addition, the ^{36}Cl profile, which was evaluated in nearby, similar sediments, also does not indicate preferential flow processes. The depth affected by elevated chloride mass cannot be assessed because the borehole did not extend beyond 15 m and the depth to groundwater at this location is 100 m. The other mechanism that may result in a small amount of the chloride mass displaced below the zone of evaporative enrichment is simply displacement of sands during drilling. The sands are extremely dry below the root zone and can "flow" during the drilling process. This makes sediment recovery difficult and can easily lead to cross-contamination along the vertical borehole.

B.5 Conclusions

Tracer measurements are effective in providing direct estimates of recharge in the natural environment. This approach can yield a range in recharge rates that often reflect the spatial heterogeneity in stratigraphy, surface land forms, and vegetation, as well as the temporal history at a particular site. Tracer measurements and physical characteristics were evaluated at two different locations at the proposed ILAW Disposal Site. In 1995, two exploratory boreholes were drilled within the ILAW boundaries. In 1998, one deep and three shallow boreholes (B8500 series) were drilled just outside the southern boundary of the proposed ILAW Disposal Site. The fine-scale stratigraphy at the two locations is quite different, which is not unusual for the Hanford formation. At the B8500 location, the shallow stratigraphy (0 to 15 m) shows slightly higher clay contents (5 to 10%) and higher and more variable silt contents. These variations lead to more pronounced horizontal layering at the B8500 site and greater fluctuations in water content and bulk density along the vertical profiles than was evident in the profiles from the exploratory boreholes. The mature and dense sagebrush vegetation at the exploratory boreholes would also contribute to the more uniform (and low) gravimetric moisture profiles at this site.

Although drilling is relatively easy in the predominantly sandy sediments found at the proposed ILAW Disposal Site, core recovery is quite difficult. The depth of the bottom of the root zone was defined operationally as the depth of the zone of evapotranspirative enrichment of chloride. At and below this depth the sediments were extremely dry, loose, and uncompacted, and it was sometimes impossible to keep the sediment within the split tube samplers. The chloride mass balance method was applied to samples from those boreholes that had relatively continuous core recovery within the critical zone of evapotranspirative enrichment of chloride. Recharge rates were estimated for two exploratory boreholes (299-E24-161 and -162) and two shallow boreholes (B8501 and B8502). In all cases the tracer measurements showed relatively low long-term averages of recharge, ranging from 0.013 to 0.036 mm/yr. At one borehole, B8501, a secondary chloride bulge below the initial peak suggests a past period of recharge (possibly in the early Holocene) with an average rate of 0.065 mm/yr.

The variable total masses of the chloride in the different boreholes is most likely caused by spatial and temporal variations in the extraction rate of water over time. The two borehole locations were subjected to repeated glacial-outburst flooding during the late Pleistocene, which would have erased the pre-Holocene chloride signal (Murphy et al. 1996). The stratigraphy at the different locations suggests early Holocene establishment of vegetation at the B8500 location followed by a period of dune formation in the mid-Holocene, and then vegetation establishment again in the late Holocene. The exploratory borehole stratigraphy, north of the sand dune, shows no evidence of establishment of vegetation in the early Holocene. It is likely that no evapotranspirative enrichment of chloride occurred prior to the establishment of vegetation approximately 4,000 to 5,000 yBP. Without vegetation, the movement of water through the vadose zone would be rapid.

A bomb-pulse ^{36}Cl peak was measured in samples excavated from a trench with a backhoe. A sharp peak at a depth of 1.5 m showed that this tracer was still in the root zone and, therefore, could not be used to estimate recharge. Scanlon et al. (1997) suggested that the presence of ^{36}Cl near the surface indicates little or no water flux below the root zone. The sharp ^{36}Cl profile suggests that the water is moving by piston flow through the root zone. If preferential flow is occurring in a particular sediment, we would expect to see evidence of this process in the root zone where old root channels and macropores are common. However, the chloride concentrations are too high to draw firm conclusions.

Ratios of Cl/Br were also used as a tracer in this study to investigate non-meteoric sources of chloride input. These ratios, which were consistently elevated in the zone of evapotranspirative enrichment of chloride, may be due to preferential uptake of bromide into the plant biomass. Although the Cl/Br ratios do not quantify recharge, the ratios have the potential to suggest invalidation of some recharge estimates. At the ILAW Disposal Site, the Cl/Br evidence does not contradict the recharge estimates from other methods.

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Appendix C

Simulation Estimates of Recharge Rates for the Two ILAW Disposal Sites

M. J. Fayer

Appendix C

Simulation Estimates of Recharge Rates for the Two ILAW Disposal Sites

C.1 Introduction

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in near-surface, shallow-land burial facilities. The LMHC project to assess the performance of these disposal facilities is known as the Hanford ILAW Performance Assessment (PA) Activity, hereafter called the ILAW PA. Acceptance of ILAW disposal at the Hanford Site depends on demonstrating that public health and the environment are adequately protected. Achieving this goal will require predictions of contaminant migration from the facility. To make such predictions will require estimates of the fluxes of water moving through the sediments within the vadose zone beneath and around the disposal facility. These fluxes, loosely called recharge rates, are the primary mechanism for transporting contaminants to the groundwater.

Mann (1999) indicated that two disposal sites will be considered: the ILAW Disposal Site (located southwest of the PUREX Plant) and the Existing Disposal Site (the former Grout Vaults). For each, recharge rate estimates are needed for a fully functional surface cover, its sideslope, and the immediately surrounding terrain. In addition, recharge estimates are needed for degraded conditions and for the case of irrigated farming directly on the cover. Mann (1999) indicates that the temporal scope of the 2001 ILAW PA is 10,000 years, but could be longer as some contaminant peaks occur after 10,000 years.

Pacific Northwest National Laboratory (PNNL) assists LMHC in their assessment activities. One of the PNNL tasks is to provide defensible estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of ILAW (LMHC 1999). A major goal of the PNNL task is to collect sufficient data for the conditions and scenarios deemed to be important for evaluating the performance of the disposal facilities. These rate estimates will be provided using lysimetry, tracer studies, and modeling studies.

The recharge task uses a numerical recharge model to estimate the recharge fluxes for scenarios pertinent to the ILAW PA for which data do not currently exist. Because of the long time periods involved, data do not exist for many of the scenarios. Therefore, the model is used to extend the observations and to estimate recharge rates for potential future scenarios. This appendix summarizes the process used to provide LMHC with recharge estimates for scenarios identified for the 2001 ILAW PA.

C.2 Methods

PNNL used a one-dimensional numerical model to estimate recharge rates for the two proposed ILAW disposal locations—the ILAW Disposal Site and the Existing Disposal Site. Figure C.1 shows where the two sites are located within the 200 East Area. Two soil types (Rupert sand and Burbank loamy sand) occupy both sites (Hajek 1966). Much of the proposed ILAW Disposal Site is covered by a relatively undisturbed shrub-steppe plant community. A shrub-steppe community existed at the Grout Vault Site at one time, but it was removed to construct the four existing vaults and place the spoils pile (located to the east). Most elevations at the proposed ILAW Disposal Site range from 219 to 222 m. The dune along the southern edge rises above the surrounding terrain by as much as 9 m, with a peak elevation of about 229 m. Elevations at the Existing Disposal Site are slightly lower, ranging from 204 to 206 m.

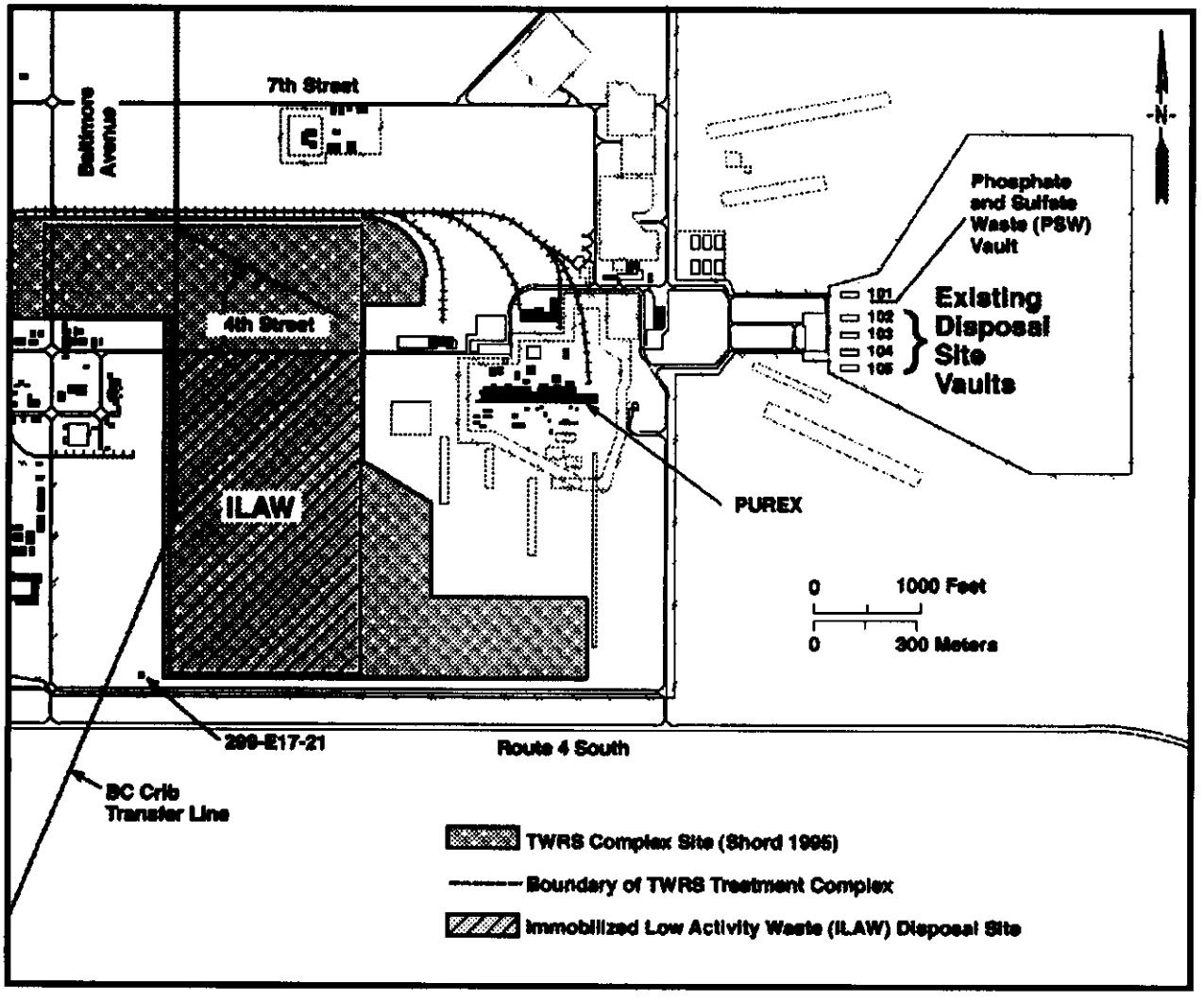

Figure C.1. Locations of the ILAW Disposal Site and the Grout Disposal Vaults

Based on this information, three scenarios were identified for simulation: the surface cover, Rupert sand, and Burbank loamy sand. Two additional scenarios were included to address two types of surface cover degradation. The sideslope component of the cover was not evaluated here. The simulation cases and associated model parameters are described in the following sections. The purpose of the surface cover is to store water and promote evapotranspiration rather than promote lateral flow. Thus, the one-dimensional UNSAT-H model is appropriate.

C.2.1 Simulation Cases

Table C.1 shows the five scenarios that were evaluated to estimate the response of recharge rates to variations in several variables, including climate, vegetation, soil properties, and irrigation. The first three scenarios addressed functional disposal facility features: the proposed surface cover and the two soil types found in the surrounding terrain. The fourth scenario addressed the impacts of dune sand deposition on the surface cover. The fifth scenario addressed the impact of erosion of a portion of the surface cover. All five scenarios were evaluated for current climate conditions and for the future climate possibility most likely to promote recharge (i.e., increased precipitation and decreased temperature, denoted P↑T↓ symbolically).

Table C.1. Scenarios and Variables Tested with Simulations Using the Isothermal, Non-Hysteretic Mode of UNSAT-H and a Shrub-Steppe Plant Community (unless noted otherwise)

		Scenario				
Variable	**Condition**	**Modified RCRA Subtitle C Cover**	**Rupert Sand**	**Burbank Loamy Sand**	**Dune Sand on Cover**	**Eroded Surface Cover**
Climate	Current	√	√	√	√	√
	P↓		√			
	P↑		√			
	T↓		√			
	T↑		√			
	P↓T↑		√			
	P↑T↓	√	√	√	√	√
Vegetation	Cheatgrass		√			
	No plants	√	√	√	√	√
	No plants, future climate (P↑T↓)		√	√		
Shrub Leaf Area Index	High (0.4 vs. 0.25)		√			
	Low (0.1 vs. 0.25)		√			
Rupert Sand Properties	Higher $K(h)$ vs. Rupert sand		√			
	Lower $K(h)$ vs. Rupert sand		√			
Complete Areal Plant Coverage	Cheatgrass		√			
	Sagebrush		√			
Irrigation Efficiency	75%	√	√			
	100%	√	√			

Plant community composition will likely change in response to climate changes. Wing et al. (1995) reported that the plant communities in the Columbia Basin have fluctuated between sagebrush-dominated shrub-steppe and bunchgrass-steppe in the Holocene. Also, there is modern evidence of invasive plant species supplanting native species. Finally, the modern record clearly indicates that fires occur regularly, removing vegetation in the short term and altering the composition of the plant community for years after a fire.

C.2.2 Model Description

Simulations were conducted using the UNSAT-H computer code (Fayer and Jones 1990). UNSAT-H was accepted for use at Hanford via the Tri-Party Agreement process (DOE 1991). The ILAW project has used this code for several years specifically to calculate recharge rates. In FY 1998, the code was updated to include new features such as hysteresis and the ability to simulate multiple years with one input file.

The UNSAT-H code has been tested with lysimeter data. Fayer et al. (1992) and Martian (1994) compared predicted and measured water storage values for lysimeters at Hanford. Both found that calibration of several parameters improved the match of predicted to measured values as determined by the root-mean-square (RMS) error. For a 1.5-year test of a lysimeter receiving an enhanced precipitation treatment, Fayer et al. (1992) calculated a RMS error of 0.8 cm after calibration (versus 2.2 cm without calibration). Martian (1994) looked at a much longer time period (5.5 versus 1.5 years) and found the RMS error was higher—about 1.8 cm for the calibrated model. The analysis was not done for the uncalibrated model. Martian determined the correlation coefficient for the comparison of measured and simulated soil water storage was 0.94, which is quite good. Fayer and Gee (1997) extended the comparison to 6 years. The data were collected from a non-vegetated weighing lysimeter containing 150 cm of silt loam over sand and gravel. They found that the RMS error for water storage predictions was about 2.3 cm regardless of whether the model was calibrated or whether it included heat flow or hysteresis. Fayer and Gee (1997) extended the comparison to matric potential and drainage. They found that the simulation with hysteresis was far better at predicting matric potentials throughout the 6-year period and it was the only simulation to predict drainage (52% of the measured amount, with timing that matched the observations). Fayer and Gee (1997) concluded

- UNSAT-H can reasonably predict the water balance components of a capillary-break type cover.
- The inclusion of heat flow has only a minor effect on surface evaporation and vapor flow within the soil (the impacts of heat flow on snow accumulation and melt and on soil freezing were not evaluated).
- A calibrated model will not necessarily apply well outside of the calibration period.

Khire et al. (1997) tested UNSAT-H for simulating water movement in surface cover test plots in a semiarid setting in Washington and a humid setting in Georgia. They tested the model using a 3-year record of data that included overland flow, soil water storage, evapotranspiration, and percolation. Time series plots of the data and predictions showed that UNSAT-H generally mimicked the seasonal trends.

The authors noted several conceptual features that were important to the Washington site but were not included in the model: snow cover, snow melt, and freezing soil. These features are scheduled for inclusion starting in FY 2000 (LMHC 1999).

The UNSAT-H code has been used at the Hanford Site to estimate the areal distribution of recharge rates (Fayer et al. 1996). The code has also been used elsewhere to evaluate infiltration through surface covers (Magnuson 1993) and surficial sediments (Martian and Magnuson 1994).

C.2.3 Model Domain and Discretization

The model domain for the surface cover extended to the base of the gravel filter layer, which was located at a depth of 130 cm. We would have extended it to the base of the gravel drainage layer, but the hydraulic properties of this material were too difficult to simulate using the standard hydraulic functions. Fortunately, our experience has shown that neglecting the additional thickness of gravel has only a minimal impact on the results. Differences in drainage caused by variations in filter gravel thickness were less than 0.1 mm/yr. For the other simulation cases, the model domain was extended to 400 cm. The node spacing in all simulations started at 0.2 cm at the soil surface and gradually increased with depth. At material interfaces, the node spacing was decreased to 2 cm. Changes in node spacing from node to node were limited to less than 50%. Time step sizes were allowed to range from 10^{-10} to 1 hour, depending on the mass balance error.

C.2.4 Soil Hydraulic Properties

Soil hydraulic properties consist of the soil water retention function and the hydraulic conductivity model. For all materials in this report, soil water retention was described with the van Genuchten function and hydraulic conductivity was described with the Mualem conductivity model. Three soil models were considered: modified RCRA Subtitle C Cover, Rupert sand, and Burbank loamy sand. Table C.2 lists the parameters for the materials making up each soil model. We did not address possible changes in soil hydraulic properties in response to soil development.

Martian (1994) simulated the performance of the modified RCRA Subtitle C Cover by accounting for all five materials that reside above the asphalt layer: silt loam/gravel admix, compacted silt loam, filter sand, filter gravel, and drainage gravel. For this report, the sand and gravel parameters were described using the Martian (1994) parameters without modifications. In contrast, some of the silt loam parameters were modified to accord with known relationships and/or measurements. The silt loam admix parameters were derived using the parameters for silt loam reported by Martian (1994) and correcting for a gravel content of 15% by weight using relationships in Bouwer and Rice (1983). The gravel and silt loam particle densities were assumed to be equal (i.e., 2.72 g/cm^3). The gravel correction changed θ_s, θ_r, and K_s. The parameters α and n were not changed from the Martian (1994) values because no known relationship with gravel content exists.

The values of the compacted silt loam parameters θ_s and K_s differ from the values reported by Martian (1994). θ_s was calculated to be 0.353 cm^3/cm^3 based on the uncompacted bulk density

Table C.2. Parameters Used to Describe Soil Hydraulic Properties in the Simulations. The van Genuchten parameter m was set equal 1-1/n. The pore interaction term was specified using the standard value of 0.5.

Soil Type (depth interval, cm)	θ_s cm^3/m^3	θ_r cm^3/m^3	α 1/cm	n –	K_s cm/h
Modified RCRA Subtitle C Surface Cover					
Silt Loam Admix (0 to 50)	0.422	0.0042	0.0163	1.37	2.64
Compacted Silt Loam (50 to 100)	0.353	0.111	0.0077	1.78	0.0049
Filter Sand (100 to 115)	0.445	0.01	0.0726	2.8	392
Filter Gravel (115 to 130)	0.419	0.005	4.93	2.19	1260
Drainage Gravel (130 to 145)	0.4	0.005	10.0	3.0	3600
Rupert Sand					
BWTF Sand (0 to 400)	0.433	0.0381	0.106	1.78	35.3
Sensitivity Case 1 (0 to 400)	0.357	0.007	0.155	1.72	21.6
Sensitivity Case 2 (0 to 400)	0.408	0.035	0.0355	2.04	21.6
Burbank Loamy Sand					
BWTF Sand (0 to 41)	0.433	0.0381	0.106	1.78	35.3
Loamy Sand, 45% gravel (41 to 76)	0.279	0.0160	0.0292	1.35	2.44
Loamy Sand, 85% gravel (76 to 89)	0.0760	0.0040	0.0292	1.35	0.519
Sandy Gravel (89 to 400)	0.0833	0.0084	0.0061	1.52	0.572

(1.37 g/cm^3), compacted bulk density (1.76 g/cm^3), and particle density (2.72 g/cm^3). The K_s value was set equal to the value 0.0049 cm/h based on measurements of compacted silt loam reported by Skelly (1994).

The Rupert sand is very deep sand (Hajek 1966; also called Quincy sand by USDA 1971). The hydraulic properties of this sand were represented using parameters describing the sand in the lysimeters at the Buried Waste Test Facility (Fayer and Gee 1992). The values of θ_s, θ_r, and K_s were used directly. Because Fayer and Gee (1992) used the Brooks-Corey (BC) function, two parameters had to be converted for use in the van Genuchten (VG) function used for this report. The BC parameter h_e was inverted to yield the VG α parameter and the BC parameter b was transformed into the VG n parameter using the relationship $n = 1+1/b$.

Ward et al. (1998)[(1)] conducted a field infiltration test at the proposed ILAW Disposal Site. They collected water content and matric potential data for five depth increments in the upper 1.5-m of soil for six different infiltration fluxes. Ward et al. then used the data collected in situ to fit parameters for the van Genuchten retention function. The resulting five functions were similar and appeared to bracket the Rupert sand function determined above, supporting the use of a single function to represent Rupert sand.

(a) Ward AL, RL Clayton, and JC Ritter. 1998. "Hanford Low-Activity Tank Waste Performance Assessment Activity: Determination of in situ hydraulic parameters of Hanford Sediments," Letter Report to Fred Mann, Fluor Daniel Northwest, Richland, Washington, August 31, 1998.

The Burbank loamy sand consists of loamy sand from the soil surface to 41 cm, gravelly loamy sand (45% gravel) from 41 to 76 cm, very gravelly loamy sand (85% gravel) from 76 to 89 cm, and sand and gravel below 89 cm (USDA 1971). The hydraulic properties of the surface layer of loamy sand were described using the properties for Rupert sand. The properties of the second and third layers were obtained by scaling the properties of Sample 25 C (a loamy sand from Rockhold et al. 1993) using the gravel percentages of each layer. The properties of the fourth sample (a sandy gravel) were assigned those from the 4.1-m sample from Well 216-B-61-A (p. A-55 of Connelly et al. 1992). This sample was referred to as sandy gravel, and the particle size distribution (p. A-56 of Connelly et al. 1992) shows it to contain 76% gravel. Therefore, the hydraulic properties were scaled to account for the gravel.

The hydraulic properties of the soil profiles described in Table C.2 are shown in Figures C.2 to C.4. In addition to Rupert sand, Figure C.3 shows the retention functions determined for five soil depths with an infiltration test at the proposed ILAW Disposal Site (Ward et al. 1998).[a] The retention properties for two of those depth ranges (0.0 to 0.25 m for sensitivity case 1and 0.75 to 1.0 m for sensitivity case 2) were used to show the impact of variations in the Rupert sand properties. The K_s value for these depths was set to 21.6 cm/h, which represent the median of 29 surface measurements distributed across the proposed ILAW Disposal Site (Fayer et al. 1996).[1]

C.2.5 Initial Conditions

All simulations were started using the weather data for 1957. Initial matric potential values were not available for any of the scenarios, so the initial conditions were specified as -10^3 cm. This value is wetter than some measured vadose zone potentials (e.g., Prych 1998), so early drainage could reflect this initial water if recharge rates are lower for the given scenario. However, this limitation was overcome by repeating the 41-year sequence until the beginning and ending water storage values were within 0.1 mm of each other. This procedure uncoupled the results from the impact of using arbitrary initial conditions. The implicit assumption is that the 41-year weather record, when repeated, is representative of much longer periods.

C.2.6 Boundary Conditions

Boundary conditions describe the water inputs and outputs at the top and bottom of the model domain. For this report, these conditions are the weather data that affect the calculation of evapotranspiration, precipitation, and the drainage rate from the bottom of the profile. The weather data were derived from the meteorological data collected at the Hanford Meteorological Station (HMS) for the years 1957 to 1997 (Table C.3 shows typical 30-year variations in some of the annual values). The HMS is located about 6 km west-northwest of the proposed ILAW Disposal Site at an elevation of 223 m (Hoitink et al. 1999). This elevation differs by less than 10 m from the elevations of the two disposal sites so that topographic differences in weather between the HMS and the proposed disposal sites should be negligible.

(b) Fayer MJ, JL Downs, BN Bjornstad, and K Mahan. 1996. "Integrated recharge assessment: Summary of FY 1995 Activities," Letter report to Fred Mann, Fluor Daniel Northwest, Richland, Washington, April 1996.

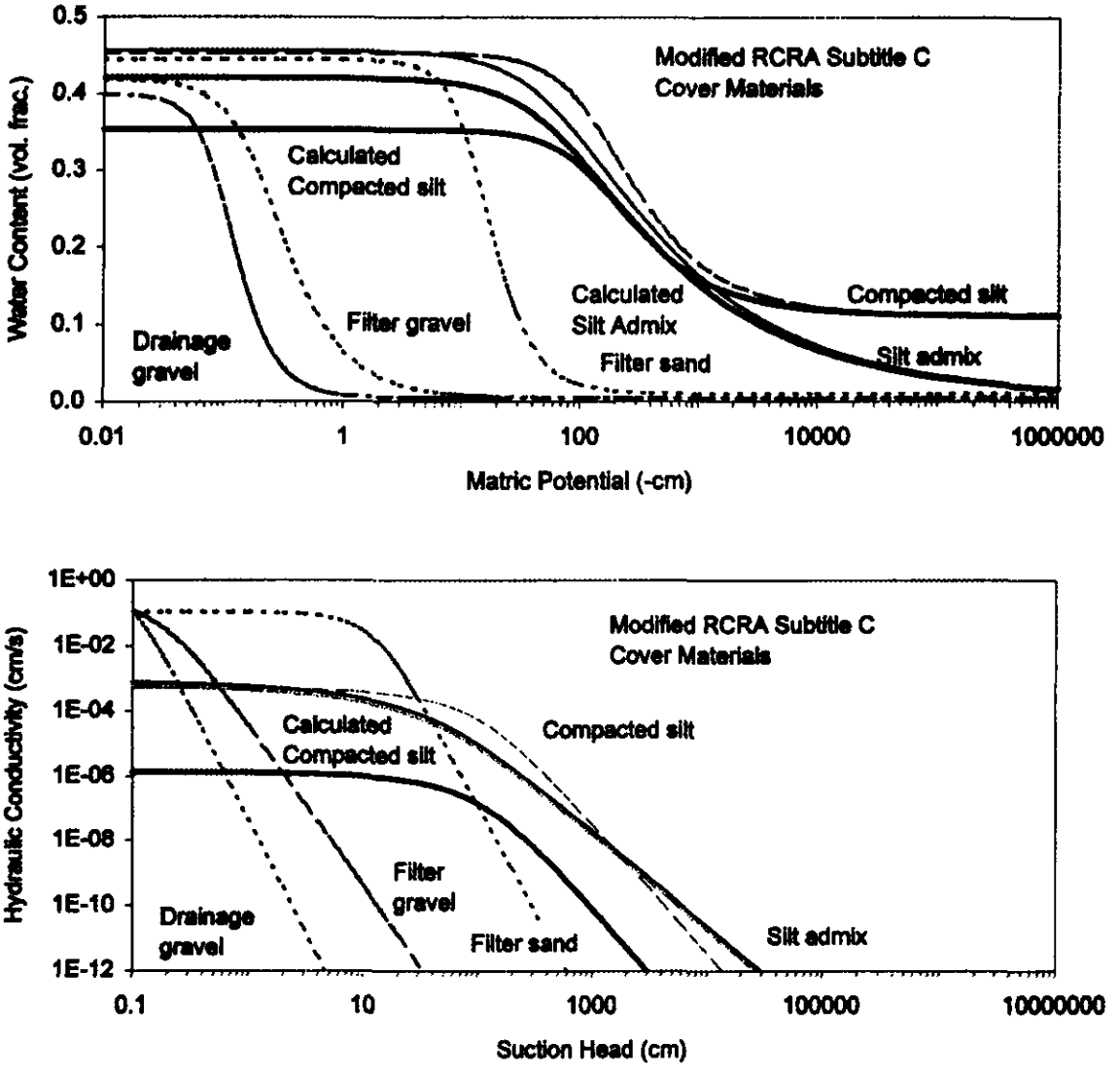

Figure C.2. Hydraulic Properties of the Materials Composing the Modified RCRA Subtitle C Cover

The current climate conditions were represented using the daily weather data. Measured hourly precipitation rates were used to describe the water inputs. Snowfall was treated as an equivalent rainfall at the time it occurred. Weather data such as wind speed, cloud cover, relative humidity, solar radiation, and maximum and minimum air temperature were used to calculate potential evaporation using the Penman Method (Doorenbos and Pruitt 1977).

Future climate conditions were represented by scaling the current temperature and precipitation data to match paleoclimate observations derived from pollen data. Whitlock and Bartlein (1997) described a 125,000-year paleoclimate record constructed from the pollen record in cores taken from Carp Lake, near Goldendale, Washington. Carp Lake is located about 175-km southwest of the Hanford Site, at an

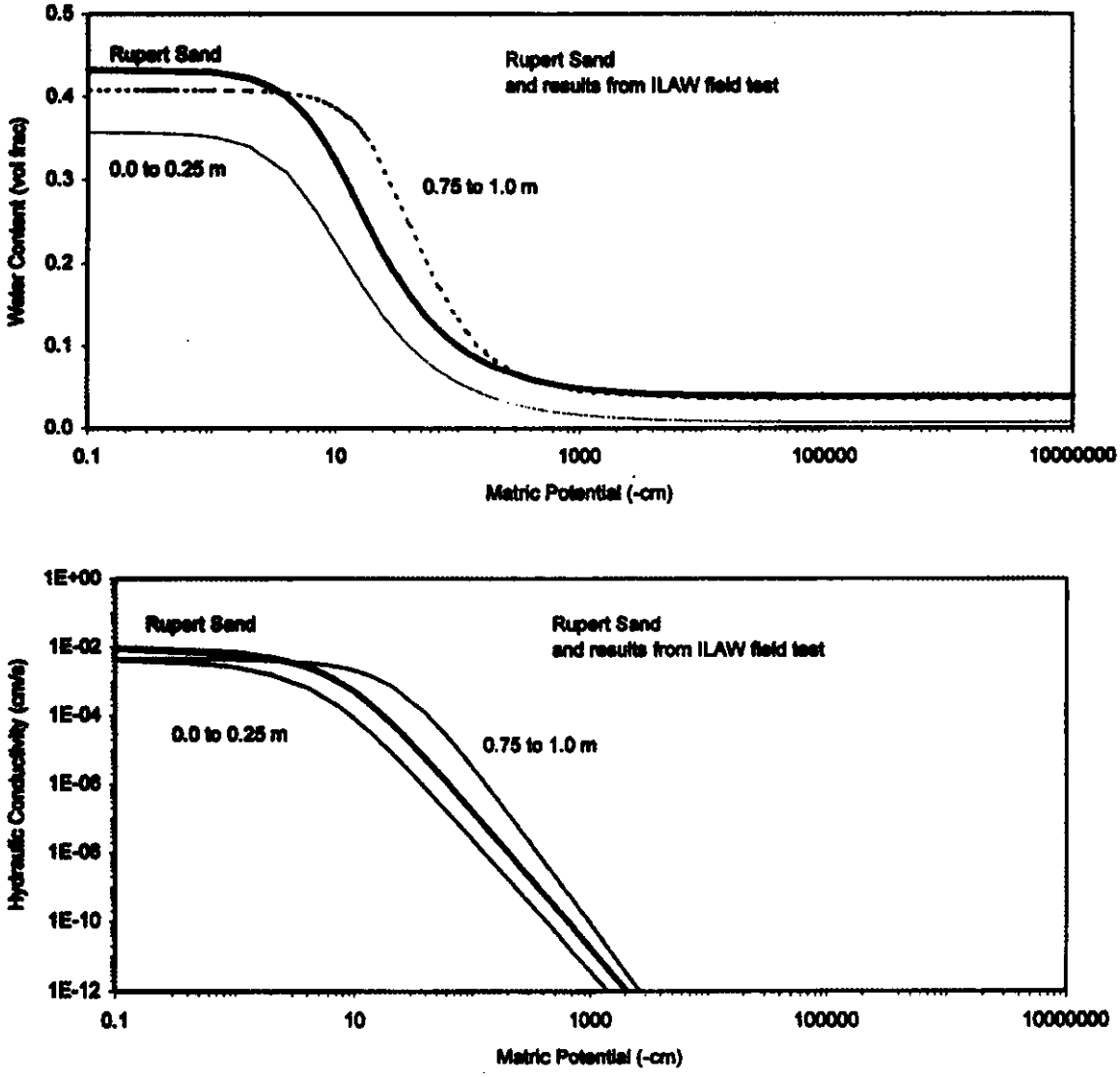

Figure C.3. Hydraulic Properties of the Rupert Sand

elevation of 714 m. Similar pollen records at the Hanford Site were eliminated during the glacial flooding 13,000 years ago. Thus, Carp Lake provides a proxy for paleoclimate information. Wing et al. (1995) described the Carp Lake pollen interpretation relative to precipitation and temperature. For the entire Holocene (i.e., the last 10,000 years), the data suggest that annual temperatures and precipitation ranged from 0 to 2.8°C warmer and 0 to 50% drier compared to modern climate. During the glacial period prior to the Holocene, annual temperatures ranged from 0.2°C warmer to 2.5°C cooler and precipitation ranged from 75 to 128% of modern levels. In summary, for the last 100,000 years, annual precipitation ranged from 50 to 128% of modern levels and annual temperatures ranged from -2.5 to 2.8°C (-4.5 to 5°F) of modern levels.

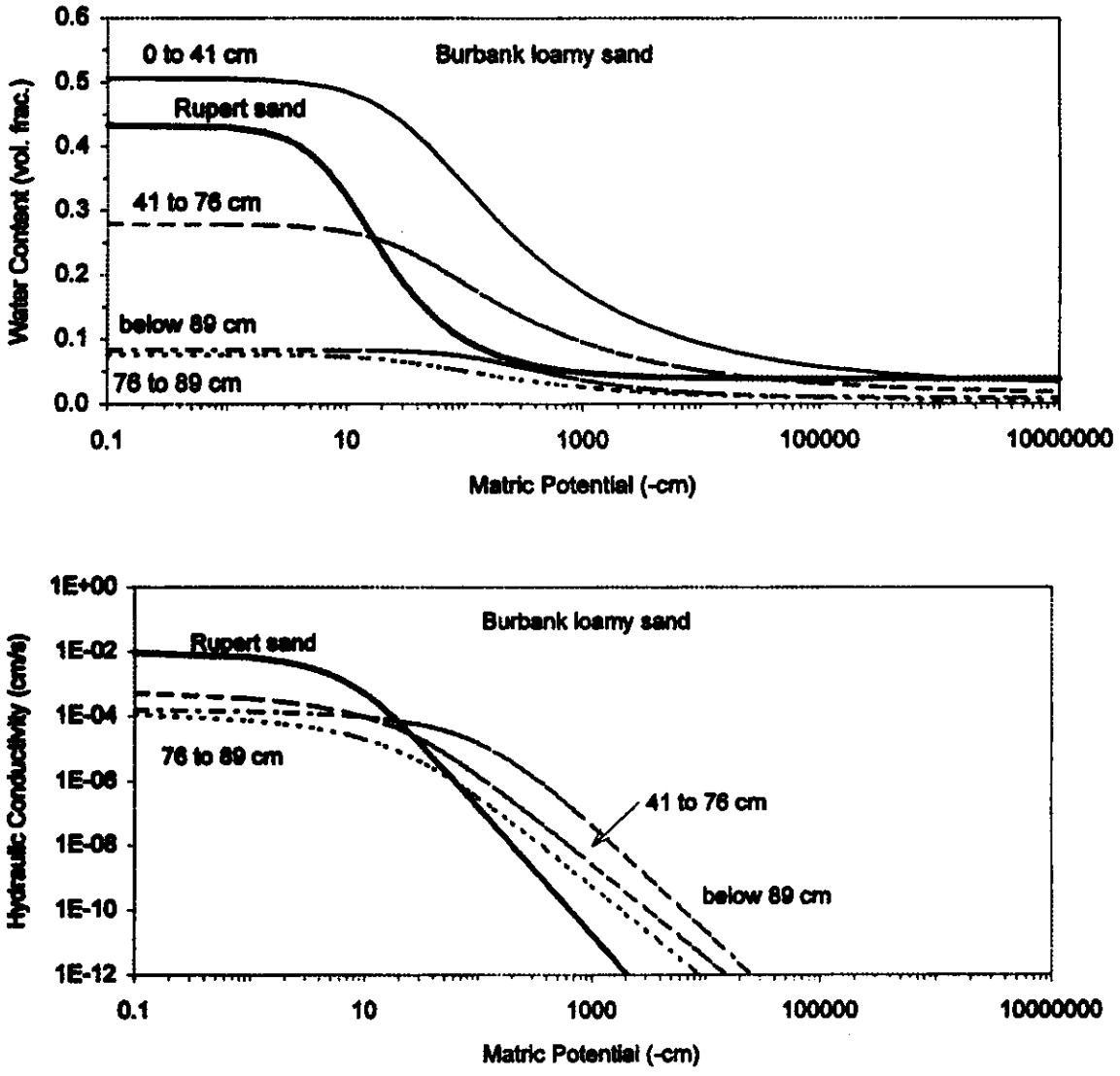

Figure C.4. Hydraulic Properties of the Burbank Loamy Sand

Table C.3. HMS Weather Statistics for 1961 to 1990 (* indicates a daily value)

Weather Variable	Period of Record	Annual Values		
		Average	Minimum	Maximum
Precipitation, mm (in.)	1961-1990	163 (6.26)	75.9 (2.99)	313 (12.31)
Air Temperature, °C (°F)	1961-1990	11.8 (53.3)	9.8 (49.6)	13.6 (56.4)
Dewpoint Temperature, °C (°F)	1950-1997	1.3 (34.4)	-0.3 (31.5)	3.2 (37.7)
Wind at 15.2 m (50 ft), kph (mph)	1945-1997	12.2 (7.6)	10.0 (6.20)	13.5 (8.4)
Solar Radiation, W/m^2 (ly/d)	1953-1997	172 (355)*	4.4 (9)*	406 (838)*

To represent future climate conditions with weather information, the Hanford weather record for 1957 to 1997 was used as the base data. From that base, future precipitation conditions were constructed by linearly scaling the current data. Future temperature conditions (daily maximum and minimum air temperatures) were constructed by adding or subtracting the projected temperature change. Changes in dewpoint temperature (humidity), solar radiation, wind speed, and cloud cover were not addressed. Seasonal changes implied by the pollen record will be addressed in subsequent work for the 2003 PA. Also not considered here are possible short-term changes caused by increased carbon dioxide. To date, the suggested carbon dioxide-induced changes fall within the range of climate changes inferred from the pollen record and so were not considered any further.

For the irrigation simulations, we modified the precipitation input files to include irrigation events. If a precipitation event coincided with an irrigation event, the two were added to yield a single water application event. Irrigation was applied between the hours of 0600 and 1200 once every 8 days. James et al. (1989) estimated the total crop irrigation requirement of about 81 cm for potatoes grown on silt loam in Richland, assuming 100% irrigation efficiency. This requirement was met using an hourly irrigation rate of 0.75 cm/h. If the efficiency dropped to 75%, James et al. (1989) estimated the irrigation requirement would increase to 108 cm for the season. This requirement was met using an hourly irrigation rate of 1.0 cm/h.

The bottom boundary was represented with a unit-gradient condition. This condition is generally acceptable when the boundary is well below the deepest plant roots, which were at 2 m in this report, and the drainage rate exceeds 1 mm/yr. For lower drainage rates, temperature cycling can have a significant effect on overall water movement via the temperature effect on vapor flow. In these cases, heat flow modeling can be used to examine total flux rates (such modeling was not done for this report).

C.2.7 Plant Information

The plant community is an important component of the disposal facility. The two major functions performed by the plants are the efficient removal of water stored in the near-surface soil (thus minimizing recharge) and protection of the soil surface from wind and water erosion (thus protecting the integrity of the surface cover). By minimizing recharge and protecting the integrity of the surface cover, plants help to ensure the successful long-term protection of the disposal facility.

The majority of simulations performed for this report included a shrub-steppe plant community, which is the dominant community in and around the 200 Areas. As indicated earlier, Holocene pollen records indicated that plant communities in the Columbia Basin have alternated between shrub-steppe and bunchgrass-steppe. Recently, non-native species such as cheatgrass have been shown to compete successfully with native species and, in some cases, can dominate disturbed areas for years. Finally, range fires and industrial and waste management activities can eliminate vegetation for short periods of time. To address some of these alternate conditions, supporting simulations were conducted in which the plant community was either cheatgrass or no plants. A bunchgrass-steppe community was not included in this analysis; we assumed its impact would fall between that of shrub-steppe and cheatgrass. Finally, an irrigation scenario was evaluated using a potato crop.

To simulate plants with UNSAT-H Version 3.0 requires the following information:

- the method of partitioning potential evapotranspiration (PET)
- the active season
- the bare fraction
- the root length density
- the maximum rooting depth during the year
- the effectiveness of plant water withdrawal as a function of matric potential.

UNSAT-H allows only one plant to be simulated at a time. For this report, the shrub-steppe was simulated using shrub parameters and the cheatgrass community was simulated using cheatgrass parameters. In both cases, other species that might be present were not considered (e.g., shrub understory species). Table C.4 shows the parameters that were chosen based on literature parameters or reasonable estimates of parameters. The plant parameters were held constant for each simulation year. Not addressed by this study were the potential plant community responses to yearly precipitation and temperature variations, fire, diseases, nutrient cycling, grazing, and land use changes.

For shrubs and potatoes, the leaf area index (LAI) method was used to partition potential evapotranspiration into potential evaporation and potential transpiration. Figure C.5 shows the shrub leaf area variation throughout the year. Link et al. (1990a) reported a maximum LAI value of 0.25 for sagebrush for 4 years in a sagebrush-bunchgrass community growing on a silt loam soil on the Fitzner/Eberhardt Arid Lands Ecology (ALE) Reserve. Our preliminary measurements at the proposed ILAW Disposal Site are showing similar LAI values. The maximum potato LAI was 2.5. Although not shown in Figure C.5, the variation throughout the year was similar to that of the shrub. For cheatgrass, the PET-partitioning method used was the cheatgrass model in UNSAT-H. This model was developed by Hinds (1975) using field data from a 2-month cheatgrass experiment.

Table C.4. Plant Parameters for UNSAT-H Simulations (see text for descriptions)

Parameter Description	Parameter Value		
	Shrub	**Cheatgrass**	**Potatoes**
PET Partition Function	LAI	Cheatgrass	LAI
Active Days of the Year	Mar 1 to Nov 30	Mar 1 to May 31	April 9 to Sep 16
Bare Fraction	0.27	0.27	0.0
Maximum Rooting Depth (m)	2.0	0.6	0.6, Surface cover 0.9, Rupert sand
Root Density Coefficients			
a =	0.217	1.17	1.17
b =	0.0267	0.131	0.131
c =	0.0109	0.0206	0.0206
Plant Uptake Potentials (-MPa)			
h_n =	0.003	0.003	0.003
h_d =	0.1	0.1	0.04
h_w =	7.0	2.0	1.6

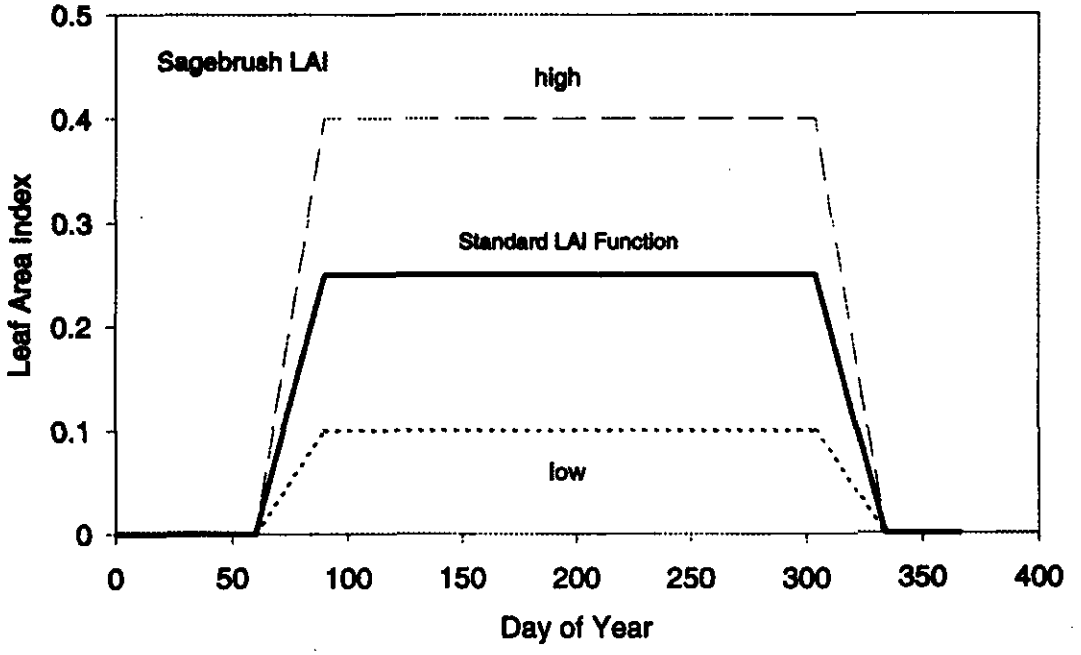

Figure C.5. Leaf Area Index for Sagebrush

The start and end dates of plant activity determine when during a growing season to calculate transpiration and root growth. Rickard and Vaughan (1988) reported that many plant species generally become active around March 1 in a normal year on the ALE Reserve. This start date coincides with the onset of air temperatures in excess of 3°C, a temperature suggested by Hanson et al. (1987), as the minimum needed for positive shrub and cool-season grass activity. Both shrubs and cheatgrass were started on March 1. Potatoes were started on April 9. This date was set 30 days prior to the initiation of irrigation, which was determined by air temperature. Irrigation was initiated on May 9, which is the average date when the 30-day running average of air temperature equals or exceeds 12.8°C (55°F) (James et al. 1989).

Because shrubs maintain LAI throughout the year, this minimum temperature was used to determine when shrub activity ceased in the fall. Based on the average temperatures reported by Hoitink et al. (1999), shrubs were allowed to be active until November 30. The end date for cheatgrass is earlier than that for shrubs. An ending date of May 31 was chosen for cheatgrass based on observations of cheatgrass at the Grass Site in 1986 and 1987 (Link et al. 1990b). The end date for irrigated potatoes was 130 days after the start date for irrigation (James et al. 1989).

The bare fraction represents the fraction of the soil surface devoid of vegetation. This value is used to scale the potential transpiration, which was calculated assuming a 100% plant cover. Roots from plants around the bare areas may (and likely do) penetrate some of the bare area. However, the one-dimensional nature of the UNSAT-H model does not allow it to represent multidimensional root behavior. Thus, reducing potential transpiration based on the bare fraction may underestimate transpiration. For the simulations with a shrub-steppe component, the bare fraction was set to 0.69. This value was derived

from preliminary measurements at the proposed ILAW Disposal Site and the Existing Disposal Site (Downs and Kahn 1998).[1] A slightly lower value of 0.577 was used for the cheatgrass simulations based on data from Downs and Kahn. Reductions to potential transpiration caused by bare areas are added to potential evaporation. Two additional simulations were conducted in which the bare fraction was set to zero for both the cheatgrass and shrub cases; a bare fraction value of zero represents 100% plant cover. A full canopy was assumed for the potato simulation; thus the bare fraction was set to zero.

Root parameters were obtained directly from the simulations reported by Fayer and Walters (1995). They used root length density data from Mayer et al. (1981) to fit the root density function

$$rld = a \exp(-bz) + c \qquad (C.1)$$

where rld = root length density (cm roots/cm soil)
z = soil depth (cm)
a, b, and c = fitting parameter.

The resulting parameters are shown in Table C.4. Maximum rooting depths were 2.0 m for shrub and 0.6 m for cheatgrass. The roots of shrubs were considered to be at their maximum depth throughout the growing season. Being an annual, cheatgrass roots were assumed to have a uniform growth rate of 1 cm/d for their entire growing season. Potatoes were simulated using the same rooting parameters as cheatgrass.

The plant water uptake parameters in Table C.4 were obtained directly from the simulations reported by Fayer and Walters (1995). There is some support for the wilting point values (h_w), which are the lowest matric potentials at which plant water withdrawal becomes zero. Sagebrush was reported to operate in soils with potentials as low as -7.0 MPa (Fernandez and Caldwell 1975; Branson et al. 1976). Cline et al. (1977) showed that cheatgrass could remove water at potentials as low as -1.5 MPa. In their first year of measurements at the proposed ILAW Disposal Site, Downs and Khan (1998 Letter Report to F Mann) have observed the lowest plant potentials in shrubs (values as low as -2.5 MPa). The parameter h_d represents soil water potential below which plant uptake decreases below the potential water uptake rate. The parameter h_n represents the soil water potential above which plant water is zero because of anaerobic conditions. Between h_n and h_d plant water uptake is set to its potential rate. For rangeland simulations, Hanson et al. (1987) suggested that plant water uptake was reduced by half when the soil potential was -0.64 MPa. Using the parameters in Table C.4, the potentials corresponding to halving the uptake rate are -0.84 and -0.45 MPa for shrubs and cheatgrass, respectively. These values are in line with the value suggested by Hanson et al. (1987). Plant water uptake parameters for potatoes were obtained from Feddes et al. (1978).

C.3 Results

Each 41-year simulation took approximately 2 hours of dedicated time to run on a UNIX workstation. In most cases, repeating the weather sequence just once was enough to establish a condition indicative of

(a) Downs JL and FO Khan. 1998. "Brief status report: FY 1998 vegetation field studies on the LLTWDS Site," Letter report to Fred Mann, Fluor Daniel Hanford, Richland, Washington, September 1998.

the long-term average. In several cases, three to four repetitions of the weather sequence were required for the profile to achieve a condition indicative of the long-term average. In some cases, one sequence was enough to establish that the soil profile was drying and that further repetition of the weather sequence would dry out the profile even more.

Table C.5 shows the average long-term deep drainage rate for all simulations conducted. The average rate was calculated for all 41 years of the last simulation sequence. For those simulations that indicated drying, the rate was assigned a value of < 0.1 mm/yr. The less than symbol was used to indicate the uncertainty of specifying such a small rate, especially given the types of assumptions used (e.g., constant plant communities and isothermal flow).

The results in Table C.5 indicate that the surface cover will perform better than the design goal of 0.5 mm/yr. This performance occurred even in the absence of plants. When the cover was exposed to the future climate state most conducive to drainage, the simulation results still indicated a drainage rate of < 0.1 mm/yr.

Table C.5. Simulated Long-Term Drainage Rates Using the Isothermal, Non-Hysteretic Mode of UNSAT-H and a Shrub-Steppe Plant Community (unless noted otherwise)

Variable	Condition	Simulated Long-Term Drainage Rates (mm/yr)				
		Modified RCRA Subtitle C Cover	Rupert sand	Burbank loamy sand	Dune sand on cover	Eroded Surface Cover
Climate	Current	< 0.1	2.2	5.2	< 0.1	< 0.1
	P↓	na[a]	< 0.1	na	na	na
	P↑	na	13.2	na	na	na
	P↓T↑	na	< 0.1	na	na	na
	P↓T↓	na	< 0.1	na	na	na
	T↓	na	7.5	na	na	na
	T↑	na	0.6	na	na	na
	P↓T↑	na	5.2	na	na	na
	P↑T↓	< 0.1	27.0	36.8	16.9	< 0.1
Vegetation	Cheatgrass	na	33.2	na	18.4	na
	No plants	< 0.1	44.3	52.5	32.7	< 0.1
	No plants, future climate (P↑T↓)	na	88.6	98.0	na	na
Shrub Leaf Area Index	High (0.4 vs 0.25)	na	1.6	na	na	na
	Low (0.1 vs 0.25)	na	5.6	15.2	4.1	na
Rupert Sand Properties	Higher $K(h)$ vs Rupert sand	na	2.7	na	na	na
	Lower $K(h)$ vs Rupert sand	na	3.3	na	na	na
Complete Areal Plant Coverage	Cheatgrass	na	26.6	na	na	na
	Shrub	na	<0.1	na	na	na
Irrigation Efficiency	75%	26.4	58	na	na	na
	100%	< 0.1	30	na	na	na

(a) na = not analyzed

The results in Table C.5 indicate that the two soils, under shrub-steppe vegetation, have long-term drainage rates of 2.2 and 5.2 mm/yr., respectively. When plants were removed, the drainage rates jumped by a factor of 10 to 20. Under the future climate state most conducive to drainage, the drainage jumped by factors of 7 and 12, respectively.

Two cover degradation cases were evaluated. In the first, dune sand was deposited on the cover to a depth of 20 cm. The results in Table C.5 indicate that the cover still had drainage rates < 0.1 mm/yr under the shrub-steppe vegetation. When shrubs were removed to leave just cheatgrass, simulated drainage increased dramatically to 18.4 mm/yr. Clearly, deeper rooted plants like shrubs are needed to prevent drainage under these conditions. When all plants were removed, the cover drainage rate jumped to 32.7 mm/yr. The simulated increase in drainage is consistent with lysimeter data (e.g., Sackschewsky et al. 1995).

Under the future climate state most conducive to drainage, the drainage went from zero to 16.9 mm/yr. These results indicate that barrier performance in limiting drainage could be significantly degraded by the deposition of wind-borne sand. Efforts are under way to collect data on this case at the Field Lysimeter Test Facility under a separate ILAW task.

The second degradation case was an eroded surface cover, in which 20 cm of the surface silt layer was removed. The results in Table C.5 indicate that cover performance in limiting drainage was not impaired, even for the case without plants.

The simulation results in Table C.5 demonstrate that irrigation and its efficiency can have a large impact on recharge. Reducing the efficiency from 100 to 75% increased recharge on the cover from 0.1 to 26.7 mm/yr. The same reduction of irrigation efficiency for Rupert sand increased recharge from 30 to 58 mm/yr.

The sensitivity of long-term drainage rates was evaluated using the Rupert soil primarily because this soil yielded reportable rates. The rates for the surface cover were too low to be effective for this evaluation. Table C.6 shows that decreasing precipitation led to nearly zero drainage regardless of the temperature conditions. For modern precipitation conditions, drainage was inversely related to temperature. If temperatures rise in the near future in response to rising carbon dioxide levels, we can

Table C.6. Comparison of Rupert Sand Drainage Rates for Various Future Climate States (data from Table C.5)

	Long-Term Deep Drainage Rates (mm/yr)		
	Precipitation		
Air Temperature	Low (50% of modern)	Modern	High (128% of modern)
Low (modern - 2.5°C)	< 0.1	7.5	27.0
Modern	< 0.1	2.2	13.2
High (modern + 2.8°C)	< 0.1	0.6	5.2

expect a decrease in drainage rates. If an ice age recurs, the decreasing air temperatures will lead to an increase in deep drainage rates. At the high precipitation level, drainage rates will increase for all temperature conditions. The magnitude of the increase will be more than four times greater for the high temperature versus the low temperature condition.

Table C.7 shows that the median annual drainage rate is much less than the average rate. The large difference is indicative of a non-normal distribution, where many years of drainage are punctuated by just a few years with very high rates. In all cases, the standard deviation was roughly one-half to one-third of the average rate. Figure C.6 shows the annual drainage rate for two of the cases in Table C.7. For the Rupert sand under the current climate, there was only one time in the entire 41-year period when significant drainage occurred.

Additional simulations were conducted to highlight sensitivities to three parameters: hydraulic properties, shrub LAI, and the fraction of bare ground. Two alternative sets of hydraulic properties for Rupert sand were derived from a field infiltration experiment at the ILAW Disposal Site. The alternative properties resulted in drainage rates of 2.7 and 3.3 mm/yr under shrub-steppe vegetation. These rates are not much different than 2.2 mm/yr predicted using the original properties for Rupert sand.

The second set of simulations compared different shrub LAI values selected to encompass the range of values measured at the ILAW Disposal Site in 1998 (Appendix F). For LAI values ranging from 0.1 to 0.25 (the original LAI value) to 0.4, the predicted drainage rates were 5.6, 2.2, and 1.6 mm/yr, respectively, for Rupert sand. These results show that recharge is sensitive to this plant parameter.

The third set of simulations assessed the impact of the fraction of bare ground. For cheatgrass, reducing the bare fraction from 0.577 to 0.0 reduced drainage from 33.2 to 26.6 mm/yr, which is still a high drainage rate. For the shrub-steppe, reducing the bare fraction from 0.69 to 0.0 reduced the drainage rate from 2.2 to < 0.1 mm/yr.

An alternative method for characterizing drainage rates for the heterogeneous shrub-steppe plant community is to weight the predicted drainage rates for the different conditions according to their areal

Table C.7. Statistical Summary of Annual Drainage Rates Beneath a Shrub-Steppe Plant Community Under Two Climate States (n = 41)

	Simulated Long-Term Drainage Rates (mm/yr)									
	Current Climate					Climate Extreme (P↑T↓)				
Scenario	Min.	Mean	Median	Max.	SD[a]	Min.	Mean	Median	Max.	SD
Rupert Sand	0.2	2.2	0.5	27.1	5.4	1.6	27.0	11.5	178.5	55.2
Burbank Loamy Sand	0.1	5.2	0.8	96.8	15.7	2.2	36.8	194.2	359.6	43.0
Dune Sand on Cover	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	16.9	0.1	142.4	33.1

(a) SD = standard deviation

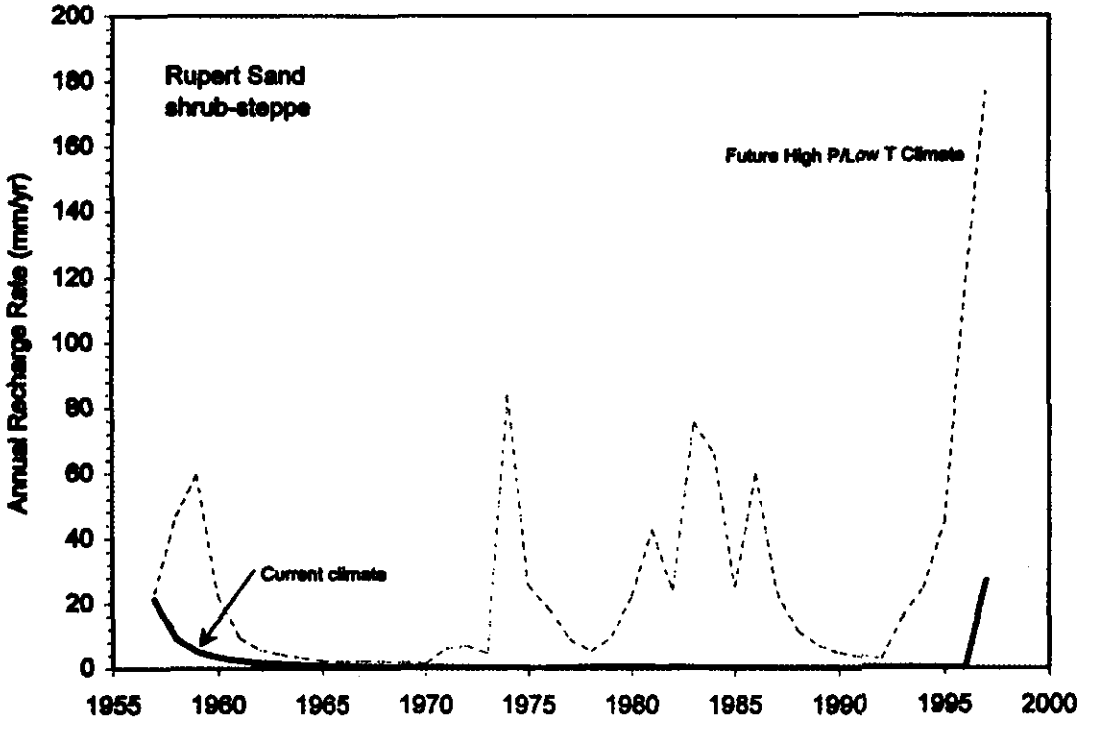

Figure C.6. Predicted Annual Recharge Rates for Rupert Sand, Shrub-Steppe Plant Community, and Two Climate States: Current and High Precipitation/Low Temperature

coverage. Based on FY 1998 data from the proposed ILAW Disposal Site, shrub coverage is 31%, grass coverage is 42.3%, and bare ground accounts for 26.7%. Assuming plant coverage is 100% within each zone, the lumped predicted recharge rate is (0.31*0.0 + 0.423*26.6 + 0.267*44.3 =) 23.1 mm/yr. This value is biased high because the method assumes there are no plant roots penetrating adjacent bare areas, which we know not to be the case. Work is ongoing to document the lateral extent of these roots. It may be possible to adjust the effective area covered by the shrubs to provide a more realistic estimate of recharge for these types of plant communities.

C.4 Conclusion

A set of simulations was used to estimate recharge rates for scenarios pertinent to the 2001 ILAW PA. The scenarios included the surface cover and two surrounding soil types, as well as two types of surface cover degradation. The simulations were conducted using a 41-year sequence of weather collected at the Hanford Site from 1957 to 1997. This sequence was repeated until the results remained unchanged to uncouple results from assumed initial conditions.

The low LAI value was tested for two other cases on Burbank loamy sand, lowering LAI sand on cover from 0.25 to 0.1 increased recharge from 5.2 to 15.2 mm/yr. On the surface cover with dune sand, lowering LAI increased recharge from <0.1 to 4.1 mm/yr.

The simulation results indicated that the surface cover limits drainage to < 0.1 mm/yr, which is much better than the design goal of 0.5 mm/yr. The cover maintained this performance level when plants were removed, when the climate became wetter and cooler, and when 20 cm of the silt loam layer was eroded. The cover also maintained this performance when windblown sand was deposited, but significant drainage (32.7 mm/yr) occurred when plants were removed. Under a wetter, cooler climate, the cover had 16.9 mm/yr of annual drainage even though shrub-steppe vegetation was present.

Drainage rates in the two surrounding soils were 2.2 to 5.2 mm/yr under shrub-steppe vegetation. Additional simulations highlighted model sensitivities to variations in climate, soil hydraulic properties, plant parameters, and irrigation.

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Appendix D

Eolian Activity at the ILAW Disposal Site, Central Hanford Site

B. N. Bjornstad

Appendix D

Eolian Activity at the ILAW Disposal Site, Central Hanford Site

D.1 Introduction

The U.S. Department of Energy is planning to vitrify the low-activity waste from single- and double-shell tanks. This immobilized low-activity waste (ILAW) will then be disposed in a near-surface burial facility at Hanford. Lockheed Martin Hanford Company is designing and assessing the performance of this disposal facility. An issue of concern is the possibility of sand dunes forming on or around the surface cover and affecting recharge rates. For example, active sand dunes at the Hanford Site lack vegetation, which could lead to an increase in the rate of natural recharge (Gee et al. 1992). An increase in natural recharge would increase water contact with the waste as well as transport through the vadose zone to the groundwater.

In 1995, three trenches were excavated at Hanford to collect samples for tracer analyses of recharge and to look for datable soil horizons to determine the approximate age of surface soil and sand dune formation. This appendix describes sand dune formation and age at the Hanford Site and reports the results of trench studies.

D.2 Dunes at Hanford

The proposed ILAW Disposal Site is located in the south-central portion of the 200 East Area. Figure D.1 shows that the disposal site lies along the northern margin of a giant dune field that extends from the northeastern flank of Rattlesnake Mountain to the Columbia River (a distance of 27 km) and southward to the boundary of the city of Richland. The existence of the dune field in this area appears to be controlled by wind moving, from west to east, down the adjacent Dry Creek and Cold Creek valleys and across the central Hanford Site toward the Columbia River. Most dunes are stabilized by vegetation and are not actively growing or migrating, except locally within a narrow 3.2 to 4.8-km-wide area that extends westward from the natural wind gap created by Ringold/Koontz Coulee (Gaylord et al. 1991). The northern limit of dune formation lies in the southern portion of the 200 East Area and consists of stabilized dunes that occupy part of the proposed ILAW Disposal Site. Presently, the point of active sand dune formation that is closest to the proposed ILAW Disposal Site is ~3.2-km south of the 200 East Area (Figure D.1).

Although eolian features are generally not present elsewhere in the 200 East Area and the Hanford Site, there is still a significant amount of wind energy available. Apparently, in these areas the material available is too coarse grained making it unsuitable for transport and dune development; or the surface is

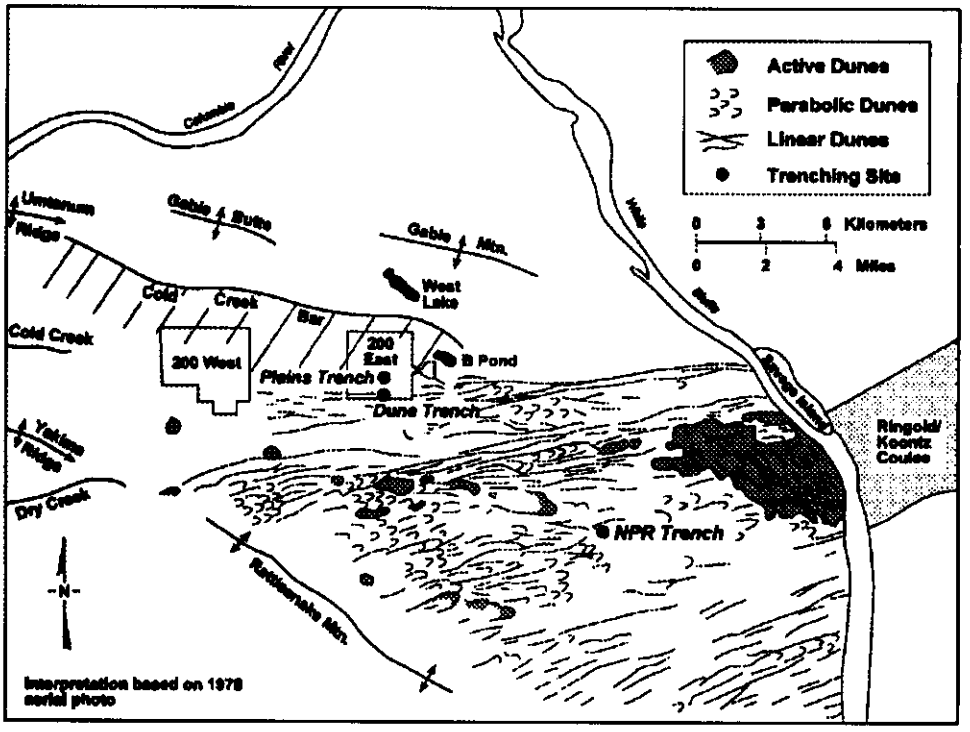

Figure D.1. Locations of the Sand Dune Features at the Hanford Site and the Trenching Studies Conducted in 1995

stable, which inhibits dune formation (Kasper and Glantz 1987). Dune formation and migration is complex and the result of the interaction between time, topography, climate, and man-related activities such as fire or construction.

D.2.1 Dune Types/Wind Directions

Figure D.1 shows that the most predominant eolian bedforms (i.e., the shapes of wind-formed sediment deposits) on the Hanford Site are linear sand ridges aligned in the direction of the strongest winds (southwest to northeast). This is particularly true where dunes are stabilized by vegetation. In some cases, the same ridge can be traced for miles with little or no discontinuity. In other cases, ridges may divide in two or end at a parabolic dune in the downwind direction. Linear sand ridges are reported to form in variable wind regimes (Brookfield 1984). The predominant wind direction at Hanford is from the northwest (Glantz et al. 1990). The strongest winds blow out of the southwest, although less frequently than the northwest. Based on recent meteorological data, winds capable of moving sand-sized particles occur ~40 days/year at the Hanford Site (Gaylord and Stetler 1994).

Where dunes are active or dune blowouts occur, parabolic dunes are the predominant bedform. Parabolic dunes are convex in the downwind direction with arms that point in the upwind direction. From aerial photographs (the basis of Figure D.1), it appears that linear ridges result from the migration of the parabolic dunes. In these situations, the arms become anchored with vegetation while the central part of the dune continues to migrate forward. Linear ridges can also result from the interaction of winds coming

from two directions (i.e., northwest and southwest), but the evidence of linear dunes parallel to the predominant high-wind direction does not support this mechanism. In areas where dunes are extremely active and void of any vegetation, a wide range of bedforms has developed, including transverse, parabolic, and complex barchanoid bedforms. This is the case for the very active dune field that is present immediately west of Ringold/Koontz Coulees (Figure D.1).

D.2.2 Volcanic Time Markers

At least three distinct volcanic ash layers may be associated with Quaternary age sediments at the Hanford Site. These provide key time markers from which to perform regional stratigraphic correlation. The layers of volcanic ash are recognized by their white color and gritty texture. The oldest Quaternary-age volcanic layer observed at the Hanford Site is the Mount St. Helens "set S" layer. This layer was dated at 13,000 years ago using a technique that relates time to the reference year 1950 (Mullineaux et al. 1978). All subsequent time estimates are relative to this reference year. This layer occurs as a couplet; the upper layer is about 2.5-cm thick while the lower layer is often barely visible and is about 0.16-cm thick. When observed, this ash layer lies near the top of the cataclysmic flood sequence and thus forms a lower stratigraphic marker for identifying eolian and other post-cataclysmic flood deposits at the Hanford Site. The second volcanic layer that may be observed also occurs as a couplet and is related to the two closely spaced eruptions from Glacier Peak around 11,200 years ago (Mehringer et al. 1984). Where found within the Pasco Basin, the combined thickness of the Glacier Peak ash couplet is about 8 cm. The third volcanic layer that may be observed is from an eruption 6,850 years ago of Mount Mazama commonly known as Crater Lake (Bacon 1983). Where preserved, Mount Mazama ash usually has a pink cast and may be 30- to 90-cm thick, especially where it has been eroded and redeposited. The latest Quaternary ash layer, from the May 18, 1980, eruption of Mount St. Helens, is preserved in the extreme northern portion of the Pasco Basin. It is not found in the southern part of the basin, including the proposed ILAW Disposal Site. We can obtain information to determine the time and rate of eolian deposition by observing the relationships between these volcanic layers and adjacent eolian deposits.

D.2.3 Age of Sand Dunes at Hanford

Sand dunes found at the Hanford Site appear to be late Pleistocene to Holocene in age. The maximum age of the dunes is limited to 13,000 years ago, the age of the last cataclysmic flood from glacial Lake Missoula (Mullineaux et al. 1978). Petrologic and petrographic analyses demonstrate Hanford dune sands were derived primarily from reworking of Pleistocene Missoula flood deposits (Gaylord et al. 1991). While eolian activity occurred prior to this time, wind-related deposits were probably either buried beneath younger flood deposits or eroded away during subsequent flooding. Due to erosion and deposition that occurred during flooding, most of the area below 366-m elevation in the vicinity of the Hanford Site was probably void of vegetation immediately following the floods (Baker et al. 1991). Without the anchoring effects of vegetation, the bare ground would have produced abundant sedimentary material for eolian transport. For this reason, a significant amount of eolian transport may have occurred immediately following the floods, slowly tapering off over time as vegetation took hold. It is likely the sand dunes at the proposed ILAW Disposal Site formed soon after the last flood. Smith (1992) estimated that sand transport was most active prior to 4,400 years ago, at which time they had become mostly stabilized. On the other hand, Gaylord et al. (1991) reported that the dune sands they

examined appear to have developed since volcanic ash from Mount Mazama was deposited 6,850 years ago. Dunes are presently active in the central and eastern portions of the dune field (Figure D.1). It is not certain whether these areas have been continuously active since the late Pleistocene or whether they have been reactivated due to range fire or some other natural event.

D.3 Trenching Results

Three trenches were excavated at the Hanford Site on September 28-29, 1995. Trenches as deep as 4.6 m were dug with a backhoe. The purpose of the trenches was to collect samples to determine moisture content and to estimate recharge via chlorine-isotope analysis. Another purpose of the trenches was to look for datable horizons in the soil column that could be used to determine the approximate age and rate of deposition. Samples were collected every 0.15 to 0.3 m from the surface to the bottom of the trench. Two trenches, referred to here as the Plains Trench and the Dune Trench were dug within the proposed ILAW Disposal Site. A third trench was dug about 13 km to the southeast, near the Wye Barricade. This site, which is referred to as the New Production Reactor (NPR) Trench (Figure D.1), was chosen to provide a contrast to the proposed ILAW Disposal Site trenches. It also lies within the zone of stabilized sand dunes. Descriptions of the three sites are presented in the following sections.

D.3.1 Plains Trench

The Plains Trench was dug to a depth of ~4.3 m. The sediments within this trench consisted of essentially two stratigraphic units. The upper unit was composed of 1.2 m of a structureless, loose, light gray, silty sand. This unit, consisting of eolian material, contains reworked windblown sand deposited since the last cataclysmic flood less than 13,000 years ago. The lower unit consisted of a stratified coarse-grained, basaltic sand and gravel from 1.2 m to the bottom of the trench. This unit contains deposits known as the Hanford formation that were laid down during the last cataclysmic flood(s). No buried soil horizons were observed in this trench, suggesting the flood deposits are probably entirely late Wisconsin 13,000 to 18,000 years in age. There were no volcanic layers or other datable horizons observed in this trench. The absence of the thick Mazama ash layer indicates significant wind reworking of sediments as recently as 6,850 years ago.

D.3.2 Dune Trench

The Dune Trench was excavated just south of the Plains Trench, on the north (leeward) side of a prominent east-west linear sand ridge (Figure D1). The trench was oriented north-south, perpendicular to the axis of the sand ridge (Figures D.2 and D.3). This aspect of the sand ridge was chosen for the trench because it was believed this is where volcanic layers or other marker horizons would most likely be preserved. The maximum depth of the trench was 4.0 m. The entire sequence exposed within the trench appeared to consist of eolian sand; no cataclysmic flood deposits of the Hanford formation were observed. The absence of flood deposits is not surprising because the 6.1- to 9.1-m-high sand ridge is an eolian feature that developed since the last flood. Thus, flood deposits probably lie at depths well below the bottom of the trench.

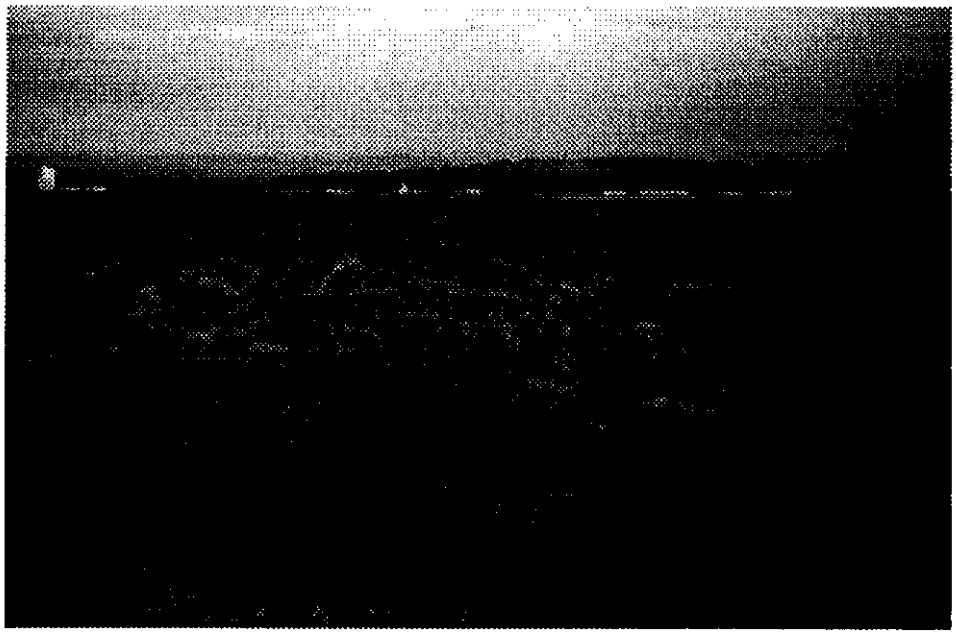

Figure D.2. Looking North from the Dune Trench Overlooking Old-Growth Sagebrush of the Proposed ILAW Disposal Site. The Plains Trench is located about 600 m north along the dirt road. Facilities in the distance are about 900 m north.

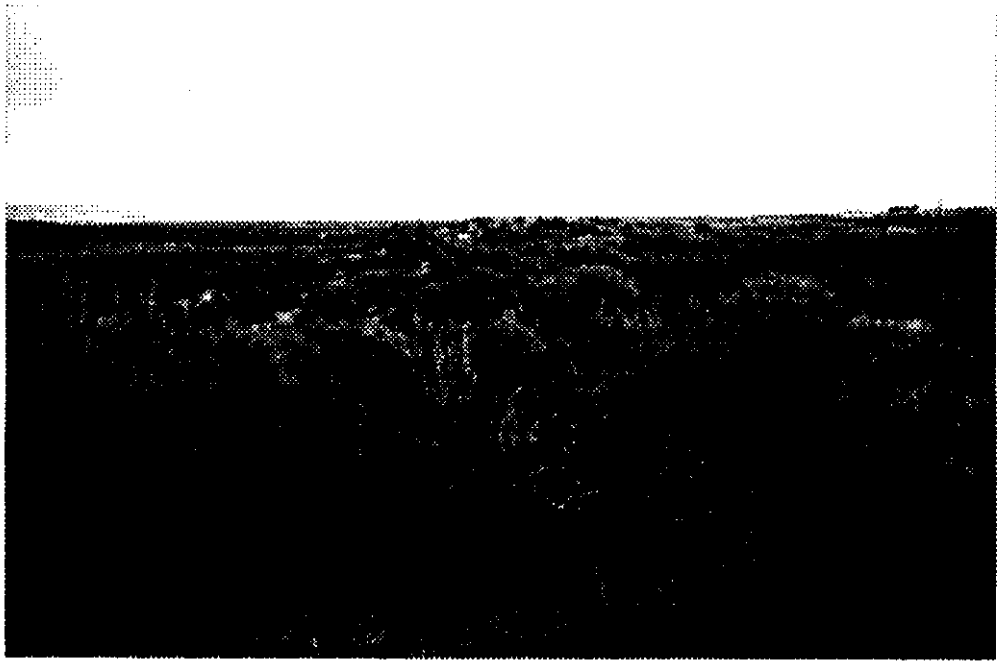

Figure D.3. Looking East from the Dune Trench Over Old-Growth Sagebrush and Parallel to the Axis of the Dune

Figure D.4 shows several contrasting layers within the eolian sequence. The upper 2.4 m consisted of a relatively uniform, structureless, loose, brown (10YR5/3) silty fine sand. Of this 2.4 m, the uppermost 0.6 m is slightly darker in color (Figure D.5) due to staining and weathering associated with surficial soil processes. From a soil development viewpoint, the upper 0.6 m would probably be classified as a weakly

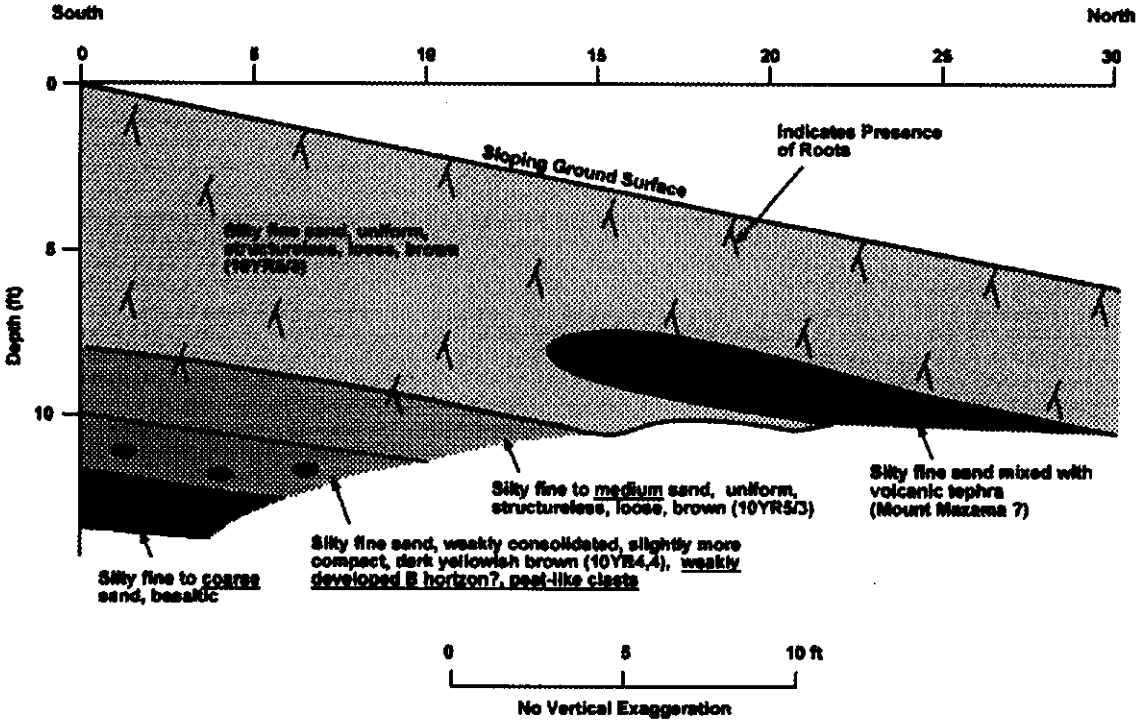

Figure D.4. Cross Section View of the Dune Trench Showing the Approximate Location of the Possible Tephra Layer

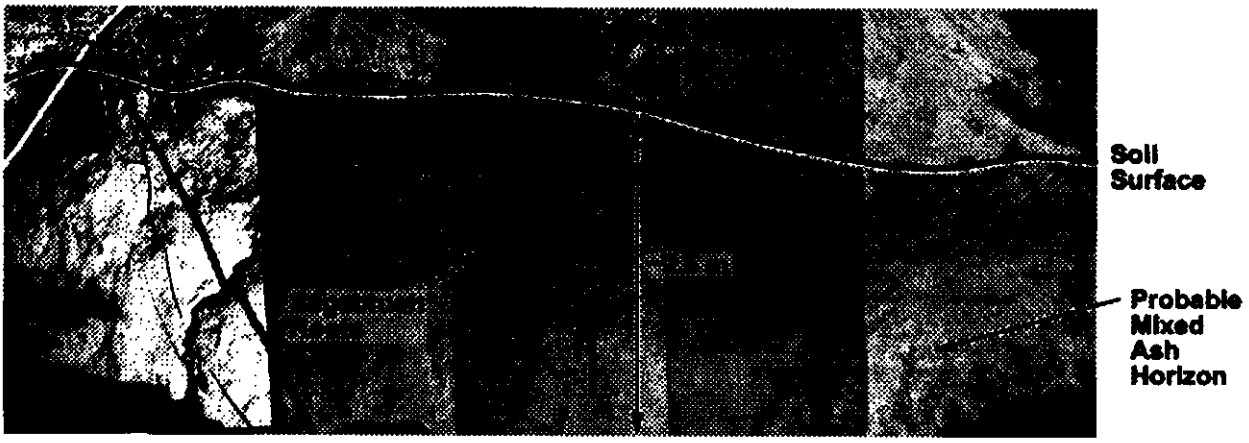

Figure D.5. Profile of the Dune Trench Showing the Lighter Colored Horizon Suspected of Containing Reworked Ash from the Mt. Mazama Eruption that Occurred 6,700 Years Ago

developed A or B horizon. Modern roots appeared to penetrate to a depth of about 2.4 m. Between 2.4 and 3.0 m is a slightly coarser layer of silty fine to medium-grained sand (Figure D.4). Underlying this layer was 0.45 m of weakly consolidated, slightly more compact, dark yellowish brown (10YR4/4) silty fine sand. This layer of finer-grained material may represent possibly a weak B paleosol horizon. Several peat-like clasts, consisting of a dense, partially decomposed mat of root hairs were collected for carbon-14 dating from this layer. At the very bottom of the excavated trench was a coarser textured layer of fine to coarse sand. Mineral grains in the coarse sand fraction were composed of about 50% basalt.

After attaining the maximum depth (~4 m) the equipment would allow, the backhoe was relocated downhill to extend the length of the trench to about 9.1 m. Soon after moving the backhoe downhill the trench caved, and it was no longer possible to keep the trench open to more than 2.4 to 3.0 m deep. About 4.6 m from the beginning of the trench and around a depth of ~1.2 to 1.5 m, there was a lighter colored layer 0.3 m or more thick, that appeared to be soil mixed with what appeared to be light-colored volcanic ash (Figure D.4). The ash is probably from Mount Mazama. This implies that the upper 1.2 to 1.5 m must be ≤ 6,850 years old and that at least 3.0 m of eolian sediments were deposited between 6,850 and 13,000 years ago.

D.3.3 NPR Trench

The NPR Trench was excavated to a depth of 4.4-m (Figure D.6). The stratigraphy was similar to that observed at the Plains Trench, which consisted of a thin layer of eolian sand over flood deposits. Overall, the exposed sedimentary sequence became finer grained nearer the surface. The eolian material at the surface was limited to about 0.15 m of pale brown, structureless, silty fine sand (Figure D.7). Immediately below this was another 0.15 m of silty medium to coarse basaltic sand, which represents the top of the cataclysmic flood deposits (Hanford formation). This layer of sand was moderately cemented with calcium carbonate (i.e., near-surface calcic-soil development) and displayed well-developed cross bedding to the east. This is consistent with the west-to-east paleocurrent direction associated with cataclysmic floods in this area. From the 0.3- to 1.5-m depth was a layer of gravelly medium-to-coarse basaltic sand that displayed low angle cross bedding. From 1.5 m to the bottom of the trench, the sediments consisted of a poorly sorted, gravelly coarse sand to sandy gravel typical of the Hanford formation. There were no volcanic layers or other datable horizons observed in this trench. The absence of the thick Mazama ash layer indicates significant wind reworking of sediments as recently as 6,850 years ago.

D.4 Conclusion

The existence of eolian sand dunes at the proposed ILAW Disposal Site demonstrates the potential for sand dune development, at least under the conditions of the early-to-middle Holocene period. Lack of a Mount Mazama ash layer in the Plains Trench and NPR Trench suggests significant wind reworking of sediments at these sites as recently as 6,850 years ago. A mixed ash/sediment layer in the Dune Trench suggests that 1.2 to 1.5 m of eolian sand has been deposited there in the last 6,850 years. Deposition rates like this will have to be considered when interpreting hydrologic and tracer data from these sites. Modern

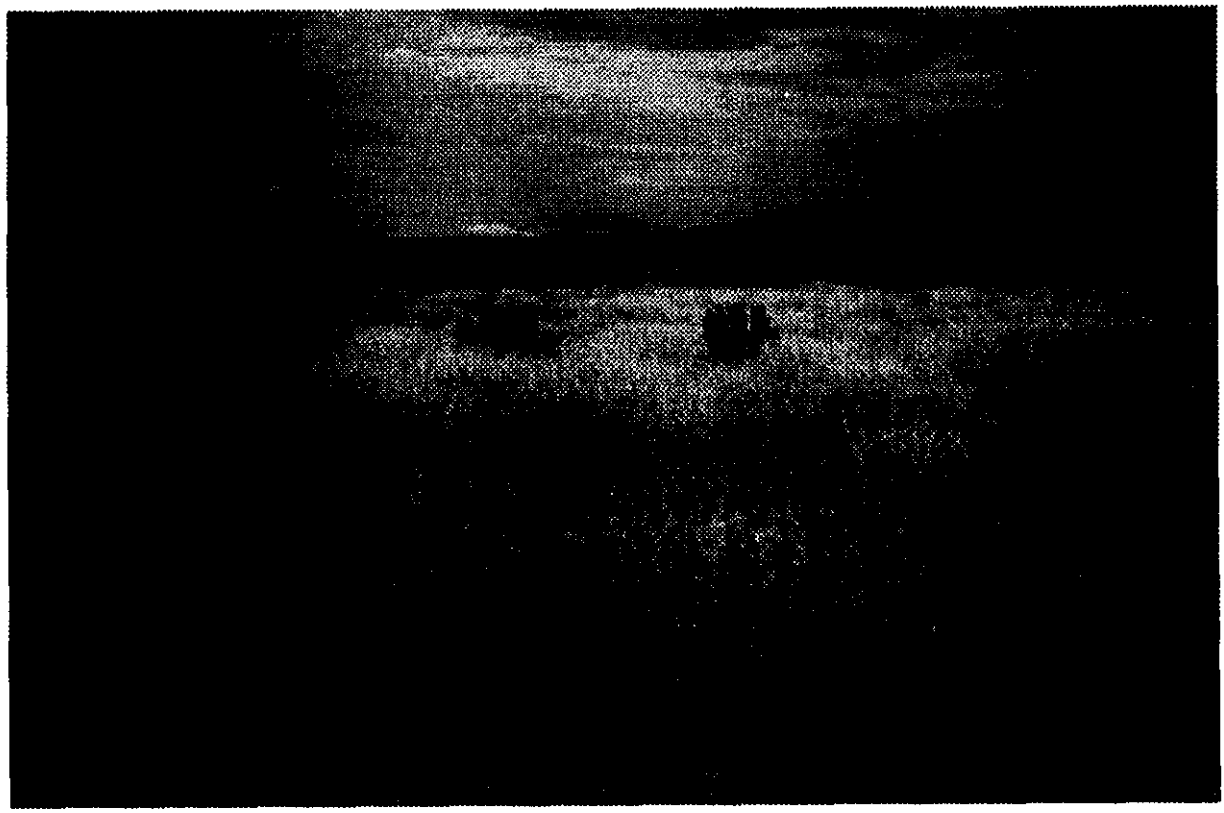

Figure D.6. View to the North of the NPR Trench. The vegetation is primarily big sagebrush, Sandberg's bluegrass, and cheatgrass. The nearest shrub in the photograph is about 10 m from the trench.

land use patterns may preclude any major sand dune formation or movement in the near future. However, the potential for some sand deposition still exists and its impact on facility performance needs to be considered.

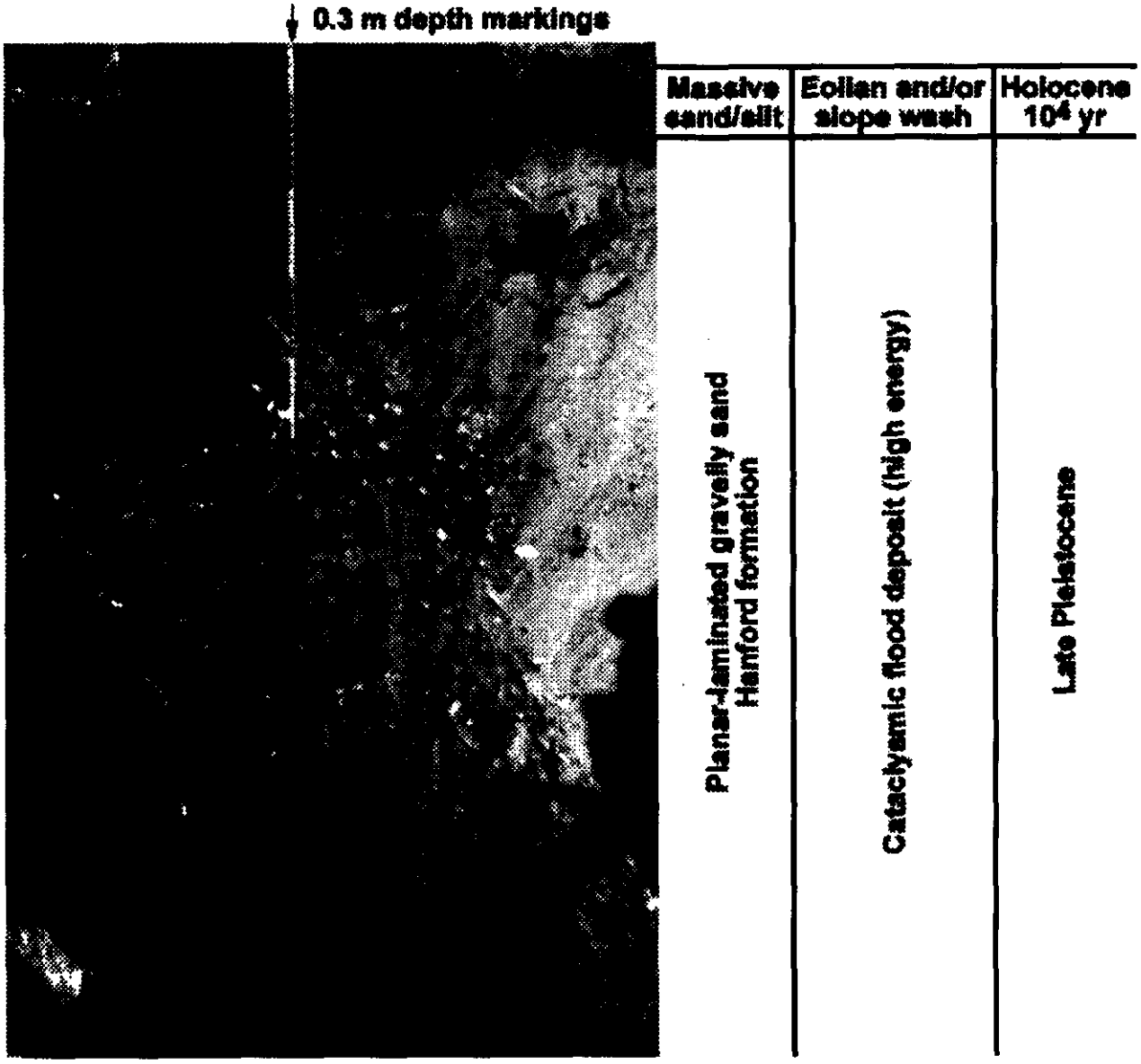

Figure D.7. Profile of the NPR Trench Showing the Thin Surface Veneer of Eolian Material on Top of the Coarser Flood Deposits of the Hanford Formation. The base of the trench (at 4.4 m) is in shadow.

D.5 References

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Appendix E

Evaluation of Anthropogenic Chloride Deposition at the ILAW Disposal Site

C. W. Lindenmeier, R. J. Serne, M. J. Fayer, and R. E. Clayton

Appendix E

Evaluation of Anthropogenic Chloride Deposition at the ILAW Disposal Site

E.1 Introduction

As part of the performance assessment under way to evaluate the suitability of the unsaturated zone of the Hanford Site for Immobilized Low-Activity Waste (ILAW), Pacific Northwest National Laboratory (PNNL) conducted a preliminary site investigation to determine if human activities in years past may influence data used for the determination of recharge rates. Because the natural recharge rate is a key parameter needed to perform calculations of the transport of water and contaminants through the vadose zone and into the groundwater, several methods are currently being employed to estimate the long-term recharge rate. One method under consideration is the chloride mass balance (CMB) method described by Murphy et al. (1991, 1996). This method uses chloride as an environmental tracer to estimate natural recharge rates. However, one concern about using this method is the potential for excess chloride deposition in the region of investigation due to anthropogenic activity. Excess chloride that is not accounted for in the calculations would change the mass balance ratios and subsequently bias the calculated recharge rate lower than the actual value.

The proposed ILAW Disposal Site is located in the 200 East Area (Figure E.1) just southeast of the 284-E Power House and Steam Plant (Figure 7.1). The site contains a relatively undisturbed old growth sagebrush area and has two predominant sediment types: Burbank loamy sand, and Rupert sand (Hajek 1966). Because this site is near a formerly active coal-fired power plant, we focused on examining the assumption that this power plant could have been a potential source of chloride deposition. This assumption is supported by the premise that the predominant form of chlorine released during the combustion of coal is an HCl aerosol that would have high affinity for particulates released in the stack of the plant. Additionally, we expected that deposits from stack emissions would correlate with prevailing wind patterns, readily determined from meteorological data. Wind data collected from the 60-m tower in the 200 Area between 1986 and 1998 (Hoitink et al. 1999) suggest that the proposed ILAW Disposal Site is downwind of the power plant.

E.2 Objective

The objective of this task was to develop and implement a quick and inexpensive chemical screening technique that would be sufficient to indicate whether or not emissions from the 284-E coal-fired power plant may have contributed excess chloride into the sediments at the proposed ILAW Disposal Site. The

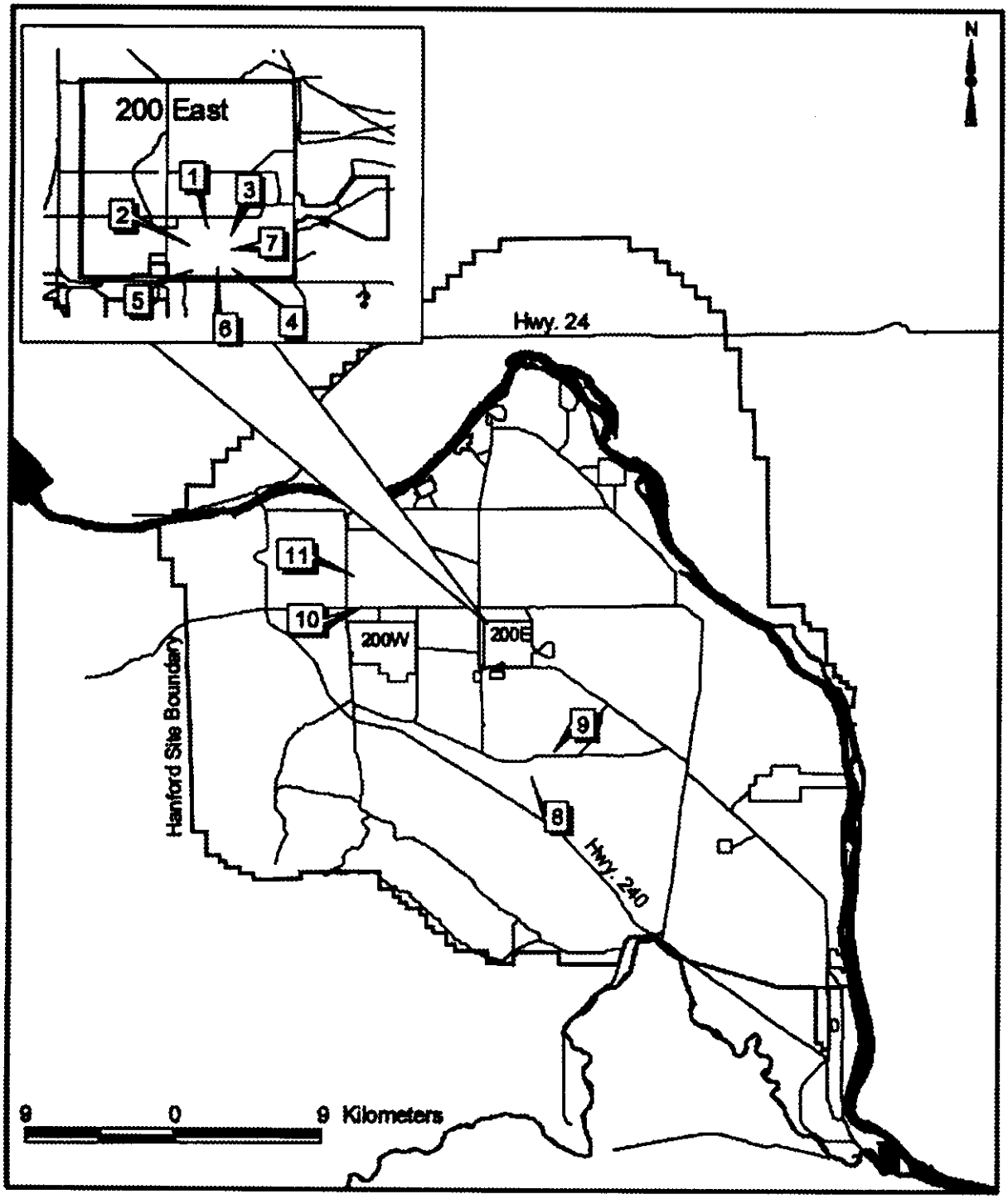

Figure E.1. Sampling Location Map

coal power plants at the Hanford Site began operation in 1945 and did not use emission control devices until 1980 (Fayer et al. 1996).[1] Coal power plants without emission controls are known to emit large quantities of nitrous oxides, sulfur oxides, and particulates, as well as a suite of trace metals such as arsenic, cadmium, chromium, or manganese. First we sought to determine if a chemical "fingerprint" could be identified from analyses of coal and fly ash materials found near the proposed ILAW Disposal Site. This fingerprint would be used to compare surface and below surface sediment samples removed from the proposed ILAW Disposal Site along with representative background sediment samples collected at various locations on the Hanford Site. X-ray fluorescence analysis of surface sediments was used to determine metal and trace metals. Ion chromatography (IC) analysis was used to determine major anions in water from leached sediments.

E.3 Methods

As shown in Table E.1, sample cores were collected from

- the top of the coal ash pile (Station 1)
- the remaining coal pile (Station 12)
- locations southwest of the proposed ILAW Disposal Site (Stations 8 and 9)
- locations northwest of the proposed ILAW Disposal Site (Stations 10 and 11)
- locations within the proposed ILAW Disposal Site boundaries (Stations 2, 3, 4, 5, 6, and 7).

Our rationale for sampling at these stations was based on the need to collect screening data that would be fairly representative of the entire site. Thus core samples were collected from the four corners of the proposed ILAW Disposal Site, a sample from a large sand dune laying along a southern, east-west transect, and two internal locations that were selected in part because they were accessible with the sampling truck. Additionally, for Stations 3 and 7, sample cores were removed from two separate locations—one an area clear of sagebrush, and the other under the canopy of living sagebrush. Dual sampling at Stations 3 and 7 was done to determine if different vegetation conditions might create significant variability and thus be a factor to consider when assessing the data. Background sampling stations were selected by a combination of visual examination, using sediment charts (Fayer and Walters 1995) that identified similar sediments associated with the proposed ILAW Disposal Site, and using a minimum distance of 5 km from the proposed ILAW Disposal Site. The 5-km distance was selected by using a calculated deposition rate for chloride as a function of distance as reported by Fayer et al. (1996).[a] Based on their simple model, at 3.4 km from the point source, deposition rates for chloride would essentially equal the natural rates. A 5-km point source distance minimum was thought to be both conservative and practical for selecting representative background sediments.

For most of the sampling, 5.08-cm-diameter cores were collected to an average depth of 152 cm using aluminum pipe (Type 6061-T6 with 5.08 cm OD x 0.12 cm wall) and a motorized impact driver (Bosch Rotary Hammer). The coring was accomplished by driving one segment of pipe to a depth of 76.2 cm to

(a) Fayer MJ, JL Downs, BN Bjornstad, and K Mahan. 1996. *Integrated recharge assessment: summary of FY 1995 activities.* Letter report to Fred Mann, Fluor Daniel Northwest, Richland, Washington.

Table E.1. ILAW Sampling Locations

	Station	Description	Sampling Location	Sample No.	Depth Sampled in.	Depth Sampled cm
Coal Ash Pile	1	Ash pile located east of the 200 East coal power plant	Top of the ash pile	Surface	24	61
ILAW Disposal Site	2	NW Corner	Bare spot within dense shrub-steppe	02-1	0-35	0-89
				02-2	36-47	91-119
	3	NE Corner	Bare spot with cheatgrass, within shrub-steppe	03-1a	0-34	0-86
				03-2a	34-52	86-132
				03-3a	52-56	132-142
			Next to sagebrush	03-1b	0-40	0-102
				03-2b	40-60	102-152
	4	SE Corner, on side of sand dune	Cheatgrass with scattered shrubs	04-1a	0-39	0-100
				04-2a	39-66	100-168
	5	SW Corner, about 50 m northeast of FY 98 ILAW borehole	Cheatgrass with scattered shrubs; hit rock at 1 m	05-1x	0-33	0-84
			Cheatgrass with scattered shrubs, about 1 m from above location	05-1a	0-34.5	0-88
				05-2a	34.5-67	88-170
	6	SE Corner, on top of sand dune	Cheatgrass with scattered shrubs	06-1a	0-37	0-102
				06-2a	37-70	0-94
	7	SE Middle	Mostly bare, with scattered shrubs	07-1a	0-40	0-102
				07-2a	40-67	102-170
			Next to sagebrush	07-1b	0-38	0-97
				07-2b	38-60	97-152
Rupert Sand Background	8	Near Well A5069, about 9 km west of the Wye barricade	Cheatgrass with no shrubs (a 1984 fire may have removed shrubs)	08-1a	0-29	0-74
				08-2a	29-47	74-119
				08-3a	42-54	107-137
	9	Just off Army Loop Road, about 8 km west of the Wye barricade	Cheatgrass with no shrubs (a 1984 fire may have removed shrubs)	09-1a	0-35	0-89
				09-2a	35-52	89-132
				09-3a	52-61	132-155

Table E.1. (contd)

	Station	Description	Sampling Location	Sample No.	Depth Sampled	
					in.	cm
Burbank Loamy Sand Background	10	Northwest of 200 West Area	Shrub-steppe, surface sample because of rocks	10-1a	0-16	0-41
	11	Northwest of 200 West Area	Rocky soil, very few shrubs, surface sample	11-1a	0-10	0-25
			Rocky soil, very few shrubs, surface sample, about 5 m from above location	11-1b	0-10	0-25
Coal Pile	12	Coal pile south of 200 East coal power plant, between the end of the rail spur and the power plant building	Grab sample			

91.4 cm. A second segment was driven down as far as possible usually resulting in a recovery of approximately 50.8 additional cm. The second core was partially hand dug out of the ground to facilitate removal. In one case at Station 3, a third segment of pipe was used allowing for the recovery of an additional 10.2 cm. After reaching the desired depth, the tubes were extracted by hand or with pipe wrenches. Excess tube length was removed and the cores were labeled and taped for transport to the lab. This method helped minimize material loss from the end of the pipe and reduced core shrinkage due to compaction. Depth measurements were taken from the hole and compared to the actual core material collected in each pipe segment. We noted an average of 5.08 to 10.2 cm shrinkage in both segments inside the pipes compared to the open hole. Following the completion of core removal, a flagged fence post was placed at the location. One exception to our collection protocol occurred when we attempted to collect the background samples for the Burbank sediment. We were successful only in obtaining shorter cores—a 25.4-cm depth in one case and 40.6-cm depth in the other.

Samples were identified using the station number as the first number followed by a dash; a second number representing the core number followed by a lowercase letter identifying the hole at a specific station. Thus a sample such as 3-3a represents Station 3, the third core removed at hole 'a.' Sub-samples sent for analyses followed this notation with the addition of a depth value. The cores were then transported to PNNL's Sigma 5 Building and placed in cold storage for sub-sampling at a later time. Actual sampling locations were recorded using a Trimble Geoexplorer2 Geographical Positioning System (GPS) unit. The GPS locations collected from each station were downloaded to a computer and corrected by differential correction for real-time data. The locations were then mapped on a Hanford Site map (Figure E.1).

The screening method selected to determine total chemical composition and chlorine extraction measurements (x-ray fluorescence analysis and water leach followed by chlorine analysis by ion chromatograph) involved separating the core into 25-g aliquots beginning at the surface and continuing until we reached the 10-cm depth. Each 25-g portion was sealed in a 30-mL glass bottle; a 10-g portion was then removed from each of the first surface samples and the last samples near 10-cm depth. These

10-g portions were stored in other 30-mL glass bottles and delivered to Ron Sanders (KLM Analytical) for x-ray fluorescence analysis.

Preliminary IC and pH analyses were performed using a 2:1 ratio water to sediment extract (Methods of Soil Analysis. Part 2; 62-1.3.2.2) with the remaining 15 g of sediment from the sample taken at the 10-cm depth, and 15 g of sediment taken from the bottom of the last core removed from a given sampling site (ranging from 119 to 178 cm deep). Each 15-g sediment sample intended for IC and pH analyses was then combined with 30-mL of deionized water in a 50-mL Nalgene centrifuge tube and gently agitated for 24 hours, centrifuged at 2500 rpm for 20 minutes, decanted into a syringe, and passed through a 0.2 μm membrane filter into a 30-mL glass bottle. The filtrate was then submitted for IC and pH analyses. In addition, a 10-g sample from the 11- to 12-cm depth was carefully weighed and placed in an oven at 105°C for 24 hours to determine moisture content.

E.4 Results and Discussion

Table E.2 shows the moisture content and 2:1 extract pH data of all sub-sampled depths for each core. Anion data from IC analysis are shown in Table E.3, and metals data from x-ray fluorescence analysis are shown in Tables E.4, E.5, and E.6.

Our preliminary assessment of the data does not offer a conclusive answer to the question of whether or not chloride data obtained from the proposed ILAW Disposal Site and used in recharge calculations may be compromised by operation of the 284-E power plant. It was our hope that by using trace metal analysis from the coal-ash and coal materials, a clear fingerprint could be identified. This fingerprint could then be readily compared to sediments within the proposed ILAW Disposal Site and sediments used for background comparison. This does not appear to be the case when reviewing the x-ray fluorescence data. The x-ray fluorescence analyses were performed only on near-surface samples because we expected the trace metals to be sorbed near the surface. However, if emission controls began in 1980, then the majority of deposition likely occurred prior to 1980. In the 20 years since then, precipitation could have leached trace metal deeper in the soil. Therefore, x-ray fluorescence analyses of deeper samples are warranted.

The ion chromatograph sulfate data, however, suggest that atmospheric deposition resulting from power plant emissions may have occurred. Specifically, sample 3-3a at the 142-cm depth shows a sulfate concentration of 182 ppm, sample 3-2b at the depth of 120 cm shows a sulfate concentration of 144 ppm, sample 6-2a shows a sulfate concentration of 35 ppm, sample 7-2a at the depth of 170 cm shows a concentration of 11 ppm, and sample 7-2b at the depth of 152 cm shows a concentration of 38.6 ppm. Sulfate concentrations at each of these sites are at least 3 times greater, and in one case, as much as 46 times greater than the highest background sulfate value from a comparable depth. These high sulfate values are at depths far below x-ray fluorescence analyses. If the high sulfate values represent deposition of coal emissions, then trace metals (if present and relatively weakly adsorbing) are likely much deeper than the 10-cm samples analyzed during this task.

In reviewing Environmental Protection Agency (EPA) data associated with sulfur dioxide emissions from coal-fired plants (EPA 1998), it could be assumed that the sulfur dioxide emitted over the life of the

Table E.2. Sample Site Depths, Moisture Content, and pH

Station No.	ILAW-1B Description	Core Samples Label	Depths in.	Depths cm	H_2O % (grav) Sample Bottom	H_2O % (grav) Sample ~10 cm depth	pH Sample Bottom	pH Sample ~10 cm depth
1	Coal Ash Pile		24	61	18	8.0	5.9	7.9
2	NW Corner	02-1	0-35	0-89		7.0		8.3
		02-2	36-47	91-119	3		8.7	
3	NE Corner	03-1a	0-34	0-86		6.2		7.9
		03-2a	34-52	86-132				
		03-3a	52-56	132-142	3		9.0	
	NE Corner Sage Brush	03-1b	0-40	0-102		5.4		7.5
		03-2b	40-60	102-152	3		9.1	
4	SE Corner	04-1a	0-39	0-99		9.2		8.0
		04-2a	39-66	99-168	3		8.4	
5	SW Corner (rock)	05-1x	0-33	0-84				
	SW Corner	05-1a	0-34.5	0-88		6.3		7.5
		05-2a	34.5-67	88-170	3		8.8	
6	SE Corner bluff area	06-1a	0-37	0-94		6.4		7.8
		06-2a	37-70	94-178	3		9.0	
7	SE Middle	07-1a	0-40	0-102		5.7		8.3
		07-2a	40-67	102-170	4		9.4	
	SE Middle sage brush	07-1b	0-38	0-97		5.8		7.8
		07-2b	38-60	97-152	5		8.8	
8	Rattlesnake Well A5069	08-1a	0-29	0-74		4.6		8.2
		08-2a	29-47	74-119				
		08-3a	42-54	107-137	1		8.4	
9	Near Ecology	09-1a	0-35	0-89		8.2		7.4
		09-2a	35-52	89-132				
		09-3a	52-61	132-155	6		8.7	
10	200W (mile marker 12)	10-1a	0-16	0-41	9	5.5	7.9	7.6
11	200W (surface)	11-1a	0-10	0-25	9	8.2	8.0	8.2
		11-1b	0-10	0-25	10	8.1	7.8	8.1
12	Coal Grab Sample						7.3	

plant may be related to elevated levels of sulfate within the proposed ILAW Disposal Site. It is also possible that chloride deposition would coincide with sulfur dioxide deposition from stack emissions.

Table E.3. IC Analysis

Dionex AI450 Chromatographic System Analysis Results (all results in ppm unless otherwise stated)											
Ion	[illegible]	**1-1a** 11-cm	**1-1a** 61-cm	**2-1a** 11-cm	**2-2a** 119-cm	**3-1a** 11-cm	**3-3a** 142-cm	**3-1b** 11-cm	**3-2b** 152-cm	**4-1a** 11-cm	**4-2a** 167-cm
Fluoride	[illegible]	1.19	<0.05	0.37	0.76	0.26	0.91	0.35	0.72	0.13	0.48
Chloride	[illegible]	2.89	15.3	0.32	0.63	0.81	76.2	5.86	111	0.39	0.74
Nitrite	[illegible]	0.05	<0.04	<0.04	<0.04	0.09	<0.04	0.38	<0.04	0.06	<0.04
Bromide	[illegible]	0.07	<0.04	<0.04	<0.04	<0.04	0.28	<0.04	0.44	<0.04	<0.04
Nitrate	[illegible]	43.5	1390	6.41	1.03	2.95	0.66	16.24	0.44	3.06	0.82
Phosphate	[illegible]	0.51	<0.2	4.09	<0.2	3.72	<0.2	2.33	0.63	3.24	<0.2
Sulfate	[illegible]	391	969	1.74	1.84	2.00	182	7.36	144	0.85	12.3
Oxalate	[illegible]	<0.2	<0.2	<0.2	<0.2	<0.2	0.28	<0.2	<0.2	<0.2	<0.2

Ion	[illegible]	**5-1a** 11-cm	**5-2a** 170-cm	**6-1a** 11-cm	**6-2a** 177-cm	**7-1a** 11-cm	**7-2a** 170-cm	**7-1b** 11-cm	**7-2b** 152-cm	**8-1a** 11-cm	**8-3a** 137-cm
Fluoride	[illegible]	0.13	0.32	0.14	0.56	0.21	2.32	0.09	2.58	0.13	0.26
Chloride	[illegible]	0.21	0.27	0.30	0.79	0.27	1.16	0.23	12.08	0.37	0.26
Nitrite	[illegible]	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Bromide	[illegible]	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Nitrate	[illegible]	1.28	0.24	2.80	<0.06	0.60	0.17	1.42	1.22	1.35	0.34
Phosphate	[illegible]	2.89	<0.2	2.24	<0.2	1.09	0.92	1.80	<0.2	1.22	<0.2
Sulfate	[illegible]	0.61	0.80	0.78	35.1	0.64	11.00	0.77	38.6	0.86	3.25
Oxalate	[illegible]	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.36	<0.2	<0.2

Ion	[illegible]	**9-1a** 11-cm	**9-3a** 155-cm	**10-1a** 11-cm	**10-1a** 41-cm	**11-1a** 11-cm	**11-1a** 25-cm	**11-1b** 11-cm	**11-1b** 25-cm	**12-1a** NA	
Fluoride	[illegible]	0.19	1.24	0.12	0.19	0.18	0.22	0.38	0.21	0.38	
Chloride	[illegible]	1.05	0.42	0.36	0.53	0.16	0.36	0.52	0.31	1.88	
Nitrite	[illegible]	0.14	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Bromide	[illegible]	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Nitrate	[illegible]	13.3	0.40	2.15	2.31	1.95	2.61	2.86	1.57	1.86	
Phosphate	[illegible]	3.67	<0.2	1.07	0.41	4.00	1.57	3.55	1.50	<0.2	
Sulfate	[illegible]	11.0	3.94	1.18	1.76	0.77	1.51	1.36	0.92	111	
Oxalate	[illegible]	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	

NOTE: Sample numbers contain the station number (i.e., "12" in sample number 12-1a)
< = below detection limit

Table E.4. X-ray Fluorescence Analysis of Stations 1 through 4

		Sample Number									
		1-1a	1-1a	2-1a	2-1a	3-1a	3-1a	3-1b	3-1b	4-1a	4-1a
Units	Element	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)
%	AL	8.38	11.03	7.19	7.72	7.99	7.82	6.34	7.59	7.22	7
%	SI	27.4	24.1	27.8	30.4	30.7	30.4	22.2	29.4	29.4	28.9
%	P	0.145	0.093	0.1	0.11	0.111	0.11	0.1	0.1	0.108	0.099
%	S	0.045	0.075	0.045	0.023	0.023	0.023	0.093	0.022	0.022	0.022
%	CL	0.011	0.01	0.011	0.012	0.012	0.011	0.01	0.011	0.012	0.011
%	K	1.6	0.835	1.73	1.88	1.78	1.87	1.295	1.75	1.65	1.73
%	CA	2.59	2.06	2.7	2.82	2.85	2.95	2.62	2.72	2.49	2.48
%	TI	0.476	0.443	0.606	0.718	0.697	0.749	0.496	0.667	0.611	0.628
PPM	V	75	28	167	199	213	205	131	174	119	138
PPM	CR	34.9	11.6	25.1	21	21.6	25.3	24.8	21.5	27.8	32.1
PPM	RB	57.8	35.7	59.8	61.6	56.6	57.6	44.7	57.2	56.4	55.6
PPM	U	3.9	3.5	5.1	3.9	3.7	3.9	5	3.8	4.3	3.7
PPM	SR	777	1850	381	363	378	367	401	366	373	349
PPM	Y	30.6	28	27.2	29	29.2	30.3	26	26.9	27.9	26.3
PPM	ZR	200	233	254	223	252	226	205	237	276	229
PPM	NB	11	11.8	10.8	10.2	10.3	9.5	10.6	11.4	11.6	11.7
PPM	MO	2.5	2.8	2.5	2.4	2.4	2.4	2.4	2.5	2.5	2.4
PPM	TH	16.5	12.5	7.4	7.5	7.3	7.6	6.7	6.5	6.8	6.2
PPM	MN	447	207	744	861	822	871	646	819	775	768
%	FE	3.28	3.25	4.21	4.72	4.61	5.01	3.45	4.69	4.31	4.38
PPM	NI	31.4	22.4	16	25.1	18.6	20.7	22	21.6	24.4	26.9
PPM	CU	38.1	53.3	34.2	19.6	26	24	44.6	21.3	23.7	20.2
PPM	ZN	59.9	43.6	81.9	73.2	75.9	73	77.8	75.8	81.9	73.9
PPM	GA	18.8	19	12.9	16.5	13.8	15.7	15.1	16.8	15.7	18
PPM	HG	3.1	3	3.3	3.5	3.4	3.5	2.9	3.3	3.2	3.2
PPM	SE	2.99	4.2	1.4	1.53	1.5	1.5	1.3	1.4	1.4	1.4
PPM	PB	19	21.2	22.4	15.3	12.7	7.6	18.5	9	14.8	11
PPM	AS	8.5	8.2	5.4	3.9	5.8	6.5	5.2	5	5.1	4.2
PPM	BR	2.28	2.42	1.2	1.3	1.3	1.4	3.27	1.4	1.2	1.3
PPM	RB	58.5	36.7	61.9	63.1	59.3	63.2	42.7	59.8	59.2	60.7
PPM	SR	761	1878	373	369	390	385	394	384	382	370
PPM	RU	8.5	8.6	8.5	8	7.4	7.6	8.3	7.8	7.4	7.7
PPM	RH	10	10	10	9.6	8.7	9	9.6	9.2	8.7	8.7
PPM	PD	13	13	14	12	11	12	12	12	11	11
PPM	AG	15	15.3	15	14	12	13	14	13	13	13
PPM	CD	16	16	19.8	15	13	13	15	15	13	13
PPM	IN	17	17	16	15	14	15	16	15	14	14
PPM	SN	18	18	18	17	16	16	17	17	16	16
PPM	SB	21	19	22	21	18	19	20	19	18	18
PPM	TE	26	24	23	21	21	22	23	21	21	21
PPM	I	32	31	32	29	25	28	28	28	24	26
PPM	CS	39	44	40	41	32	35	42	39	38	38
PPM	BA	956	1832	745	756	748	670	648	691	712	714
PPM	LA	50	52	51	47	45	73	74	49	43	42
PPM	CE	68	102	69	97	75	88	65	63	73	93

Table E.5. X-ray Fluorescence Analysis of Stations 5 through 8

		Sample Number									
		5-1a	5-1a	6-1a	6-1a	7-1a	7-1a	7-1b	7-1b	8-1a	8-1a
Units	Element	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)
%	AL	7.41	7.52	7.27	7.38	7.76	7.91	7.3	7.06	7.69	7.52
%	SI	29.8	30.6	28.8	29.4	30.8	31.3	30	30.5	32.2	31.8
%	P	0.131	0.11	0.114	0.106	0.12	0.11	0.143	0.116	0.094	0.099
%	S	0.023	0.023	0.023	0.021	0.023	0.023	0.023	0.022	0.021	0.023
%	CL	0.011	0.011	0.011	0.011	0.012	0.011	0.012	0.011	0.011	0.012
%	K	1.7	1.74	1.56	1.7	1.66	1.77	1.72	1.83	1.96	2.01
%	CA	2.81	2.95	2.83	3	3.07	2.68	2.96	2.67	1.74	1.86
%	TI	0.671	0.717	0.628	0.769	0.75	0.684	0.71	0.682	0.349	0.333
PPM	V	129	164	140	182	200	165	174	167	40	58
PPM	CR	30.5	19.4	24.7	28.2	18.5	33.2	24.3	17.3	29	23.2
PPM	RB	56.3	51	50.2	50.6	49.5	55.5	52.3	55.7	67.5	65.8
PPM	U	3.7	3.7	3.6	3.9	3.6	5	3.7	4	4.3	4.3
PPM	SR	364	365	395	372	385	366	378	372	380	396
PPM	Y	25.4	28.9	26	29.9	27.1	27.5	23.1	28.4	22.1	17.5
PPM	ZR	184	187	211	228	210	220	166	220	153	119.7
PPM	NB	11.2	11.6	10.8	11.8	9.7	9.8	11	9.4	8.5	8.3
PPM	MO	2.3	2.3	2.4	2.6	2.3	2.4	2.3	2.4	2.4	2.1
PPM	TH	6	6.3	7.7	6.5	6.4	6.4	6.2	6.4	6.5	6.1
PPM	MN	792	875	747	907	873	855	828	828	553	534
%	FE	4.61	4.91	4.38	5.33	5.12	4.86	4.91	4.7	2.91	2.81
PPM	NI	29.2	17.8	24.4	23.3	21.7	25.8	21.4	16.3	23	22
PPM	CU	19.4	17	24.9	20.1	23	17.3	18.4	18.5	24.2	16.7
PPM	ZN	77.2	70.7	77.5	80.6	79.6	69.1	75.8	68.1	56.8	52.6
PPM	GA	17.2	16.5	15.8	15.6	15.6	16.9	17.7	15.7	15.6	16.4
PPM	HG	3.2	3.5	3.1	3.5	3.4	3.3	3.4	3.4	3.2	3.2
PPM	SE	1.4	1.5	1.4	1.5	1.5	1.48	1.5	1.4	1.4	1.4
PPM	PB	11.4	10.7	11.5	13.7	11.6	10.4	10.8	11.1	13.7	10.6
PPM	AS	3.4	3	4.8	2.3	5.3	5.4	4.1	4.3	2.6	2.8
PPM	BR	1.3	1.2	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.2
PPM	RB	58.9	57.4	51.7	56.6	52.8	60.5	54.5	59.9	73.5	73.4
PPM	SR	386	385	413	382	410	378	399	375	397	420
PPM	RU	7.4	7.2	7.6	7.3	7.7	7.6	7.3	7.9	8.5	7.2
PPM	RH	8.7	8.2	8.8	9.2	8.4	9	9.1	9.3	9.9	8.9
PPM	PD	11	10	11	12	11	11	12	12	13	11
PPM	AG	12	12	14.4	14	12	13	13	13	14	13
PPM	CD	13	13	14	15	13	13	15	15	16	14
PPM	IN	14	13	15	16	14	14	16	16	17	15
PPM	SN	16	15	16	17	15	16	17	17	18	16
PPM	SB	18	18	18	18	18	19	19	19	20	18
PPM	TE	20	20	21	23	20	21	23	22	26	20
PPM	I	25	24	27	29	23	27	25	28	30	24
PPM	CS	33	31	33	35	33	39	36	39	39	38
PPM	BA	687	753	706	655	752	667	763	708	861	843
PPM	LA	58	42	44	46	43	46	47	47	52	44
PPM	CE	52	49	91	62	60	78	112	63	82	94

Table E.6. X-ray Fluorescence Analysis of Stations 9 through 12

		Sample Number								
		9-1a	9-1a	10-1a	10-1a	11-1a	11-1a	11-1b	11-1b	12-1a
Units	Element	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	0-1 (cm)	9-10 (cm)	NA
%	AL	6.91	7.68	7.66	7.6	8.06	7.58	6.99	7.36	1.53
%	SI	30.8	32.2	31.1	30.9	30.7	29.6	28	28.6	2.93
%	P	0.096	0.098	0.11	0.135	0.185	0.133	0.155	0.11	0.047
%	S	0.022	0.022	0.024	0.023	0.024	0.023	0.022	0.023	0.407
%	CL	0.011	0.011	0.012	0.012	0.012	0.012	0.011	0.012	0.023
%	K	1.94	1.92	1.76	1.9	1.68	1.81	1.6	1.68	0.111
%	CA	1.92	2.17	2.81	2.81	3.35	3.07	3.15	3.03	0.417
%	TI	0.384	0.463	0.59	0.685	0.804	0.821	0.688	0.796	0.084
PPM	V	78	94	131	155	184	220	166	200	9.7
PPM	CR	24.7	35.8	19.9	25.1	34.2	23.4	24.4	35.2	2.7
PPM	RB	62.8	61.5	55.6	60.7	49.8	56.3	53.7	57.5	5.77
PPM	U	3.9	3.8	3.8	3.8	3.9	4	4	3.9	2
PPM	SR	389	393	378	369	362	362	351	356	200
PPM	Y	20.2	21.5	24.4	25	27.6	32	25.6	28.3	5.83
PPM	ZR	144	174	189	213	215	219	172	220	40.6
PPM	NB	8.2	9.7	9.1	10.9	11.8	9.6	10	10.5	3.16
PPM	MO	2.3	2.3	2.4	2.3	2.5	2.5	2.5	2.4	1.7
PPM	TH	6.3	6.2	6.4	6.4	6.4	6.7	6.5	6	4.4
PPM	MN	569	669	760	778	971	1038	976	1093	66.3
%	FE	3.04	3.49	4.19	4.57	5.51	5.62	5.43	5.82	0.576
PPM	NI	19.3	20.9	27.9	22.8	23	24.1	26.7	27.9	4
PPM	CU	18.3	16.6	20.4	16.8	22.9	20.9	29	24.3	8.13
PPM	ZN	57	59.2	68.4	66.6	87.4	86.9	88.3	85.1	18.7
PPM	GA	16.8	17.8	19.5	18.7	16.6	18.2	17.5	20.1	3.68
PPM	HG	3.2	3.3	3.4	3.6	3.6	3.6	3.6	3.9	1.4
PPM	SE	1.4	1.4	1.5	1.5	1.6	1.6	1.5	1.7	1.12
PPM	PB	10.5	10.3	17.5	9.9	13.7	9.6	13.7	12.8	4.4
PPM	AS	5.3	6.2	2.4	5.7	2.7	5.7	4.8	4.2	2.01
PPM	BR	1.3	1.3	1.4	1.4	1.5	1.4	1.4	1.5	3.18
PPM	RB	68.6	64.2	62.2	64.8	54.6	65.1	55.7	61.1	5.3
PPM	SR	402	403	395	389	382	384	364	376	164.3
PPM	RU	7.6	7.6	7.8	7.4	7.1	7.5	8.1	7.2	8
PPM	RH	9.4	9.3	9.3	8.7	9	8.8	9.7	8.4	10
PPM	PD	12	12	12	11	12	11	12	11	14
PPM	AG	13	13	14	12	13	13	14	12	16
PPM	CD	15	14	14	14	14	14	16	13	16
PPM	IN	16	16	16	14	16	14	17	14	17
PPM	SN	17	17	17	16	16	16	18	15	26.7
PPM	SB	19	18	19	18	19	18	19	18	21
PPM	TE	23	22	24	20	21	22	24	21	24
PPM	I	27	27	27	24	25	25	31	25	32
PPM	CS	37	34	35	34	36	35	38	37	42
PPM	BA	805	673	605	710	700	691	686	688	240
PPM	LA	49	47	72	67	47	44	51	44	53
PPM	CE	101	60	69	52	77	85	59	106	60

E.5 Conclusions

To resolve the issue of where coal emissions might be within the profile, we recommend additional analyses of the entire core from at least two stations—one from the proposed ILAW Disposal Site and one from a representative background site. Preferably, these would be Stations 3 and 9. As reported, Station 3 has the highest indication of being potentially affected, and its location is well within the prevailing wind pattern located on the northeast corner of the proposed ILAW Disposal Site. X-ray fluorescence data appear to indicate that Station 9 is reasonably representative of background sediment. Profiling should involve sub-sampling each of the cores at a minimum of 20-cm intervals for 2:1 extract IC analyses, and sediment x-ray fluorescence analysis along the entire length of each core. Additionally it is recommended that, using stable isotope ratio mass spectrometry, an effort should be made to determine if a chemical fingerprint for isotopic sulfur could help determine the source of the sulfate.

E.6 References

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Appendix F

Vegetation Data Summary for Supporting Recharge Estimates - FY 1998 and FY 1999

J. L. Downs and F. O. Khan

Appendix F

Vegetation Data Summary for Supporting Recharge Estimates - FY 1998 and FY 1999

F.1 Introduction

Pacific Northwest National Laboratory (PNNL) manages the "PNNL Geotechnical Support of Hanford Immobilized Low-Activity Waste (ILAW)" project to assist Lockheed Martin Hanford Company (LMHC) in designing and assessing the performance of a disposal facility for radioactive wastes currently stored in single- and double-shell tanks at the Hanford Site. A major challenge in assessing long-term performance of buried waste disposal facilities involves characterizing and understanding the distribution of mean recharge rates across the heterogeneous landscape at Hanford. Location-specific recharge rates are determined by site-specific climate, soils, and topography (aspect and slope), as well as the disturbance or land use history (fire, erosion, grazing), soil properties, and vegetation properties.

The overall objective of the recharge task is to provide defensible estimates of recharge rates for current conditions and long-term scenarios involving the shallow-land disposal of low-level waste at the Hanford Site (WHC 1995). Rockhold et al. (1995) outlined the conditions and scenarios that could impact the disposal facility and provided estimates of recharge rates from existing lysimeter and tracer data for four conditions. However, for most of the conditions and scenarios identified by Rockhold et al. (1995), very limited data were available with which to estimate recharge rates. Thus, a major goal of the recharge task is to collect sufficient data to enable estimation of recharge rates for the conditions and scenarios deemed to be important for evaluating the performance of the disposal facility.

This letter report outlines the vegetation studies accomplished during FY 1998 and 1999 to support the prediction of recharge rates over the lifetime of the disposal facility. Under Subtasks 2c, 2d, and 2e of the recharge task, PNNL has gathered and compiled vegetation data from the literature and at the proposed ILAW Disposal Site for use in predicting the long-term water balance and recharge. The information gathered addresses data gaps (previously identified in the letter report, Review of Existing Vegetation Data for Performance Assessment Modeling of the ILAW Disposal Site) to the extent possible given current funding levels. PNNL modeling staff have been and will continue to be consulted to prioritize data collection and interpretation. Field data are summarized and presented, along with a discussion of how these data meet future modeling requirements.

F.1.1 Background and Study Objectives

The plant community existing at a site of interest influences a number of factors that determine recharge rates for that site. Vegetation can influence the surface-water runoff, the infiltration of precipitation in the soil, the amount of water stored in the soil, and even the amount of precipitation that

reaches the soil surface. The greatest effect of vegetation on surface-water budgets is in the transpiration fraction of the total evapotranspiration. Plants growing in arid systems may actually remove all water stored in the soil column, depending on the rooting depth, plant phenology and form, and the soil type; thus, plants can effectively reduce drainage and subsequent recharge (Gee et al. 1992, 1994; Link et al. 1994).

In general, models used to estimate recharge rates for different conditions will require certain vegetative parameters including estimates of plant transpiration and plant water status (leaf water potential) that can be correlated with soil water potentials. Knowledge of rooting depths, root densities, and root distributions are also required for modeling efforts to accurately simulate sequential removal of water from different depths within the soil profile. Depending on surface, vegetation, and soil conditions, recharge rates at Hanford can range 1000-fold: from less than 0.01 cm/yr under a complete cover of shrubs to more than 10 cm/yr under graveled surfaces without vegetation (Murphy et al. 1996; Gee et al. 1992).

Because vegetation is a function of the physical environment, differences in environmental conditions such as soil depth or soil type are readily reflected by differences in the plant community composition and structure across the landscape. The density and canopy cover of mixed shrub and grass communities can vary greatly across relatively short distances. Changes in soil type and/or slope and aspect can create sharp delineations between community types or change the abundance of a particular species. Understanding the patterns of plant distribution—both above- and belowground—is key to understanding plant water use and its impact on recharge rates.

The objectives of the vegetation subtasks are to provide the descriptive information and data that are needed to better understand and predict recharge rates at the proposed ILAW disposal facility on the Hanford Site. These data will aid in understanding how and to what extent plants may control recharge at the Site and be used to develop the appropriate ranges and distributions of plant parameters that can be used in computer modeling efforts to assess recharge. In FY 1998, field data collected under these subtasks included information concerning the existing and potential plant community structure: plant canopy cover, species diversity, shrub density and distribution of size classes, plant root spatial distribution and biomass, total leaf area and biomass, and determination of leaf area index. In FY 1999, our objectives were to collect physiological and life history information over a 7-month period from November 1998 through May 1999.

Our investigation concentrated on defining water relations for three dominant plant species on the site: big sagebrush (*Artemisia tridentata*), cheatgrass (*Bromus tectorum*), and Sandberg's bluegrass (*Poa sandbergii*). The FY 1999 study focused on defining plant water status with respect to soil water status for each of the species of interest during winter and spring months. We conducted the following studies throughout the year:

- documentation of plant phenology
- measurement of leaf (xylem) water potential through winter until late spring
- concurrent measurement of leaf-level conductance as feasible
- concurrent measurement of soil water content

- finalizing measurements of root distribution and biomass of shrubs and grasses.

We also sampled plants for leaf area index (LAI) to compare with the 1998 leaf area and biomass data and to refine the community level estimates for LAI. To the extent feasible, measurements were made to document seasonal changes in LAI.

F.2 Methods

The field study area is located at the proposed ILAW Disposal Site in the 200 East Area of the Hanford Site (Figure F.1). The current plant community can be classified as either *Artemisia tridentata/Bromus tectorum* (Big Sagebrush/Cheatgrass) or *Artemisia tridentata/Poa Sandbergii* (Big Sagebrush/Sandberg's bluegrass) depending on the extent to which cheatgrass has replaced bluegrass as the understory grass species. Soils of the ILAW site are predominantly sands and loamy sands (see Section 3.0 of the main report). The topography of the ILAW site to the south and west of the plutonium-uranium extraction (PUREX) facility is relatively flat with the exception of a stabilized dune running in

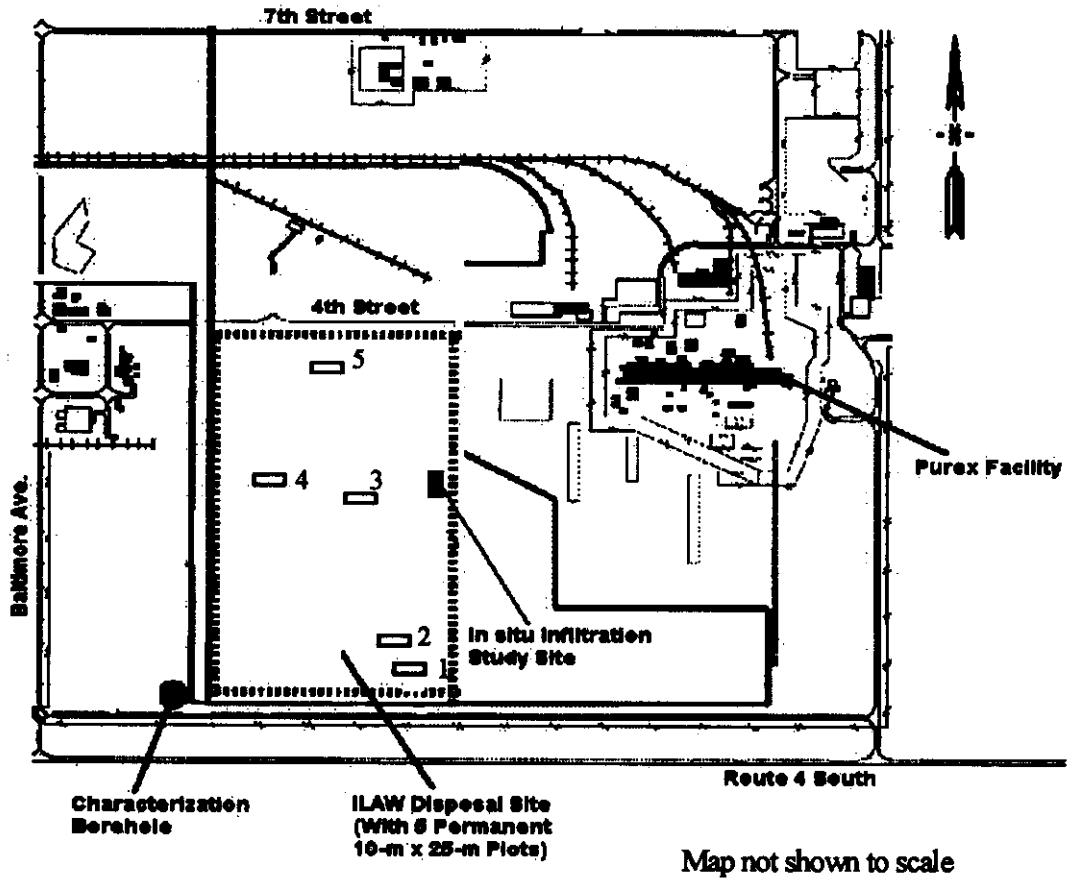


Figure F.1. Map of the Immobilized Low Activity Waste Disposal Site in the 200 East Area Displaying the Five Permanent Vegetation Monitoring Plots

an east-west direction along the southernmost edge of the site. The general climate at the Hanford Site is best described as semiarid with hot dry summers and cold, wet winters. During the 1998-1999 measurement period, winter temperatures were warmer than the long-term averages for the site. November was 5.3°F above the normal monthly average (40.2°F), December was 5.4°F above the normal monthly average (31.4°F), January was 1.6°F above the normal monthly average (31.3°F), and February was 3.7°F above the normal monthly average (38.0°F).

Efforts in FY 1998 were focused on characterizing two types of plant communities that might establish on the ILAW disposal facility: the existing sagebrush-steppe type community currently occupying the proposed disposal area, and abandoned fields that represent the unaided establishment of vegetation after construction or possible successional stages following fire. Characterization efforts included measurements of plant canopy cover, shrub density and height, species diversity, leaf area and biomass. In addition, root distributions were sampled to a depth of 1 m on the in situ infiltration test plot.[a] Leaf-level conductance, leaf water potential growth and phenology, and concurrent soil water status were measured from November 1998 through May 1999.

F.2.1 Species Diversity and Canopy Cover of Herbaceous Plants

Five 100-m transects were randomly established in 1998 at the ILAW Disposal Site and three 100-m transects at the Existing Disposal Site to determine plant diversity, abundance, and canopy cover by species for the sagebrush-steppe community. On each 100-m transect, three 10-m x 10-m plots were established along the transect at 25, 50, and 75 m. In each 10-m x 10-m plot, shrub height, widest diameter (d_1), and diameter (d_2) perpendicular to the first diameter measurement were recorded. Shrub canopy cover was calculated using this plot data. An ellipsoidal area was calculated for each shrub

$$Area = \pi\left(\frac{d_1 d_2}{4}\right) \tag{F.1}$$

and the total shrub area was summed for each plot and expressed as a percentage of ground area to determine percent canopy cover. These were averaged for each transect and a mean canopy cover was determined for each site (ILAW, n = 5; Grout, n = 3). Understory canopy cover by species was visually estimated in 0.2 x 0.5-m plots using a modification of Daubenmire's (1959) method. These 0.1-m quadrants were systematically placed along the transect to provide 25 to 30 samples of plant cover and compostion along each transect. Species lists were compiled for the area adjacent to each transect. Where feasible, percent bare ground and percent of ground covered by biotic crust was also estimated.

Data were also gathered in a similar fashion from five additional transects established randomly on abandoned fields on fine-textured soils on the Hanford Site (two transects at McGee Ranch, two transects at Lower Snively field, and one transect at Benson Ranch). No shrubs were found on abandoned field

(a) Ward AL, RL Clayton, and JC Ritter. 1998. "Hanford Low-Activity Tank Waste Performance Assessment Activity: Determination of in situ hydraulic parameters of Hanford Sediments," Letter Report to Fred Mann, Fluor Daniel Northwest, Richland, Washington, August 31, 1998.

transects, so no 10-m by 10-m plots were established on those transects. These data are compared with data obtained from the ILAW Disposal and Existing Disposal Sites.

F.2.2 Leaf Area Index and Shrub Biomass

During February 1998, all sagebrush plants were harvested from a 2-m x 10-m plot on the borehole site, southwest of the PUREX facility, and in April 1998 from the 5-m x 8-m in situ infiltration test plot, including its borders and measured for canopy cover, LAI, and shrub biomass. At the same time, herbaceous groundcover was harvested for leaf area determination from eight 1-m^2 plots at the borehole site (February 1998) and from six random 0.1-m x 0.5-m plots at the in situ infiltration test plot (April 1998). All leaves were separated from each plant and a total leaf area for that shrub obtained using a LI-COR 3100 Area Meter. Leaves and stems were dried and weighed for a total biomass of each shrub. For each harvested understory plot, all live herbaceous plant material was separated from litter and a total leaf area obtained using a LI-COR 3100 Area Meter. Equations were developed to relate sagebrush volume to leaf area and sagebrush leaf biomass to leaf area. These relationships are used with shrub density and size measurements to evaluate variability in leaf area across the assessment site.

Nine additional shrubs were harvested in spring 1999 in the ILAW Disposal Site for LAI values and shrub biomass measurements. Shrubs harvested were selected in three categories, three of each; small, medium, and large, and all plants were measured for height and diameter before harvesting. At the same time, herbaceous groundcover was harvested for leaf area determination from six random 0.1-m x 0.5-m plots at the site. These data have not been summarized for this report, but will be included at a later date.

All sagebrush in 14 randomly selected 10-m x 10-m plots across the site were measured in 1998 to obtain average shrub size, shrub density, and canopy cover. Measurements were also obtained from nine additional 10-m x 10-m plots near the Existing Disposal Site for comparison.

Root distribution sampling was conducted before excavation of the in situ permeability plot during July 1998. Approximately 75 core samples of soil 0.05 m x 1 m deep were removed in sections (>450 subsamples) for processing. Root samples were washed of soils and oven dried. Dried roots were weighed to determine root biomass. Samples were grouped for analysis according to distance from the main stem of sagebrush plants in the area.

F.2.3 Plant Phenology and Growth

Five large (10-m x 25-m) permanent plots were established in November 1998 across the proposed ILAW Disposal Site to monitor phenological changes and growth of the dominant grass species (cheatgrass and Sandberg's bluegrass) during FY 1999 (Figure F.1). Two of the five plots are located in the southeastern corner of the site adjacent to each other. One plot was established on each of two slopes located on the site: a north-facing slope and a south-facing slope. The location of these plots will enable us to monitor plant growth and development under different exposure to sunlight and rainfall determined by aspect. The other three plots were randomly located across the ILAW Disposal Site so that data collected will represent vegetation characteristics sitewide.

Within each of the five large permanent plots, ten subplots (0.5-m x 0.2-m) were established to monitor phenological changes of the two grass species of interest during the growing season. Subplots were equally apportioned either beneath shrubs or in inter-shrub spaces. Five shrubs within each 10-m x 25-m plot were chosen randomly to establish the sub-plots: five sub-plots close to or beneath the shrub canopy (one plot per shrub), and five sub-plots located in inter-shrub space.

From November 1998 through May 1999, growth and development were observed monthly in the winter and bi-weekly in the spring in each subplot, when the grasses were most active. Estimated canopy cover and growth stage for both grass species of interest were recorded at each observation period. Grass height of each species was measured at the same time through March. Growth was also measured for each of the five marked shrubs in each permanent plot. Initial height and diameter measurements were taken in November 1998 when the plots were established and a second set of similar measurements was taken in the spring 1999.

F.2.4 Leaf Water Potential and Conductance

Seven individuals of both juvenile and mature sagebrush (14 individual plants) were selected randomly on the ILAW site from outside the permanent plots and marked for measurement. Leaf water potential and stomatal conductance measurements were taken on these plants. Seven randomly selected sites in the vicinity of the marked shrubs were established for similar measurements for cheatgrass and Sandberg's bluegrass. Leaf water potential of sagebrush and cheatgrass was determined by a series of replicated measurements during the winter and spring months. These measurements were conducted monthly in the winter months (November, December, January, February, and March) and bi-weekly in the spring months (April and May) during peak growing season. Leaf water potential of Sandberg's bluegrass was measured only during April and May 1999, when the size of the leaves was large enough to allow measurement. Pre-dawn and midday leaf water potential measurements were conducted during the same day using the pressure chamber technique as described by Koide et al. (1989).

Two measurements were conducted on each shrub and grass site during each sample period. Because the entire cheatgrass plant was used for each measurement, the area of sampling was permanently marked and consecutive sampling was conducted as close to the original sample as possible. Because Sandberg's bluegrass is a bunchgrass, the bunch in each selected site was marked and samples were obtained from that bunch for each measurement. In cases where the size of the selected bunch was not adequate, bunches of bluegrass close to the original sample were used for measurements.

Stomatal conductance was measured for sagebrush and the two dominant understory grasses using standard porometry methods (Pearcy et al. 1989). A LI-COR 1600 Steady State Porometer was used for these measurements. Peak (midday) conductances were determined for sagebrush from February 1999 to May 1999, for cheatgrass from March 1999 to May 1999, and for Sandberg's bluegrass in May 1999. Because of its size, we were unable to conduct any conductance measurements on Sandberg's bluegrass until May. These measurements were taken in concert with leaf water potential measurements. Data collected were summarized to evaluate the magnitude and variability of seasonal changes in leaf water potential and conductance.

F.2.5 Soil Moisture

Soil samples were obtained at the same time as leaf water potential measurements to determine water content of the soil in the area of the plants being measured. Samples were obtained in two locations, under shrub canopies and in inter-shrub space, at depths from surface to a maximum of 1.5 m; 0 to 10 cm, 10 to 20 cm, 40 to 50 cm, 90 to 100 cm, and 140 to 150 cm. Where feasible, two or three sets of samples (near shrub and inter-shrub space) at different locations were obtained for accuracy. Soil water content (weight %) was determined by the gravimetric technique.

F.3 Results And Discussion

Work done during the 1998 fiscal year resulted in significant progress in characterizing existing plant community characteristics and defining the variability and condition of the shrub community at the ILAW site. Sampling and data analysis in FY 1999 presented here provide important information concerning the water relations of dominant species and phenology and life history information for the winter to spring growth period.

F.3.1 Plant Community Structure

The density and canopy cover of big sagebrush found on the two disposal sites vary slightly (Table F.1) and are representative of cover values reported for big sagebrush/Sandberg's bluegrass associations (average cover, 24%; range, 8 to 35%; Franklin and Dyrness 1988). It is interesting to note that although shrub canopy cover is nearly equal at the two locales (ILAW = 32% and Existing Disposal Site = 29%), the density of shrubs at the ILAW site is about 1.5 times the sagebrush density found on the Existing Disposal Site area. The overall age of shrubs in the two study areas appears to be similar with large spreading shrubs common at both sites. However, at the ILAW site, very dense patches of sagebrush are scattered across the northern and center portion of the site. Some of these patches are distinguished by multiple stemmed plants with relatively small canopy diameters that represents a slightly unusual growth form for big sagebrush in this vegetation association.

Table F.1. Summary of Sagebrush Characteristics Measured Across The ILAW Site and Existing Disposal Site

Location	Average Density Shrubs/Hectare	Average Height of Shrubs (cm)	Height Range Low - High (cm)	Average Canopy Cover (%) of Shrubs
ILAW Disposal Site	4000	101	7 - 225	32.0
Existing Disposal Site	2590	89	10 - 175	29.6

Table F.2 indicates that total plant cover on the Existing Disposal Site is also lower than that found on the ILAW Disposal Site (64% versus 83%). Native grass cover (principally Sandberg's bluegrass) and

native forb cover are higher on the ILAW site than on the Existing Disposal Site. This difference is also reflected in the higher species diversity found on the ILAW site. The percent bare ground and percent biotic crust cover were also estimated on a subset of the transects. Estimates of bare ground were 19.9% at the ILAW site and 34.8% at the Grout Site; biotic crust estimates were 8.3% at the ILAW site and 12.6% at the Existing Disposal Site.

Table F.2. Summary of Species Diversity and Canopy Cover Data

Location	Plant Form	Native Species	Alien Species	Totals	Average Native Species Cover (%)	Average Alien Species Cover (%)	Total Average Cover (%)
ILAW Disposal Site	Forbs	12	5	17	7.0	1.40	8.4
	Grasses	2	1	3	13.6	28.6	42.2
Total Herbaceous		14	6	20	20.6	30.0	50.6
	Shrubs	1	0	1	32.0	0	32
Total		15	6	21	52.6	30.0	82.6
Existing Disposal	Forbs	8	4	12	2.2	0.9	3.1
Site	Grasses	1	1	2	4.0	26.8	30.9
Total Herbaceous		9	5	14	6.3	27.7	34.0
	Shrubs	1	0	1	29.6	0	29.6
Total		10	5	15	35.9	27.7	63.6
Abandoned Fields	Forbs	6	5	11	4.1	13.2	17.2
	Grasses	1	2	3	1.3	63.7	65.0
Total		7	7	14	5.4	76.9	82.0

Communities on abandoned (disturbed) agricultural fields were evaluated as analogs to unaided vegetation development on a constructed cover. Mean canopy cover of all plant functional types on the abandoned fields was about the same as total cover at the ILAW site, but was greater than the total mean canopy cover found on the Existing Disposal Site. However, 77% of the total cover on abandoned fields is composed of alien grasses (64% canopy cover), specifically cheatgrass. Alien grass cover on abandoned fields is more than twice that found on shrub-dominated sites. Fewer native species (which are more likely to be deeper-rooted perennial plants) are found on the abandoned fields than in shrub-dominated communities. No shrubs were encountered along transects placed in abandoned fields. Although shrubs may be present in abandoned fields, canopy cover is less than 1% and considered negligible.

F.3.2 Phenology and Growth

Cheatgrass is a winter annual, and although most seeds germinate in the fall after sufficient rainfall, a second recruitment of seedlings in early spring months also occurs. Sandberg's bluegrass is a '*cool-season*' perennial grass that is senescent and dormant during the dry hot summer and becomes green and active after fall rains. Both species maintain green leaves and are assumed to lie quiescent

when temperatures become cold over the winter months. Observations of phenology and growth of the two dominant grass species at the ILAW site from November 1998 through May 1999 indicated that both species were active throughout the winter months. Warmer than normal winter temperatures during the measurement period (see study site description) must be taken into consideration when evaluating these data. Nighttime temperatures in December and January fell to the low- to mid-20s F, but daytime temperatures were often in the upper 30s to low 40s (Hanford Meteorological Station data for 1998 and 1999).

Plant growth as evidenced by changes in canopy cover of dominant grasses at the ILAW site was estimated over the 7-month period (November 1998 through June 1999) and is shown in Figures F.2 and F.3. Canopy cover of the grasses more than doubled between October and February, indicating the grasses were not quiescent; growth and development continued throughout the winter, as weather allowed. Direct measurements of plant height for the two species over the winter months also provide evidence of growth and plant activity during the winter (Table F.3). Measurements of big sagebrush on the fire plots indicated increases in shrub canopy between November 1998 and April 1999. On average, canopy increased by about 5 cm and the two diameters (d_1 and d_2) increased by 7 and 5 cm.

Measurements of plants in different microhabitats showed significant differences in plant growth determined by spatial and structural relationships with the shrub component of the plant community. Plants of both grass species showed greater growth and canopy cover under shrubs than plants in inter-shrub spaces. This increased growth under the shrub canopies may be a result of several factors. The microclimate under shrubs may be more favorable for growth than that found in more open areas. Also, soil nutrient levels may be higher underneath shrub canopies, which can act to create "islands of fertility" within semiarid systems (Allen 1991).

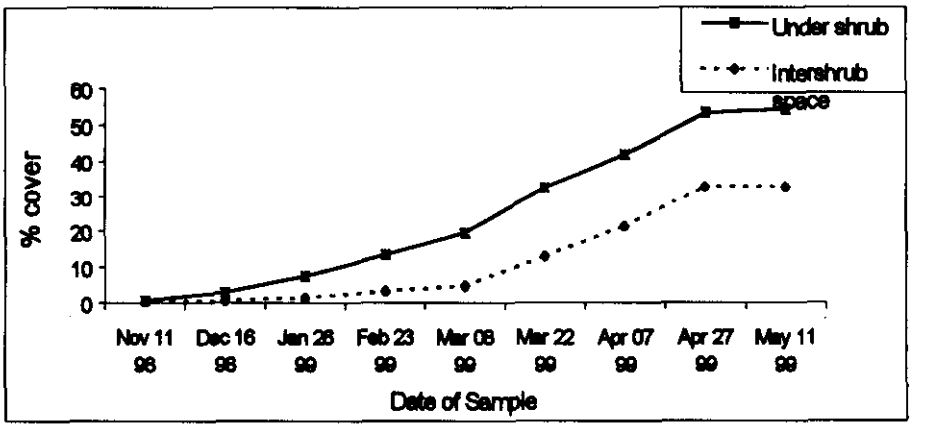


Figure F.2. Mean Percent Canopy Cover for Cheatgrass at the ILAW Site Throughout the Measurement Period

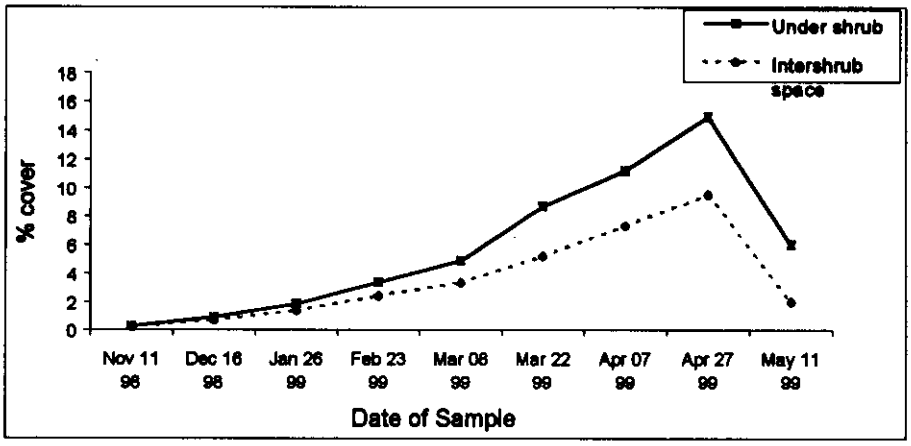


Figure F.3. Mean Percent Canopy Cover for Sandberg's Bluegrass at the ILAW Site Throughout the Measurement Period

Cheatgrass developed two to three times greater mean canopy cover than Sandberg's bluegrass at the proposed ILAW site, depending on the microhabitat. In Figure F.3, we can see that the peak canopy cover of Sandberg's bluegrass occurred at the end of April at the ILAW site and that the bluegrass began to senesce by early May. Cheatgrass maintained green canopy for approximately 2 weeks longer than Sandberg's bluegrass, although total canopy cover did not change significantly between April 27 and May 11.

Phenological stages recorded from November through May (shown in Figure F.4) indicate that both species initiate floral structures very early in the spring, about mid-March. These data along with the canopy cover estimates indicate that growth and development of these two cool season grasses occurs very early during the growing season. Observations in this study indicated that cheatgrass initiated floral structures about 1 week earlier than Sandberg's bluegrass. In contrast, previous study of phenology for these species on the Hanford Site (Link et al. 1990) found that Sandberg's bluegrass initiated floral structures approximately three weeks before cheatgrass.

Table F.3. Grass Height (cm) Measured at the Proposed ILAW Site During Winter 1998-1999

Species	October	November	December	January	February	March
Cheatgrass	2	3	4.5	5	6	7.5
Sandberg's Bluegrass	2	3.5	6	8	8.5	10

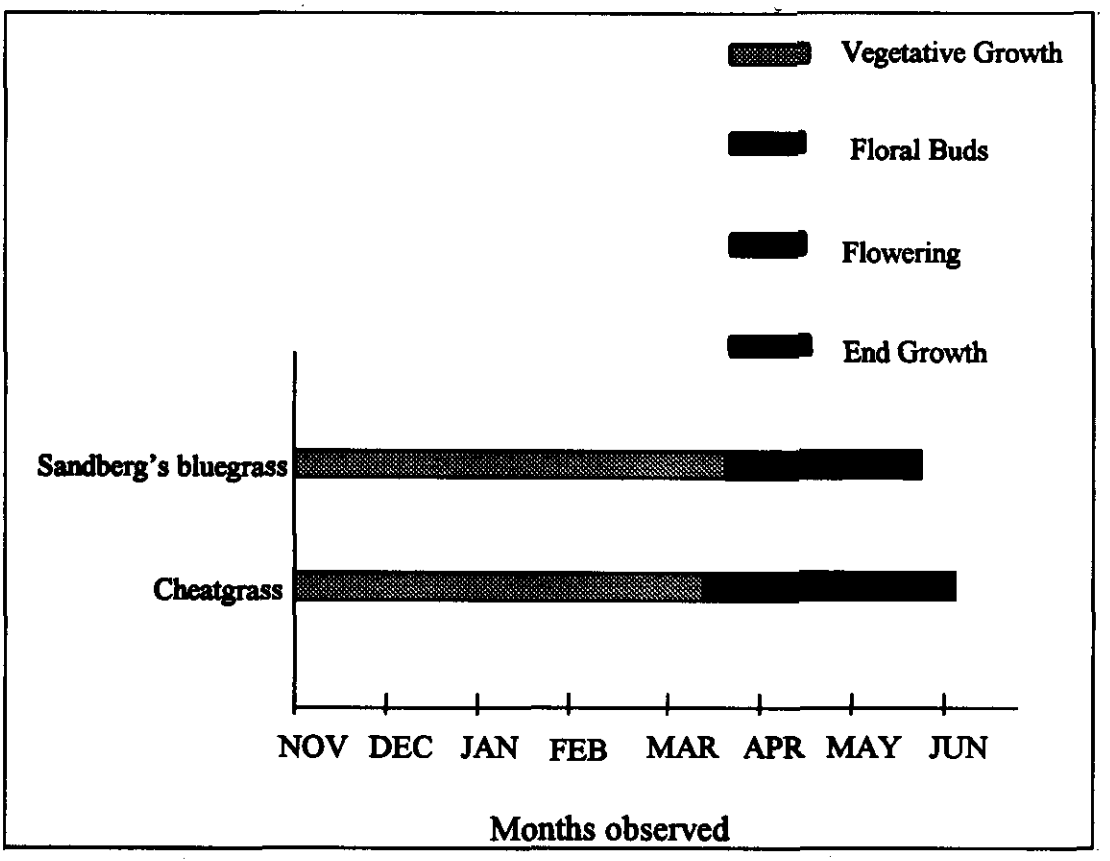


Figure F.4. Phenological Stages of Cheatgrass and Sandberg's Bluegrass at the ILAW Site Over the Measurement Period (Nov. 1998 – June 1999)

F.3.3 Leaf Area and Biomass Measures

Data collected on shrub and understory leaf area in 1998 and 1999 were compiled to provide an estimate of LAI at near peak biomass (Tables F.4a and F.4b). These values were developed using both measured leaf area indices and relationships developed from morphometric measurements of shrubs. Regression relationships were developed to relate leaf biomass to leaf area and to relate calculated shrub volume to leaf area for two different time periods: February and April (Figures F.5 and F.6). The equation describing the relationship between leaf biomass and leaf area shows a reasonable fit to the data

Table F.4a. Estimated Leaf Area Index for Shrubs Measured in 1998

Month	Location	LAI
February	ILAW Site	0.102
April	ILAW Site	0.204
June[a]	ILAW Site	0.282
July[a]	Grout Site	0.140
(a) Values estimated using morphometric and plot data.		

Table F.4b. Estimated Leaf Area Index for Understory Plants Measured in 1998 and 1999

Date	Location	LAI
February 1998	ILAW Site	0.118
April 1998	ILAW Site	0.904
May 1999	ILAW Site	0.395

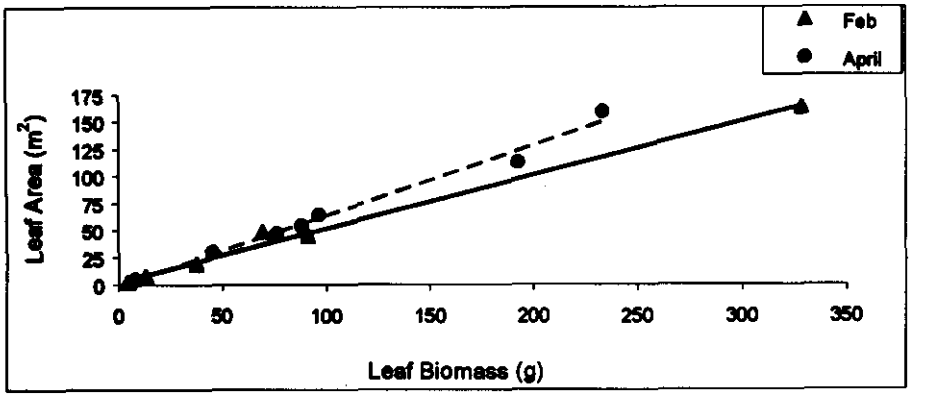


Figure F.5. Regression Relationship of Leaf Area to Biomass for Shrubs Measured in February and April 1998

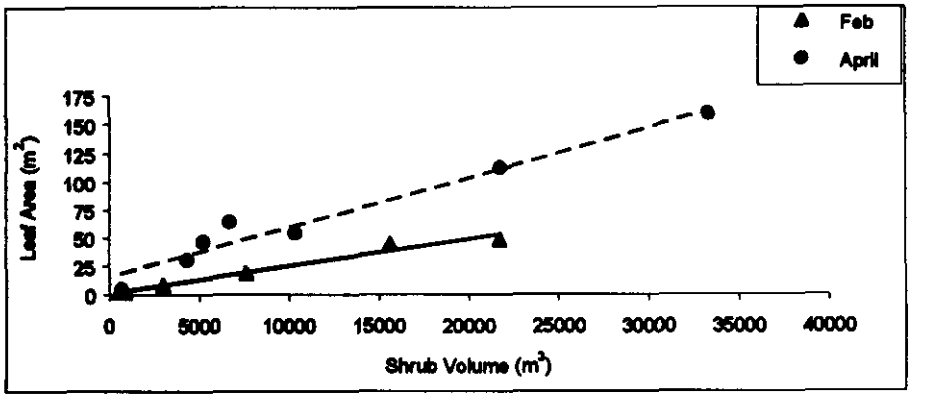


Figure F.6. Regression Relationship of Leaf Area to Volume for Shrubs Measured in February and April 1998

for both measurement time periods. Leaf area is not predicted as well by calculated shrub volumes. However, biomass data for entire shrubs or over large spatial areas are seldom available. Using a leaf area relationship developed on morphometric measurements allows us to estimate the spatial variability in

shrub leaf area through nondestructive measures of shrub size and canopy extent. The difference between the February and April relationships can be explained by the increase in shrub and grass leaf area during the spring growth period.

F.3.4 Plant Water Status

Predawn and midday water potentials were measured for mature sagebrush during the 7-month period from October 1998 to May 1999. Leaf water potential of plants varies on a diurnal schedule: as the plant goes through a daily cycle of photosynthesis and transpiration, leaf water potentials become increasingly negative because the plant loses water faster than the root system and vascular system can absorb and transport water to the leaf. At night when photosynthesis and transpiration are not occurring in C-3 plants, leaf water potentials become less negative as water is taken up from the soil and plant water potentials equilibrate with soil water potentials (Kramer 1983). Measurements of predawn leaf water potential should closely represent the soil water potential integrated over the plant's rooting zone. Differences between predawn and midday water potential indicate water use or water loss through plant transpiration. The leaf water potential differences in Figure F.7 show clearly that sagebrush were active during the winter months of the 1998-1999 season.

Leaf water potential data for different size classes of shrubs (juvenile less than 50 cm, and mature greater than 75 cm) indicate significant differences in patterns of water use at different points in time. Although predawn leaf water potential measurements (Figure F.8a) initially indicated that juvenile plants might be more stressed, the data are highly variable (November measurement), and no significant difference is found for the measurement period. A pattern occurs where the midday leaf water potential of juvenile plants appears to be more negative during November, December, and February; whereas, the same plants appear less stressed (less negative leaf water potential) during April and May (Figure F.8b). Figure 8c more clearly shows this pattern as the difference between mean predawn and mean midday values for the two size classes of shrubs.

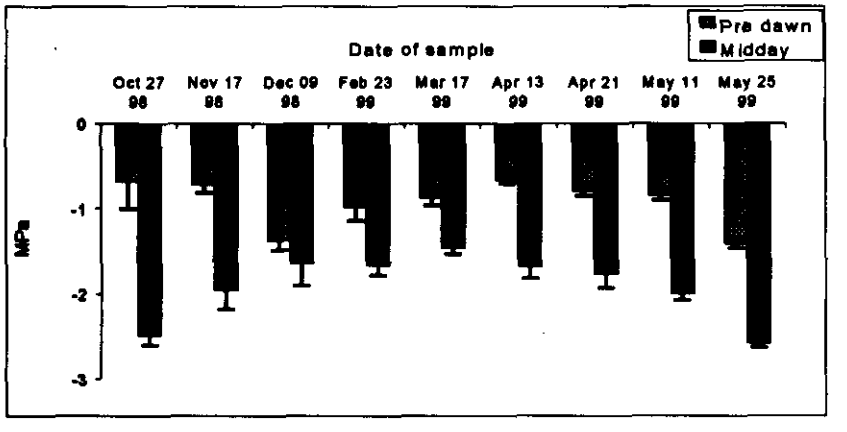
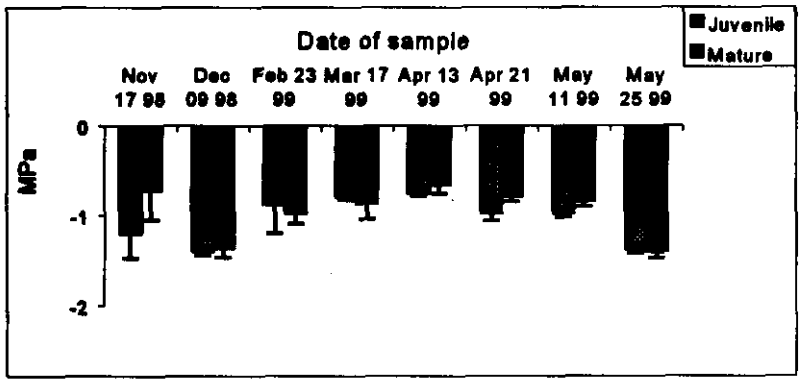
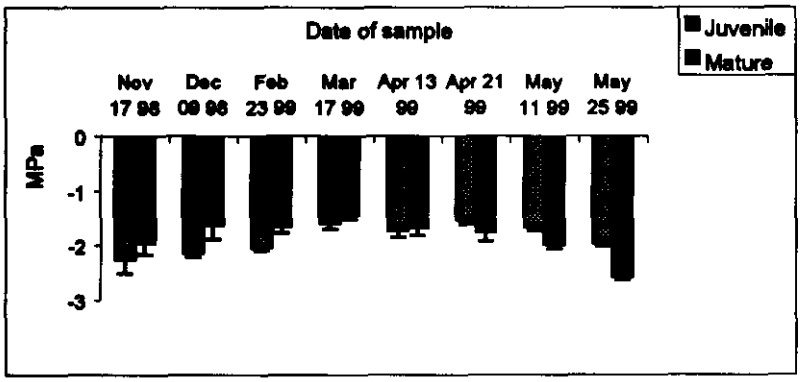


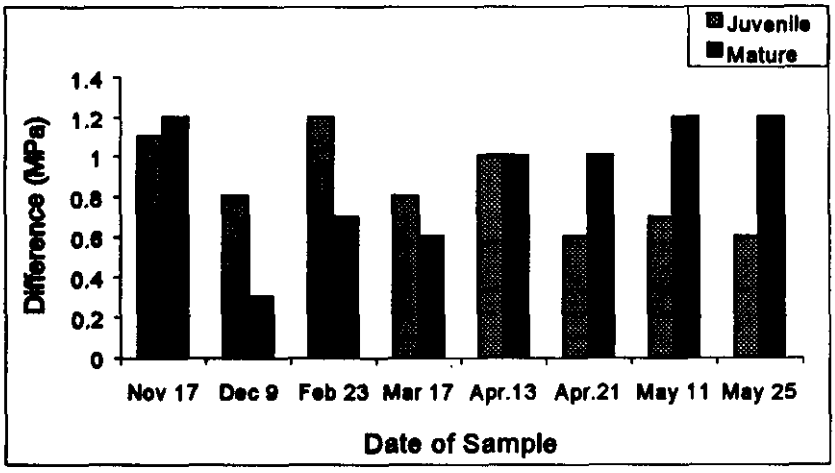
Figure F.7. Measured Leaf Water Potential for Mature Big Sagebrush: Predawn and Midday Measurements (error bars are ± one standard error)



(a)



(b)



(c)

Figure 8. Measured Leaf Water Potential for Juvenile and Mature Big Sagebrush: a) Predawn, b) Midday, and c) Predawn Minus Midday (error bars are ± one standard error)

Mean values for predawn and midday leaf water potentials for cheatgrass over the past 8 months indicate that the understory plant is less active during the winter months in terms of water use than big sagebrush. Very small differences occurred in predawn and midday leaf water potentials during the months of November, December, January, and February (Figure F.9). In contrast, the differences between predawn and midday values during March, April, and May are large, indicating significant water loss to transpiration during the spring growing season.

Although plant cover data indicate significant plant activity during the winter season for Sandberg's bluegrass, we were unable to obtain leaf water potential measurements due to the small size of leaves and equipment used. Leaf water potential information obtained for the spring season indicates that predawn values were consistently low (approximately -0.7 MPa) for the three measurement periods and midday values were significantly lower (-2.0 to -3.0 MPa) indicating significant transpirational water loss during the daylight hours (Figure F.10). In contrast to the low predawn leaf water potentials for Sandberg's bluegrass, at early April measurement periods, cheatgrass was able to obtain predawn xylem potentials of about -0.3 MPa. This may reflect that the greater rooting depth of cheatgrass allows this species to equilibrate predawn potentials with soil water potentials in deeper, wetter portions of the soil profile. The root zone of Sandberg's bluegrass generally is limited to the top 30 to 45 cm of the soil profile, whereas cheatgrass may develop roots below 75 cm (Link et al. 1990).

Leaf-level conductance data obtained during the spring months for big sagebrush were highly variable and apparently lower than values reported previously in the literature (Figure F.11) (Evans et al. 1991). Sagebrush conductance values measured previously by the author during the spring months under different soil conditions were approximately 2 to 3 times greater than values measured at the ILAW site. Although the porometer was factory calibrated before any measurements were taken, we consider these

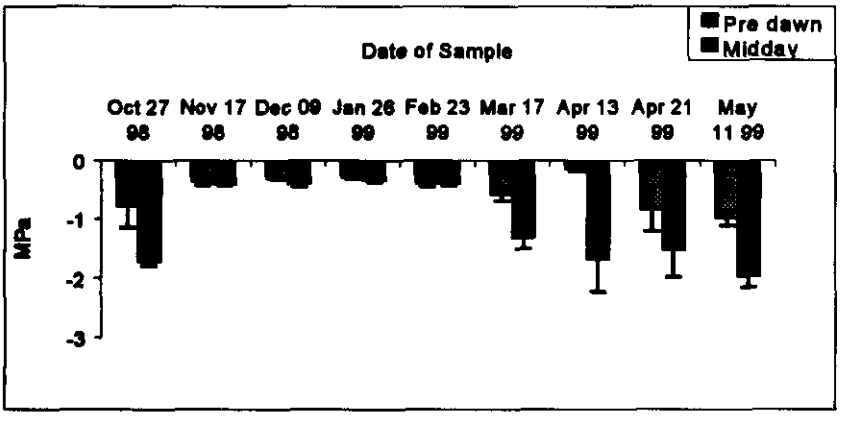


Figure F.9. Measured Leaf Water Potential for Cheatgrass at Predawn and Midday (error bars are ± one standard error)

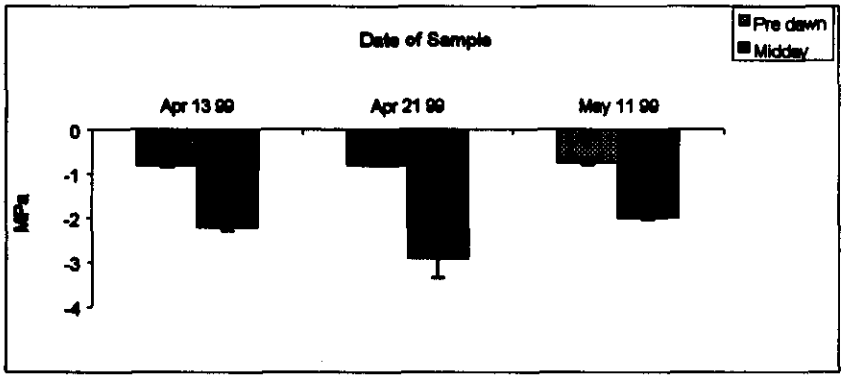


Figure F.10. Predawn and Midday Leaf Water Potentials for Sandberg's Bluegrass (error bars are ± one standard error)

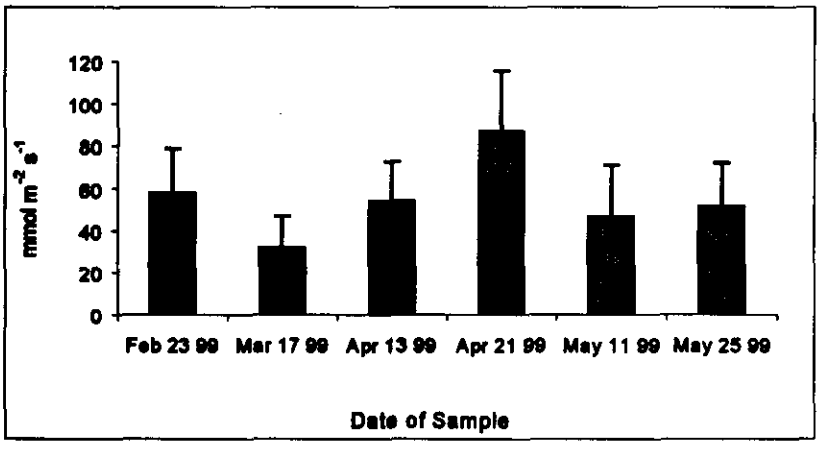


Figure F.11. Leaf-Level Conductance Data for Sagebrush (error bars are ± one standard error)

data suspect and will test the porometer system against a small-chamber gas-exchange system during the summer months. Conductance values measured for cheatgrass (Figure F.12) are also suspiciously lower than those reported previously (Link et al. 1990; Downs and Link 1993). Another possible explanation is that low conductance values could be a result of the combination of relatively low soil water availability along with cool springtime temperature.

F.3.5 Soil Water and Root Characteristics

Soil water contents of the profile measured at each measurement period (Figures 13a-e) illustrate storage of water in the soil profile throughout the winter and early spring. Initial measurements in October, November, and December show the increase in water content at depths to 20 cm. The wetting

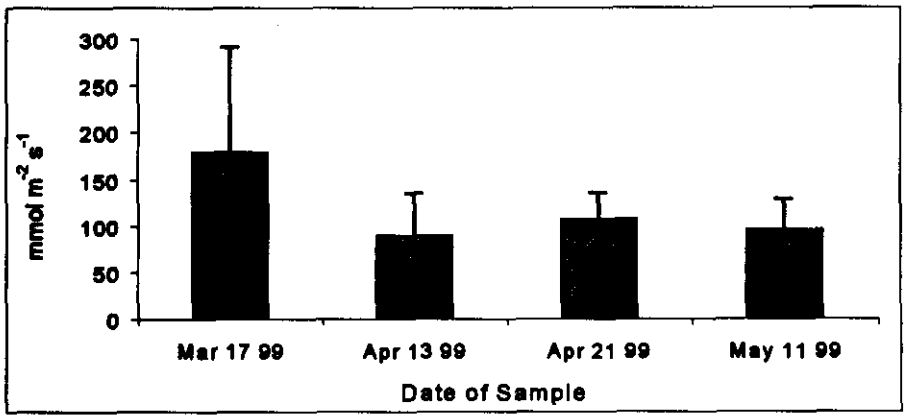


Figure F.12. Leaf-Level Conductance Data for Cheatgrass
(error bars are ± one standard error)

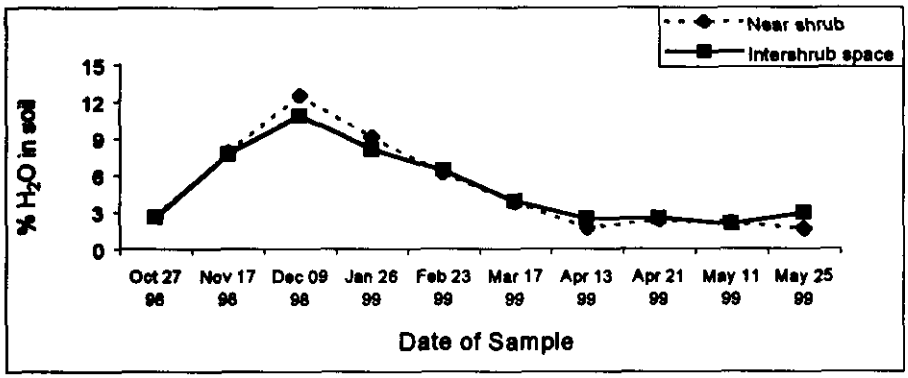


Figure F.13 (a). Soil water content (%) at 0 to10-cm depth

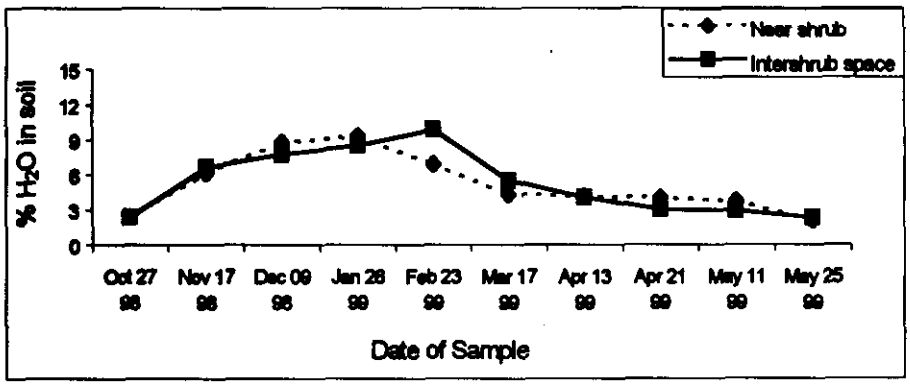


Figure F.13 (b). Soil water content (%) at 10 to 20-cm depth

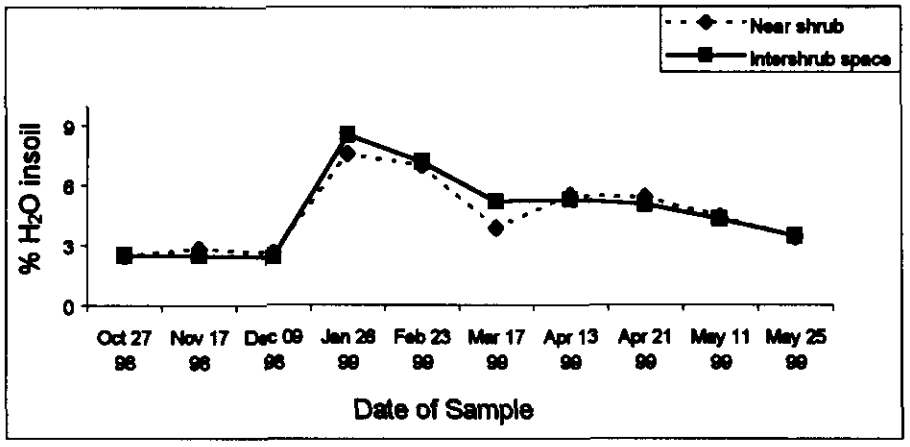


Figure F.13 (c). Soil water content (%) at 40 to 50-cm depth

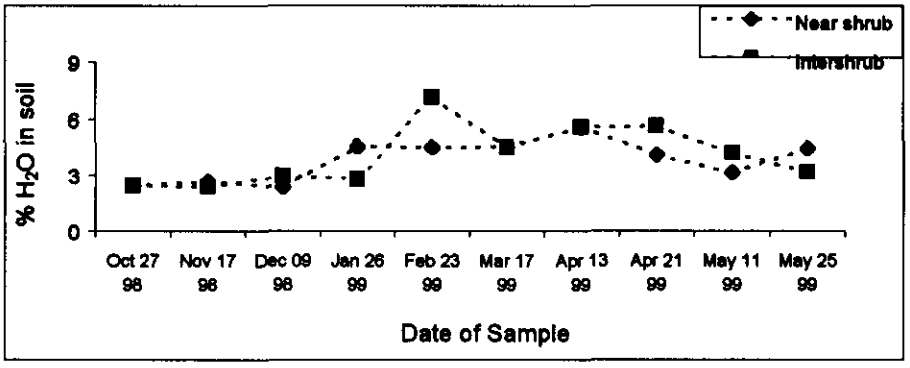


Figure F.13 (d). Soil water content (%) at 90 to 100-cm depth

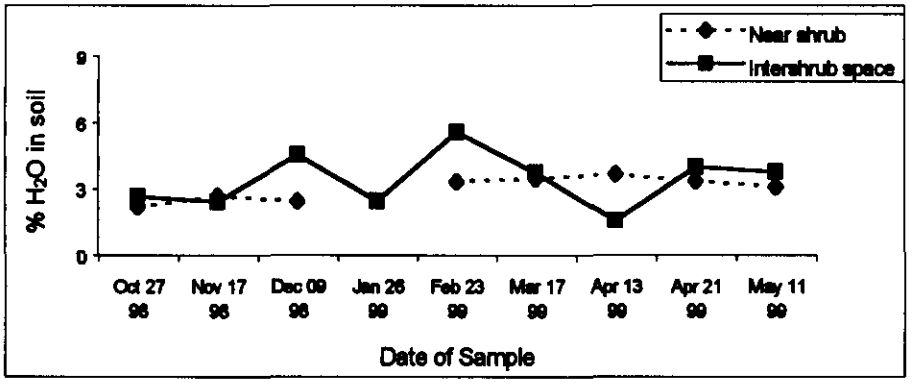


Figure F.13 (e). Soil water content (%) at 90 to 100-cm depth

front resulting from fall and winter precipitation does not reach the 50-cm and 100-cm depths until January. Soil water contents of the top 50-cm of the profile begin to decline in February with the onset of significant plant activity and growth.

Small differences in water storage may occur between areas occupied by shrubs and areas between shrubs. Soils at the 100-cm and 150-cm depths below inter-shrub spaces appear to be more variable with regard to soil water content. Although the data are based on few samples, the soil water content appears to be slightly lower at both the 100-cm and 150-cm depth near shrubs in April and May. This spatial difference in soil water content may be related to water use by the deeper-rooted shrubs. These sampling efforts were not intended to fully describe the soil water conditions on a seasonal basis, but to provide supplemental information for interpretation of plant parameters. Further investigation of soil water dynamics is needed to adequately quantify soil water availability for transpiration or drainage at the proposed site.

Data collected to describe rooting density through the top meter of the profile show considerable variability in root distribution (Figure 14). Root density (g/cm^3) is highest near the surface in the top 30-cm regardless of where the sample was collected. However, at a distance of greater than 60 cm from the main trunk of the shrub, rooting density at the surface is less than that found closer to the shrubs, and also appears to be less variable. Because we could not separate live from non-functional roots, rooting densities reported here may likely overestimate the amount of functional root system in each category. Root separation and determination of functionality is very difficult for plants growing in arid systems and little to no information is available for turnover rates of roots in shrub-steppe systems.

Figure F.14 also depicts an apparent increase in root density between 60 and 90 cm below the surface regardless of distance from shrubs. This increase may be related to a change in soil texture noted at approximately that depth. Drill logs for two of the boreholes located in the proposed ILAW site describe a change in texture between 60 cm and deeper depths.

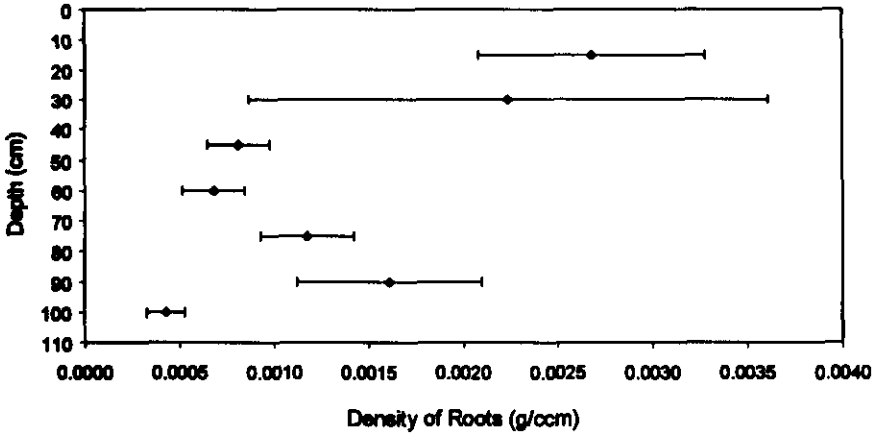


Figure F.14 (a). Plot of Mean Root Density of all Samples Within 15 cm of all Shrubs

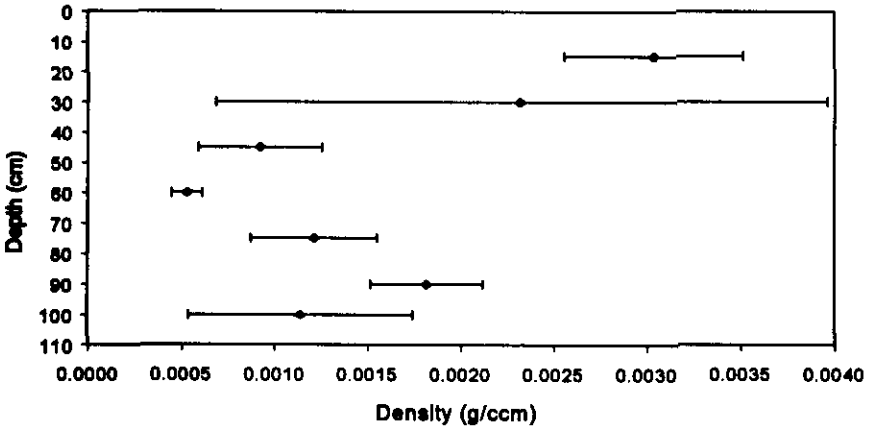


Figure F.14 (b). Plot of Mean Root Density of all Samples 15 to 30 cm from Shrubs

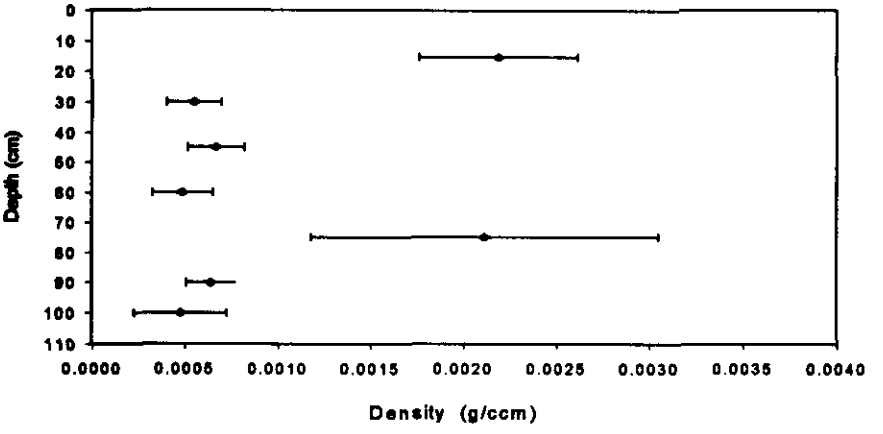


Figure F.14 (c). Plot of Mean Root Density of all Samples 30 to 45 cm from Shrubs

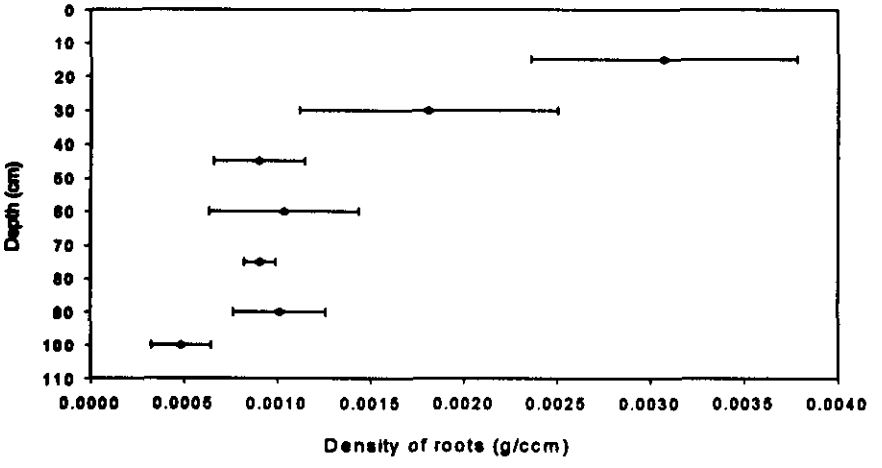


Figure F.14 (d). Plot of Mean Root Density of all Samples 45 to 60 cm from Shrubs

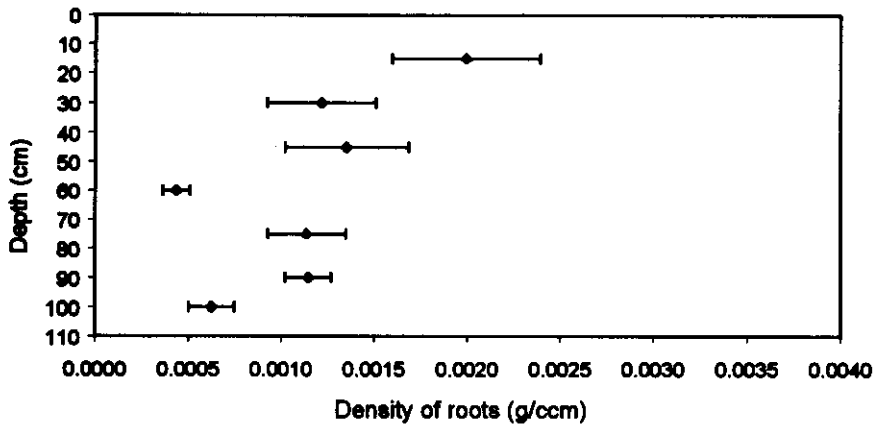


Figure F.14 (e). Plot of Mean Root Density of all Samples >60 cm from Shrubs

F.3.6 Implications for Recharge Estimation

Data collected to this point indicate that several of the assumptions generally used for plant parameters in recharge estimation may need to be revised. Current modeling simulations estimate the evapotranspiration component of recharge based only on a single species. Improvements to the model to include multiple species or multiple plant functional types (shrub, grass, and forb) would greatly improve the evapotranspiration component. The differences in timing and phenology of the multiple species likely to be present on the disposal site need to be represented in the recharge modeling efforts. Both leaf water potential and growth data indicate that all three of the dominant species, big sagebrush, cheatgrass, and Sandberg's bluegrass carry out photosynthesis and transpiration during the winter months. The current evapotranspiration component of the model also assumes that the lateral distribution of roots is uniform. Data collected under this task indicate that root distributions are highly variable, and may well be influenced by community structure.

More sophisticated modeling efforts could incorporate critical temperatures for plant growth, LAI, stomatal conductance under non-limiting soil water availability, leaf water potentials, and even values for root resistance to water uptake and transport. Determining the relationship between soil/air temperatures and plant activity and growth would allow us to better quantify seasonal evapotranspiration and provide a realistic driving force for simulations of plant water use.

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Appendix G

Quality Assurance and Safety

Appendix G

Quality Assurance and Safety

All laboratory and field experiments are conducted under PNNL quality assurance (QA) requirements as described in the guidance provided in PNNL's Standards Based Management System (SBMS) and as specified in the Project QA Plan. Significant modifications to the QA plan are made in accordance with the guidance in the SBMS.

Project staff members are qualified and receive any training needed to carry out their assigned responsibilities.

Staff use equipment of known accuracy for data collection. For measurements necessary to substantiate test results, staff ensure that standards used for calibration are traceable to nationally recognized standards. Measuring and Test Equipment (M&TE) lists are generated by each task and maintained in the project files applicable to the specific task. M&TE used is identified in the laboratory record books or other data recording location to provide traceability to instrument calibrations.

Test procedures and methods are documented and deviations noted. New methods developed during the course of this work are documented and reviewed. All test procedures, data processing software, and supporting documentation undergo independent technical review by qualified PNNL staff.

Staff maintain records necessary to substantiate results and processes of research activities. After activities are completed, records are filed and maintained per the project Records Inventory and Disposition Schedule (RIDS).

All precautionary measures are taken in accordance with standard PNNL safety procedures to ensure that field work is conducted in a safe manner. No hazardous wastes have been generated during the conduct of work described in this report.

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Section 4 of 5

Document Information			
Document #	**HNF-5636**	**Revision**	**0**
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Projects			
Other Information			

APPENDIX K

Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment

B. P. McGrail
J. P. Icenhower
D. H. Bacon
J. D. Vienna
A. Jiricka
W. L. Ebert[†]
P. F. Martin
H. T. Schaef
M. J. O'Hara
E. A. Rodriguez

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Pacific Northwest National Laboratory
Richland, Washington 99352

[†]Argonne National Laboratory
Argonne, Illinois 60439

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SUMMARY

This data package functions to document the input data that will be used for simulations of the immobilized low-activity waste disposal system with the Subsurface Transport Over Reactive Multiphases (STORM) code. The STORM code will be used to provide the near-field radionuclide release source term for a performance assessment to be issued in March of 2001 and to provide the Department of Energy with an earlier (August 2000) assessment of confidence in meeting performance objectives for the ILAW disposal system. The STORM code requires input of two main general classifications of data: 1) multiphase flow, and 2) reactive transport. Multiphase flow input will principally be defined in the near-field hydraulic properties data package or the far-field hydraulic properties data package. All input related to conducting reactive transport calculations used to compute contaminant release rates will be defined within this data package. This includes a complete set of chemical reactions and supporting thermodynamic data that will make up the reaction network in the simulations. The majority of these data were extracted from the thermodynamic database package shipped with the geochemical code EQ3/6. However, several secondary reaction products identified from laboratory tests with prototypical BNFL, Inc. glasses were not included in this database, nor are the thermodynamic data available in the open literature. One of these phases, herschelite, was determined to have a potentially significant impact on the release calculations and so a solubility product was estimated for this phase.

Because of the continuing rapid evolution in glass development underway by BNFL, Inc., this data package is still in a very preliminary stage and must be viewed as a work in progress. The available laboratory testing data for several prototypic BNFL, Inc. waste glasses covering a wide range of potential glass formulations are discussed. However, base case calculations for the 2001 ILAW PA will focus on one prototypic ILAW glass, LAWABP1. Consequently, more extensive testing and analysis regarding this glass formulation are provided in this data package. Frequent updates to this data package are to be expected as new data are developed.

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ACRONYMS

ANL	Argonne National Laboratory
ASTM	American Society for Testing and Materials
BET	Brunauer, Emmett, and Teller surface area measurement
BNFL	British Nuclear Fuels Limited
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EDS	energy dispersive spectroscopy
HLW	high-level waste
ICP-AES	inductively coupled plasma atomic energy spectrometry
ICP-MS	inductively coupled plasma mass spectrometry
ILAW	immobilized low activity waste
JCPDF	powder diffraction file
MCC	Materials Characterization Center
M&TE	materials and test equipment
ORP	Office of River Protection
PA	performance assessment
PCT	product consistency test
PNNL	Pacific Northwest National Laboratory
PUF	pressurized unsaturated flow
QA	quality assurance
QAPD	quality assurance program documents
RH	relative humidity
SAED	selected area electron diffraction
SEM	scanning electron microscope
SPFT	single-pass flow through (glass test)
SS	stainless steel
STORM	Subsurface Transport Over Reactive Multiphases (computer code)
S/V	surface area-to-solution volume ratio
TEM	transmission electron microscope
THAM	tris hydroxymethyl aminomethane
VHT	vapor hydration test (glass test)
WVDP	West Valley Demonstration Project
XRD	X-ray diffraction

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1.0 INTRODUCTION

The Hanford Low-Activity Tank Waste Disposal Program is planning to issue a performance assessment (PA) in March of 2001. The major goals of the performance assessment activity are to:

- support the design of disposal facilities
- provide the technical basis for the Department of Energy (DOE) to authorize construction of disposal facilities
- obtain approval to dispose of immobilized low-activity Hanford tank waste in those facilities
- provide a technical basis for final closure of the disposal facilities.

However, another critical near-term goal is to provide an early assessment of confidence in meeting performance objectives for the ILAW disposal system. This assessment has been requested by management at DOE-ORP to help support a decision in August of 2000 to award a contract to BNFL, Inc. for construction of a vitrification plant for low-activity waste.

A critical component of the PA will be to provide quantitative estimates of radionuclide release rates from the engineered portion of the disposal facilities (source term). Computer models are essential for this purpose because impacts on groundwater resources must be projected out to time periods of 10,000 y and longer. Details on the recommended technical strategy for developing this source term have been published [1] and have undergone review by an international panel of experts. The computer model selected for modeling the radionuclide source-term is the Subsurface Transport Over Reactive Multiphases (STORM) code [2]. The required inputs to this code will be derived from literature sources and from laboratory experiments with ILAW glasses. This report, therefore, functions to document the input data that will be used for STORM simulations. The STORM code requires input of two main general classifications of data: 1) multiphase flow, and 2) reactive transport. Multiphase flow input will principally be defined in the near-field hydraulic properties data package or the far-field hydraulic properties data package [3]. However, we will list the constants needed for STORM simulations. All input related to conducting reactive transport calculations will be defined within this data package.

For those data supplied by this activity, the values and supporting justification are described. Values are needed for (at a minimum) the best estimate case, an uncertainty case, and a reasonable bounding case. However, it must be recognized that because of the continuing rapid evolu-

tion in glass development underway by BNFL, Inc., this data package must be viewed as a work in progress. Frequent updates to this data package are to be expected as new data are developed. However, at the outset, we will attempt to bound the glass composition region currently anticipated by BNFL Inc. with the intent to reasonably bound the expected performance of their product.

Laboratory testing provides the majority of the key input data required to assess the long-term performance of ILAW glasses with the STORM code. Test data from four principal test methods, called out by McGrail et al [1], are discussed in this data package including the single-pass flow-through test (SPFT), pressurized unsaturated flow (PUF) test, product consistency test (PCT), and vapor hydration test (VHT). Test results using each of these techniques are provided in Chapter 2.0, Laboratory Testing. The different test methods focus on different aspects of the glass corrosion process. Linkages between the test methods, their principal function, and the data they provide for modeling are provided in Table 1. The interested reader is encouraged to consult reference [1] for additional details regarding these test methods and their use in evaluating long-term glass performance.

Table 1. Overview of Test Methods Discussed in this Data Package

Test Method	Temperature Range	Duration	Data Provided	Purpose
SPFT	25-90°C	14-28 d	Dissolution rate as a function of temperature, pH, and solution composition	Parameterization of kinetic rate law for glass dissolution
PUF	40-100°C	Months to years	Effluent chemical composition and dissolution rate as a function of temperature and flow rate, secondary phases, hydraulic property changes.	Highly accelerated test for glass screening, secondary phases for STORM reaction network, validation of STORM code.
PCT	20-100°C	Weeks to years	Solution composition and dissolution rate as a function of S/V ratio and temperature, secondary phases.	Glass screening, secondary phases for STORM reaction network, calibration of reaction network with EQ3/6 code.
VHT	70-300°C	Days to years	Rough estimate of dissolution rate as a function of temperature, secondary phases	Highly accelerated test for glass screening, secondary phases for STORM reaction network. Cannot be used for evaluating glass corrosion models.

2.0 LABORATORY TESTING

The results from laboratory testing of a large number of prototypic ILAW glasses are discussed in this chapter. It is organized in accordance with the four principal test methods, 1) Single-Pass Flow-Through (SPFT), 2) Product Consistency Test (PCT), 3) Vapor Hydration Test (VHT), and Pressurized Unsaturated Flow (PUF), specified in the strategic plan [1] for assessing the long-term performance of ILAW glasses.

2.1 PRELIMINARIES

The interested reader should consult McGrail et al. [1] for a thorough discussion of how each of the tests described in this Chapter fit into an overall strategy to evaluate the long-term performance of ILAW glasses. All testing work reported in this data package was conducted in accordance with PNNL's Quality Management System Description and associated Quality Assurance Program Documents (QAPD), which are maintained electronically as part of the Standards Based Management System or under an equivalent QA Program at Argonne National Laboratory (ANL). All instrument calibrations and materials are traceable, test procedures and associated training activities are documented in detail, and test methods comply with established plans and procedures. Computer Software and Database Control procedures are being followed for data analysis software being used to store, sort, and reduce data.

All staff members contributing to the work specified in this Test Plan received proper technical and quality assurance training in accordance with QAPD Training and Qualification for Staff. Equipment is either calibrated periodically or at the time of use and the calibration status of each piece of equipment is documented through a Material and Test Equipment sheet (M&TE), which is maintained as a part of the QA file. The M&TE sheets specify the required calibration methods, usually include a calibration procedure, and document the status of the equipment. All equipment requiring calibration prior to its use will be so labeled.

Documented procedures were used for sample preparation, test performance, and sample analysis. Operations not specifically covered in a documented procedure were documented in a Scientific Notebook. Comments regarding the test performance and test activities are contained in a Scientific Notebook associated with each test.

2.2 GLASS FORMULATIONS

The test results presented in the following sections will reference seven different ILAW glass compositions. These are provided in Table 2 for reference. It should be noted that LD6-5412 glass is a "high-temperature" glass formulation and has been included here because of the long history of studies with this glass. LRM-1 is an analytical reference standard glass developed at ANL [4]. LAWA23, LAWA33, and LAWABP1 are prototypic of ILAW glasses under development by BNFL, Inc.

Table 2. Composition (Mass%) of Selected ILAW Glasses

Oxide	LD6-5412	LRM-1	LAWA23	LAWA33	LAWABP1	HLP-10	HLP-31
Al_2O_3	12.000	10.000	9.700	11.970	10.000	7.150	4.000
B_2O_3	5.000	8.000	4.320	8.850	9.250	8.000	12.000
CaO	4.000	0.500	4.460			0.010	0.010
CdO		0.200					
Cl	0.350	0.800	0.360	0.580	0.580	0.28	0.320
Cr_2O_3	0.040	0.200	0.010	0.020	0.020	0.080	0.090
Cs_2O	0.150						
F	0.290	1.000	0.040	0.040	0.040	0.010	0.010
Fe_2O_3	0.003	1.000	7.430	5.770	2.500	5.63	3.360
I	0.130	0.002	0.057				
K_2O	1.460	1.500	2.310	3.100	2.200	0.420	0.470
La_2O_3		0.009			2.000		
Li_2O		0.100	2.080				
MgO	0.003	0.100	2.080	1.990	1.000	1.530	0.920
MnO	0.002	0.100					
MoO_3	0.150	0.100					
Na_2O	20.000	20.000	20.000	20.000	20.000	20.450	23.00
NiO		0.100					
P_2O_5	0.190	0.500	0.050	0.080	0.080	0.060	0.060
PbO_2		0.100					
ReO_2			0.098			0.010	0.010
SO_3	0.210	0.200	0.040	0.100	0.100	0.070	0.080
SeO_2			0.050				
SiO_2	55.912	54.370	40.520	38.250	41.890	50.160	52.000
SrO	0.110						

Table 2. Composition (Mass%) of Selected ILAW Glasses

Oxide	LD6-5412	LRM-1	LAWA23	LAWA33	LAWABP1	HLP-10	HLP-31
TiO_2		0.100		2.490	2.490	3.060	1.830
ZnO			3.340	4.270	2.600	1.530	0.920
ZrO_2		1.000	3.050	2.490	5.250	1.530	0.920

2.3 SINGLE-PASS FLOW-THROUGH TEST RESULTS

The SPFT test is an open system test where a solution at a known flow rate and constant temperature flows through a reaction cell that contains the sample. The configuration precludes recirculation of a portion of the effluent and so makes a "single-pass" through the reaction cell. Many different SPFT apparatuses have been developed, but these can all be classified as three basic types: 1) well-mixed batch, 2) packed bed, and 3) fluidized bed. The well-mixed batch type of apparatus was used for all test data reported here.

We have quantified the dissolution kinetics of LAWA33 and LAWABP1 glass compositions through the use of single-pass flow-through (SPFT). Because vitreous materials are metastable substances, and since dissolution reaction rates are slow, the glass-aqueous solution system cannot reach chemical equilibrium with the environment. Therefore, to understand the reactivity of potential waste glass candidates in subsurface environments, a complete knowledge of the dissolution kinetics of these vitreous materials is necessary. Although static (such as the PCT and MCC) tests are widely used to determine the behavior of glass-aqueous solution systems under repository conditions, SPFT experiments are ideal for elucidating the kinetic rate law parameters that will be used to model release rates into the geosphere. The usefulness of SPFT experiments stems from the system reaching a steady-state condition between the glass and the aqueous solution. Steady-state conditions ensure that the system is maintained at constant chemical affinity and the effluent is at a constant value of pH.

Over the last few decades, a general rate equation has been fashioned to described the dissolution of glass (and more ordered materials) into aqueous solution:

$$k_i = \overset{\mathrm{v}}{k} \nu_i a_{\mathrm{H}^+}^{-\eta} e^{\frac{-E_a}{\mathrm{RT}}} \left[1 - \left(\frac{Q}{K} \right)^{\sigma} \right] \prod_j a_j \qquad (1)$$

where: k_i = dissolution rate, g/m²/d
$\overset{v}{k}$ = intrinsic rate constant, g/m²/d
v_i = the stoichiometric coefficient of element i in the glass (dimensionless)
a_{H^+} = hydrogen ion activity
a_j = activity of the jth aqueous species that acts as an inhibitor or as a catalyst of dissolution
E_a = activation energy, kJ/mol
R = gas constant, kJ/mol·K
T = temperature, K
Q = ion activity product
K = pseudoequilibrium constant
η = pH power law coefficient
σ = Temkin coefficient.

Although this equation is useful, there is still considerable debate in the scientific community regarding the identity and values of the above parameters. For example, it is well established that dissolution rates increase with an increase in the activity of the hydroxyl ion (i.e., pH), but it is not clear if other aqueous species inhibit or catalyze reaction rates. It is generally recognized, for example, that aluminum in solution causes a decrease in reaction rates of aluminosilicate materials [5], yet there is disagreement over how this effect should be taken into account in Equation (1). For example, some investigators advocate that the activity of aluminate and even silicic acid should be represented as an inhibitor term [6] like the hydrogen ion activity. Other investigators have proposed that the aluminate activity should be part of the pseudoequilibrium constant, along with the activity of silicic acid [7]. An additional uncertainty rests with the nature and value of the Temkin coefficient, σ, which represents the net reaction order of the dissolution rate. Investigators have reported values of σ ranging between 0.4 and 1 whereas others have recommended that σ should be ignored in the above equation.

Findings of our SPFT experiments to date will be presented with the data can be grouped into three separate sections: First, we discuss the effects of varying the ratio *q/s* (the flow-through rate divided by the surface area of the sample) on dissolution rates. Second, we elucidate the effects of adding Si and Al into the input solution. Third, we quantify the dependence of the dissolution rate on the pH of the solution. From these data, we are able to determine the values of the pseudoequilibrium constant for a glass, K_g, the intrinsic rate constant, $\overset{v}{k}$, the power law coefficient for solution pH, η. Values of other parameters, such as the activation energy, E_a, and the Tem-

kin coefficient, σ, can be reasonably estimated, as discussed below. Finally, we illustrate how SPFT data can be used to extract Na ion-exchange rates.

2.3.1 Description of the Experiments

SPFT experiments utilize Teflon reactor vessels that are connected to lines that transport aqueous solutions from the input reservoir and lines that carry solution to the collection vials, as illustrated in Figure 1. Computerized syringe or infusion pumps precisely control flow of aqueous solutions into the reactors. Reactors are housed in constant temperature ovens and powdered samples (typically the 75 to 150 μm size fraction) react with the volume of solution within the vessel. Effluent samples are collected continuously and aliquots are periodically retained for analysis. Concentrations of the elements are determined by precision ICP-AES and ICP-MS methods. Input solutions are made by combining deionized water, THAM (tris hydroxymethyl aminomethane), and nitric acid in variable amounts to yield solutions buffered at pH values of 2 to 10. Variable amounts of LiOH, stabilized by LiCl, make up solutions with pH values to 11. Currently, experimental data with variable pH conditions are limited to LAWA33 glass at 40°C; experiments utilizing LAWABP1 glass are so far restricted to pH=9. The effect of variable silicon (up to saturation with respect to amorphous silica) and aluminum (up to 500 ppb Al) were used to explore the effects of solution composition on reaction rates of both LAWABP1 and LAWA33 glasses. All input solutions are continuously sparged by nitrogen gas to prevent deviations from the initial pH values.

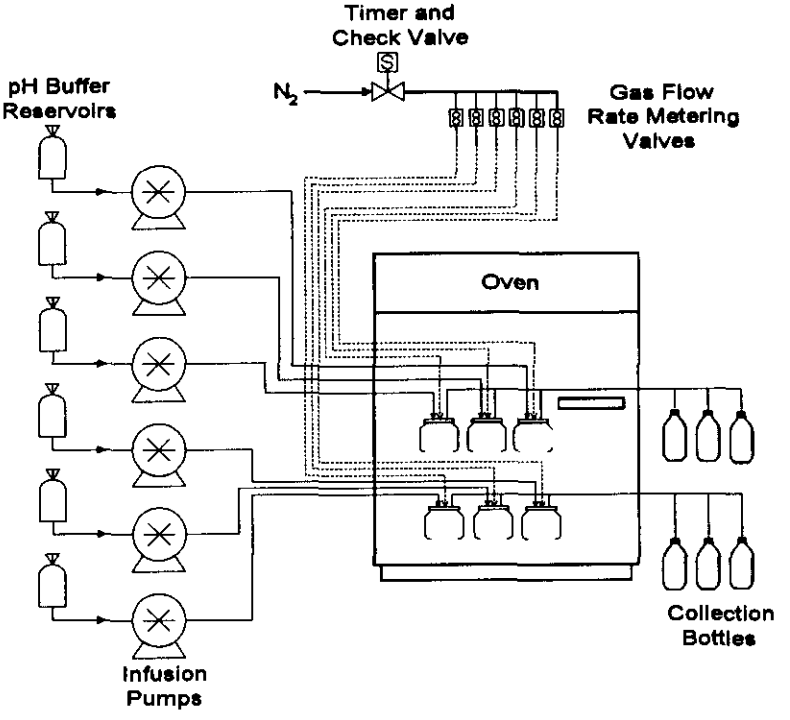


Figure 1. Schematic of Batch Flow-Through Reactor

Apparent dissolution rates are calculated from the expression:

$$rate_i = \frac{(C_i^{out} - C_i^{in})q}{f_i S} \quad (2)$$

where

$rate_i$ = the apparent dissolution rate of the glass sample as indexed by element i (g m^{-2} d^{-1})
C_i^{out} = concentration of the element of interest in the effluent (μg/L)
C_i^{in} = concentration of the element of interest in the feed solution (μg/L)
q = solution flow-through rate (L/d)
f_i = mass fraction of the element in the glass (dimensionless).
S = surface area of the material (m^2).

Blanks (effluent samples run through the system without glass powders) establish concentrations of elements of interest in the input solution. Apparent dissolution rates are calculated from steady-state concentrations of the elements of interest. 'Steady-state concentrations' refer to concentrations of the element of interest that are invariant with respect to time.

2.3.2 Results

The steady-state concentrations of elements in SPFT experiments are internally consistent, as evident by the figures discussed below. In brief, concentrations of elements of interest, especially B, Na, Al, and Si, when converted into dissolution rates by Equation (2), indicate only a small experimental uncertainty. Typically, dissolution rates based on multiple elements exhibit small differences, typically ≤0.2 log units (or ~1.6X). In some cases, particularly when low flow-through rates are used, the apparent dissolution rates between sodium and boron, for example, may be large. The reasons for this dispersion of data are rather easily rationalized, as discussed in the upcoming section. In a similar vein, duplicate experiments yield virtually no difference between the calculated dissolution rates. Typically, replicated experiments agree within 0.1 log units (or ~1.3X). There are, however, some notable exceptions to this generalization, as we discuss below. In summary, the experiments behave according to expectations and we have amassed a large amount of dissolution data that are discussed in the next several sections.

2.3.2.1 Effects of Variable q/s

Apparent dissolution rates increase with increasing ratio of *q/s* as illustrated in Figure 2. On this figure, $\log_{10}$ apparent dissolution rate is plotted against $\log_{10}$ *q/s* (m s^{-1}), where *q* is the flow-through rate (m^3 s^{-1}) and *s* is the surface area of the solid material (m^2). Thus, as the ratio of *q/s* increases (from left to right on the diagram), the apparent dissolution rates, based on concentrations of Si, Al, B, Mg, Na, and K, increase. At small values of *q/s* (left-hand side of the diagram), note that the apparent dissolution rates display a relatively wide range of values. For example, dissolution rates based on Al are systematically slower than rates calculated from boron concentrations. On the other hand, apparent rates based on sodium are faster compared to boron. As *q/s* increases, the apparent dissolution rates for the various elements converge toward a single value, so that for values of *q/s* $\geq 10^{-8}$ (m s^{-1}) rates based on Si, Al, B, Na, and K are indistinguishable. The systematics discussed above can be rationalized in the following way. For experimental conditions in which flow-through rates are low, concentrations of elements increase to the point where the system becomes saturated with respect to crystalline or amorphous phases. Aluminum is likely to reside in such phases, which keeps its concentration in the solution low and consequently artificially suppresses the apparent dissolution rate. On the other hand, sodium is released into solution by both matrix dissolution and ion exchange with hydrogen species in solution. Under conditions where glass matrix dissolution is slow due to high solute loading at low flow-through rates, the ion exchange mechanism dominates. Therefore, sodium release into solution is high and the apparent dissolution rates will have artificially high values. Boron is neither harbored in secondary phases nor is it leached to the extent that alkalis are. Accordingly, dissolution rates based on boron concentrations lie between the extremes manifested by Al and Na. With higher values of *q/s*, the convergence of dissolution rates towards a single value represents conditions in which the glass dis-

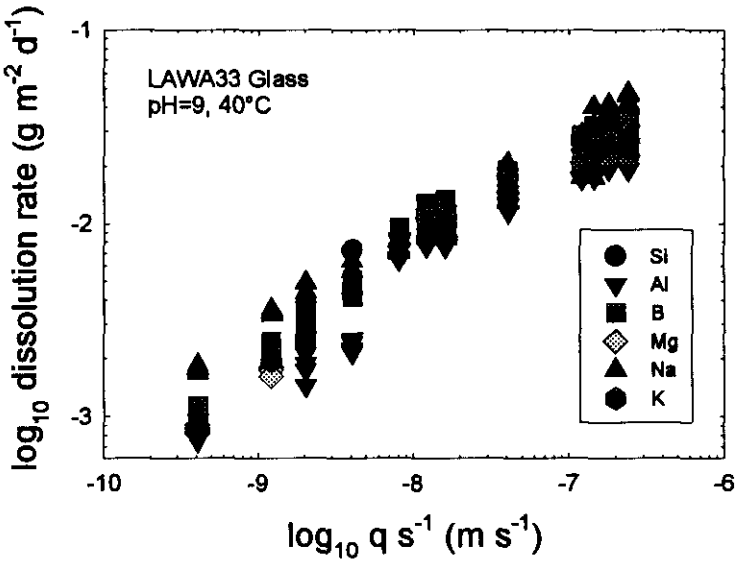


Figure 2. Plot of $\log_{10}$ q/s (Flow-through Rate/Surface Area) versus $\log_{10}$ Dissolution Rate of LAWA33 Glass, pH(25°C) = 9, T = 40°C

solves more congruently. Note also on this diagram that at the higher values of *q/s* ($\geq 10^{-7}$ m s^{-1}) that dissolution rates appear to become independent of *q/s*, although more experiments are needed to confirm this with certainty.

For the LAWABP1 glass, varying *q/s* values at 90°C yields results similar to those for LAWA33 glass at 40°C. Figure 3 illustrates that the dissolution rate (based on boron) becomes independent of flow-through rate above log *q/s* values of 6×10^{-8} (m s^{-1}). Therefore, the maximum dissolution rate under these experimental conditions (90°C, pH(25°C)=9) is ~0.14 g m^{-2} d^{-1}. Note that the relationships between rates based on Al, B, and Na displayed in Figure 3 are similar to those discussed above: at low values of *q/s*, the apparent rates based on Na are faster than those for the other elements. At higher values of *q/s*, the rates for all elements converge, indicating congruent dissolution.

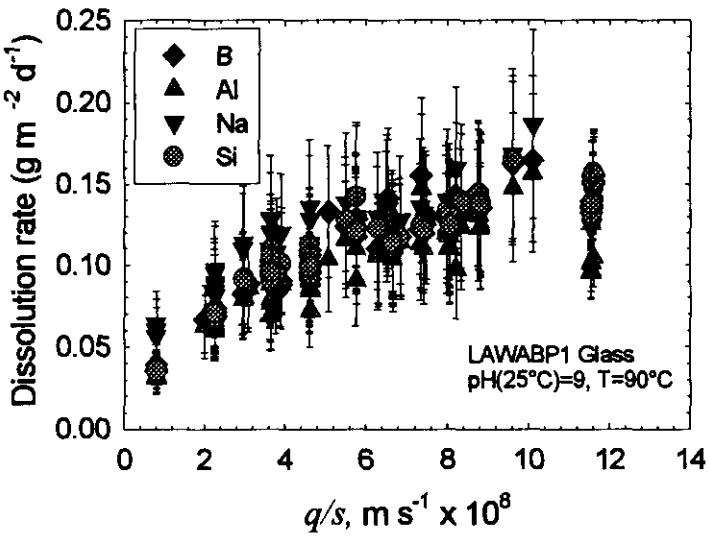


Figure 3. Plot of $\log_{10}$ q/s (Flow-through Rate/Surface area) Versus $\log_{10}$ Dissolution Rate of LAWABP1 Glass, pH(25°C)=9, T=90°C

The formal means of discussing the dependence of dissolution rate on flow-through rate is by the chemical affinity term. Succinctly, chemical affinity is a measure of a system's displacement from equilibrium; it is equivalent to the free energy of reaction as a function of reaction progress. Therefore, a small value of chemical affinity is equivalent to a small free energy value; i.e., the system is close to equilibrium with respect to a solubility-limiting phase. Conversely, a large value of chemical affinity is equivalent to a large free energy difference and the system is far from equilibrium. Accordingly, small values of log q/s (on the left-hand side of Figure 2 and Figure 3) are characterized by small chemical affinities and are closer to equilibrium. Larger values of $\log_{10}$ *q/s* (on the right-hand side of the above diagrams) are characterized by larger values of chemical affinity (dilute solutions) and the dissolution rates are predicted (and do) become independent of flow-through rates. The concept of chemical affinity is important in that it is tied to Equation (1) by the term: $1-Q/K$. As we discuss more fully below, the nature of the value of K, whether it is solely a

function of silicon activity or not, is an important concern for predicting the corrosion resistance of waste glass.

2.3.2.2 Effects of Variable Solution Composition

In Equation (1), the dissolution rate of a glass is inversely proportional to the ratio of the activity product, Q, divided by the psuedoequilibrium constant, K_g, assumed to be related to a solubility limiting phase that controls the glass dissolution kinetics. As the value of the activity product approaches that of K_g, the value of the term $1\text{-}Q/K_g$ approaches zero, suggesting that the dissolution rate should also go to zero. This is not strictly true since glass is a metastable substance and therefore cannot come to equilibrium with solution. Nevertheless, Equation (1) predicts that the dissolution will decrease as Q/K_g approaches unity.

As a starting point, K_g is represented by the equilibrium constant of amorphous silica, whose value is well understood in terms of temperature [8]. Below we address the question of whether the amorphous silica equilibrium constant is appropriate for vitreous materials other than SiO_2. To determine the relationship between silicon concentration of the solution and dissolution rate, we performed a series of experiments in which the concentration of silicic acid was varied from zero to near saturation with respect to amorphous silica. Figure 4 is a plot of dissolution rate (boron) for LAWA33 glass versus silicon concentrations in the effluent. Clearly, the dissolution rate decreases with the addition of silicon in the feed solution. It is also evident that the decrease in dissolution rate is linear over the solution compositions studied. Note also that these data can be used to compute values of k_o, K_g, and the concentration of silicon at saturation (C_{sat}); we will forgo further discussion of these parameters until a later section.

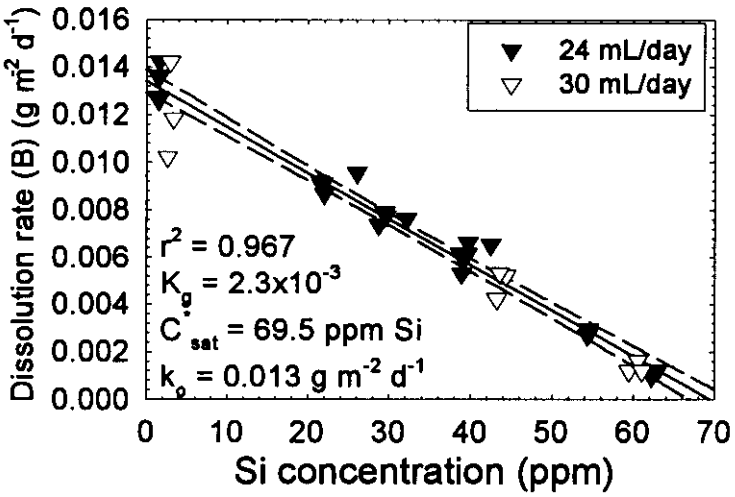


Figure 4. Plot of Dissolution Rate Versus Si Concentration of Effluent Solution, LAWA33 glass, pH=9, T=40°C. Solid line is the best fit and the dashed line is the 95% confidence interval.

The linear decrease in rate with Si concentration is interesting because it appears to validate the hypothesis of Grambow [9], which states that the dissolution of glass is rate-limited by the rupture of the Si—O bond, and so glass dissolution rate should vary linearly with the activity of silicic acid. If this relationship holds true for all glass compositions, then the task of predicting the dissolution rate with solution composition would be relatively simple.

Dissolution rate values based on elements other than boron also follow a similar linear trend as silicon is added to solution. For example, rates based on Al and Na concentrations are compared with the rates obtained for boron concentrations as a function of flow-through rate (Figure 5). In experiments with flow-through rates of 24 mL d^{-1}, apparent rates are fastest for sodium and slowest for aluminum with boron in between. These apparent discrepancies are due to the following. In the case of sodium, the rates are faster compared with boron, especially with greater silicon content of the solution. The release of sodium into solution is due to two distinct phenomena: Matrix dissolution and exchange of Na in glass for hydrogen species in solution. In the situation in which Si concentrations approach saturation with respect to amorphous silica, ion exchange is the dominant mechanism for the release of sodium into solution [10]. Accordingly, apparent sodium rates will appear to be faster compared to boron rates. In the case of Al, the rates are relatively slower with respect to boron. As previously discussed, this is due to retention of aluminum in solid phases when the solution approaches saturation. It is therefore evident that LAWA33 glass dissolves incongruently at 24 mL d^{-1}.

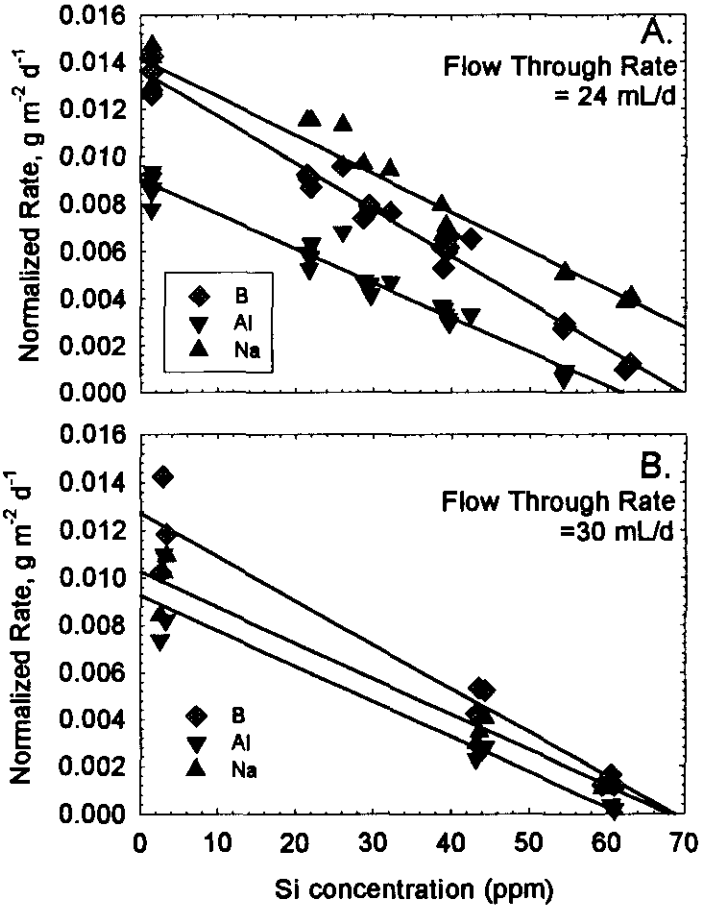


Figure 5. Plot of dissolution rate versus silicon concentration for LAWA33 Glass at 40°C and pH = 9.

In contrast, the results for experiments with flow-through rates at 30 mL/d are more consistent with congruent dissolution. Apparent rates for Na, Al, and Si

are approximately the same, within experimental error. These results again attest to the importance of the control of chemical affinity on the dissolution rate.

If dissolution of glass followed the rate law proposed by Grambow [9], it would be easy to predict the corrosion resistance of any vitreous waste products once knowledge of the chemistry of contacting solution is calculated (see Section 3.0). However, the rate law proposed by Grambow appears to fail under a potentially important set of circumstances, as described below. In addition, a number of investigators showed that dissolution rates are not linearly dependent on Si concentrations. These investigators proposed that glass dissolution is governed by the activities of aluminum and silicon in solution [7,11,12]. Gin [7] advocates a mixed Al-Si activity product formulation for the affinity term:

$$K_g = a[\mathrm{Al(OH)_4^-}]^{\nu_{Al}} a[\mathrm{SiO_2(aq)}]^{\nu_{Si}} \qquad (3)$$

where a denotes the activities of the species {$Al(OH)_4^-$ and $SiO_2(aq)$ are the dominant species in the pH-range investigated}, and ν_{Al} and ν_{Si} represent the mole fraction of aluminum and silicon in the glass, respectively. However, as pointed out by McGrail et al. [13], this assignment is strictly arbitrary and may not be consistent with the fundamental mechanisms controlling glass dissolution. The following discussion is an attempt to determine which of these formulations is appropriate for the glass compositions that we studied.

Figure 6 illustrates the relationship between dissolution rate and the concentration of Si in solution in experiments with LAWABP1 glass. This figure clearly indicates the non-linearity of the data. Therefore, the rate law proposed by Grambow [9] appears to be inappropriate for this glass composition.

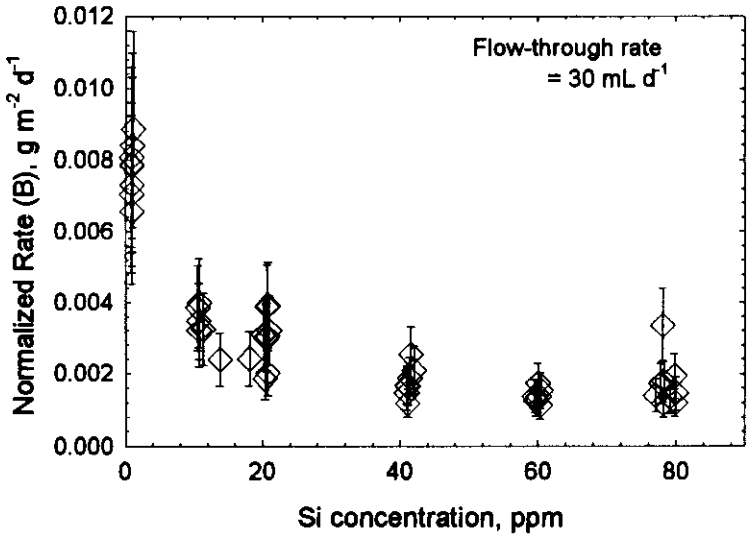


Figure 6. Plot of Dissolution Rate (Boron) Versus Silicon Concentration for LAWABP1 Glass at 40°C and pH(25°C)=9.

One possible explanation for the failure of Grambow's model is that aluminum is not accounted for in the affinity term. Accordingly, we plot in Figure 7 the dissolution rate of LAWA33 and LAWABP1 glass versus the mixed activity product term discussed above [Equation (3)]. The data for LAWA33 glass show a somewhat nonlinear relationship with the mixed Al-Si activity term. The Si sweep data in Figure 7b for LAWABP1 glass show a good linear trend but for experiments where we added Al to the input solution (labelled "Al sweep" on the diagrams), the trend of the data are in the direction opposite to that required by Equation (3).

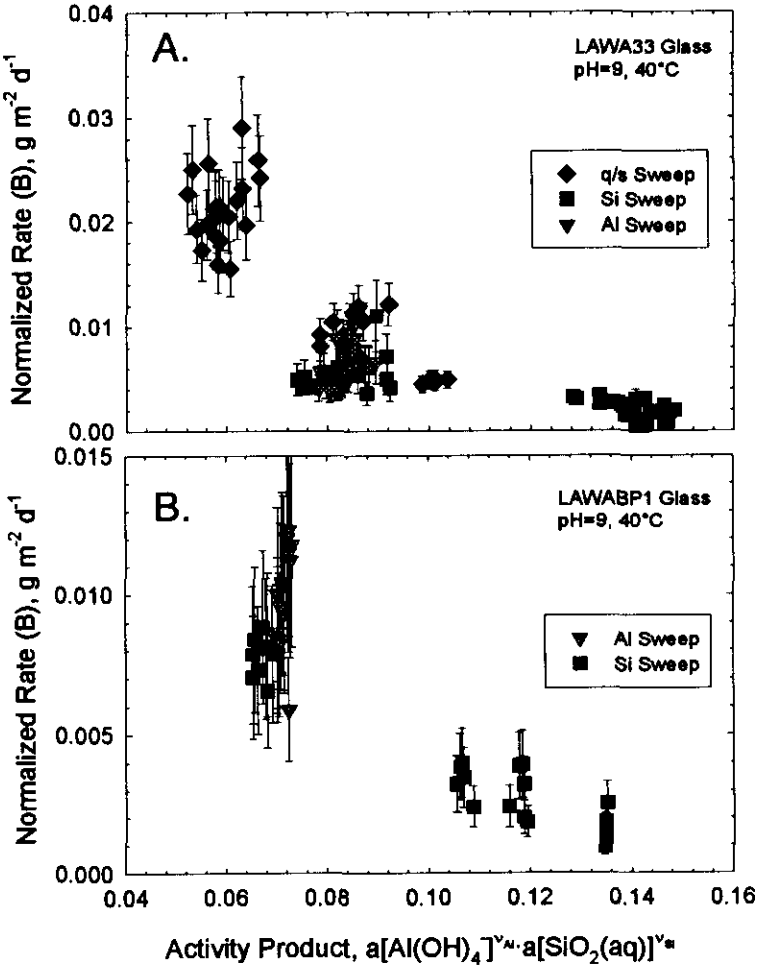


Figure 7. Plot of dissolution rate (boron) versus the mixed Al-Si activity product for (A) LAWA33 and (B) LAWABP1 glass, pH=9, T=40°C. Activities of Al and Si are raised to mole fraction of the element in glass (see text).

One potential flaw of the rate model proposed by Gin [7] is that there is no fundamental reason to raise the activities of the Al and Si species to the mole fraction of the element in glass. If the amorphous layer that develops on the surface of glass during reaction controls the chemical affinity term, there is no reason to use mole fractions of elements in glass. This is because the chemical compositions of the glass and the amorphous layer are distinctly different. In Figure 8, we plot the dissolution rate of LAWABP1 glass at 90 and 40°C as a function of the activity product K_g = $a[Al(OH)_4^-]\cdot a[SiO_2(aq)]$. Expressing the affinity term this way enhances the effect of the aluminate ion on the dissolution rate as compared with Equation (3). Although the correlation is not ideal, the overall fit to the data is much better. Consequently, we conclude that a simple activity product term best explains the entire set of data for LAWABP1 glass, although future mixed activity formulations

may prove to be better. From the x- and y-intercepts of a linear regression to the data, the forward rate constant (k_o) and K_g are obtained, as shown in Figure 8.

2.3.2.3 Effects of pH on Dissolution Rates.

Dissolution rates increase on both ends of the pH scale relative to near-neutral solutions. This is due to hydronium (H_3O^+) and OH- ions that increase reaction rates on the low and high ends of the pH scale, respectively. In basic solutions, the OH^- anion participates in a nucleophilic attack on the Si–O–Si framework bonds. In acid solutions, H_3O^+ readily exchanges with alkali ions in non-bridging oxygen sites and can also directly hydrolyze Si–O–B bonds [14]. Accordingly, most aluminosilicate glass compositions exhibit relatively fast reaction rates under acid and basic conditions and relatively slow rates at near-neutral pH conditions. Results from SPFT experiments with LAWA33 glass reveal the expected amphoteric behavior, as displayed in Figure 9A. Note that this figure depicts the dissolution rates based on multiple elements (B, Na, and Al), which are, for the most part, internally consistent. Because the solution percolating through the ILAW glass repository is anticipated to be basic, the results between pH values of 7 to 11 are especially relevant (Figure 9B). The slope of the line through these data points yields the power law coefficient, $\eta = 0.5$, for the rate-dependence on hydronium ion activity [see Equation (1)]. Although the LAWA33 and LAWABP1 glass compositions are different, we anticipate that the latter will be-

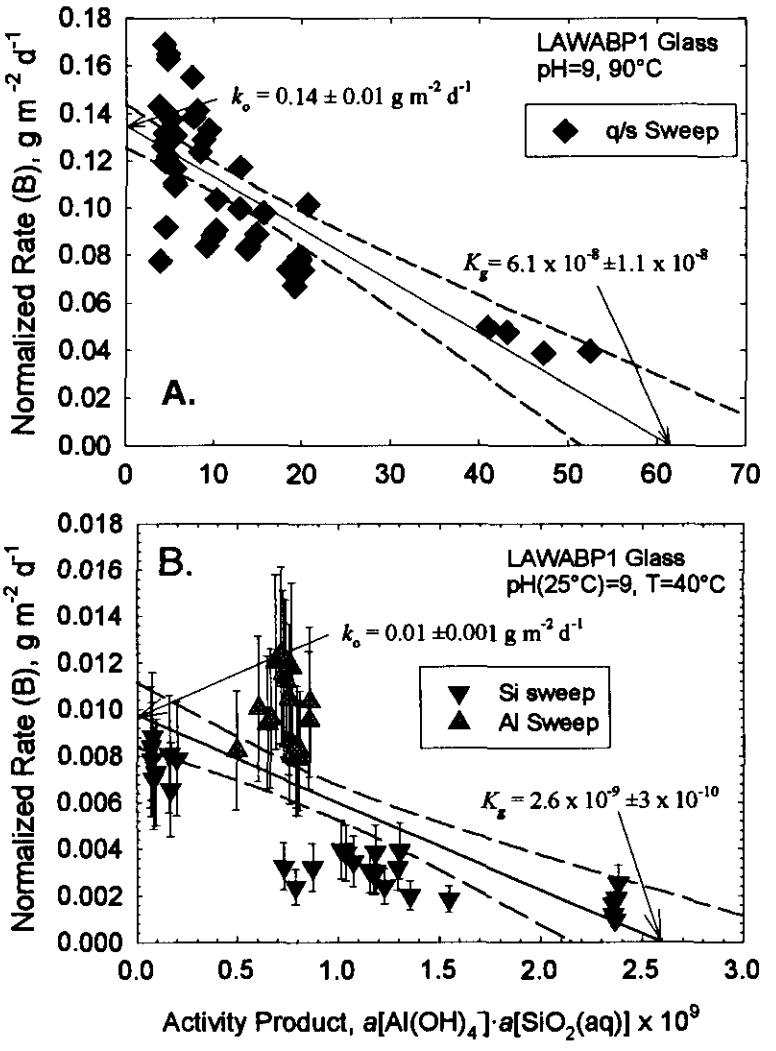


Figure 8. Plot of Dissolution Rate Versus Mixed Al-Si Activity Product for LAWABP1 glass at (A) 90°C and (B) 40°C

have similarly to the former. Accordingly, we recommend the value of 0.5 for the power law coefficient for LAWABP1 glass until the value can be determined experimentally.

2.3.2.4 Remaining Parameters

Two parameters remain from Equation (1) that have not yet been determined, the Temkin coefficient (σ) and activation energy (E_a). In previous carefully done SPFT tests with LD6-5412 glass, McGrail et al. [13] found that $\sigma = 1$ provided the best fit to their data. Furthermore, Lasaga [15] points out that the TST kinetic rate law is not fundamentally valid for $\sigma \neq 1$. Consequently, we will assign $\sigma = 1$ and not consider this "parameter" further. The apparent activation energy, E_a, can also be reasonably estimated from previous work with other glass compositions. Nearly all properly performed glass dissolution experiments yield activation energies of 75 ±5 kJ mol^{-1} and we recommend the temporary use of this value as well.

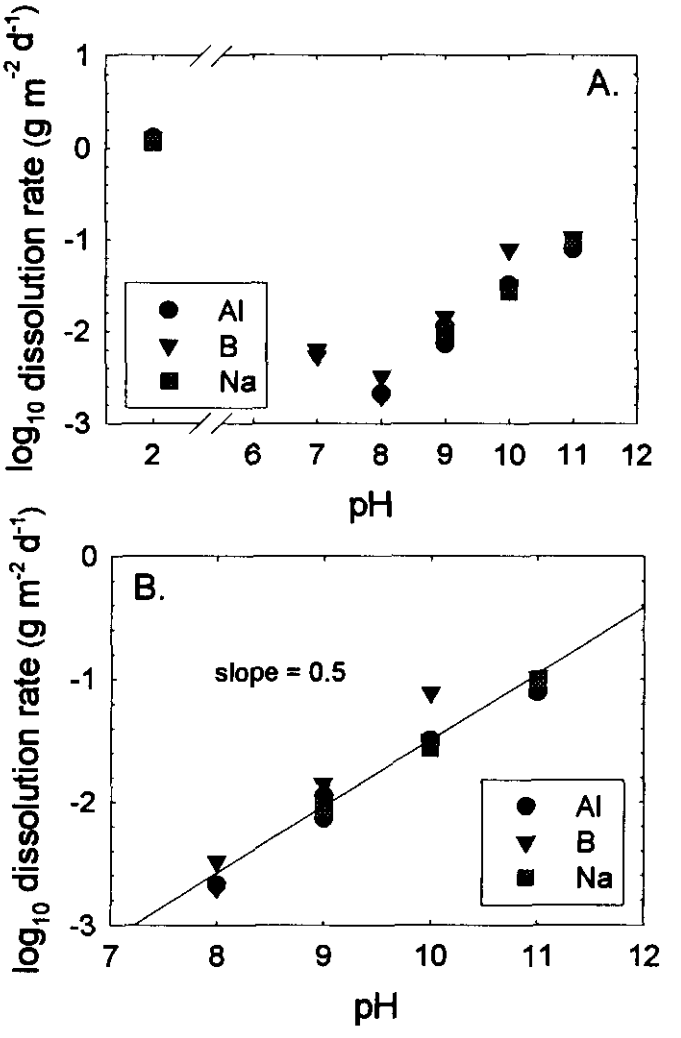


Figure 9. Plot of dissolution rate of LAWA33 glass versus solution pH for (A) full pH range investigated, and (B) alkaline range. T=40°C, flow-through rate = 30 mL d^{-1}

2.3.2.5 Na Ion Exchange

As was discussed in Section 2.3.2.2, as the solution contacting a glass becomes more concentrated with dissolved glass components, the rate of matrix dissolution declines. Under near-saturation conditions when the matrix dissolution rate is very small, a secondary reaction mechanism, alkali ion exchange, becomes the dominant process controlling the glass corrosion rate [10]. Because Na ion exchange can have a significant impact on the calculated release rates from an ILAW disposal facility [16], the Na ion-exchange rate for LAWABP1 glass is needed. Because

secondary phase formation is minimized in SPFT experiments, they provide one of the best means of extracting Na ion-exchange rates.

The rate of Na ion-exchange (r_x) was calculated via

$$r_x = f_{Na}(r_{Na} - r_B) \quad (4)$$

where r_{Na} and r_B are the normalized release rates of Na and B, respectively, and f_{Na} is the mass fraction of Na in the glass. Effectively, Equation (4) provides an estimate of the amount of Na released in excess of the amount contributed from glass matrix dissolution alone. In Figure 10, we plot r_x from SPFT experiments at 90°C at the smallest ratio of q/s tested and at 40°C from the Si sweep experiments with the largest amount of Si added to the influent solutions. These data sets were selected because they provided the smallest chemical affinity (most concentrated solutions) and thus maximized the contribution from the ion-exchange reaction. Because data are currently available at only two temperatures, the activation energy regressed from the data should be considered as tentative. Still, the estimated value of 50.6 kJ/mol is quite reasonable, consistent with a low energy barrier for removal of Na^+ from a non-bridging oxygen site in the glass and/or a transport controlled process (diffusion). Using this activation energy, the estimated Na ion-exchange rate for LAWABP1 glass at 15°C is 3.5×10^{-6} mol/(m²·d).

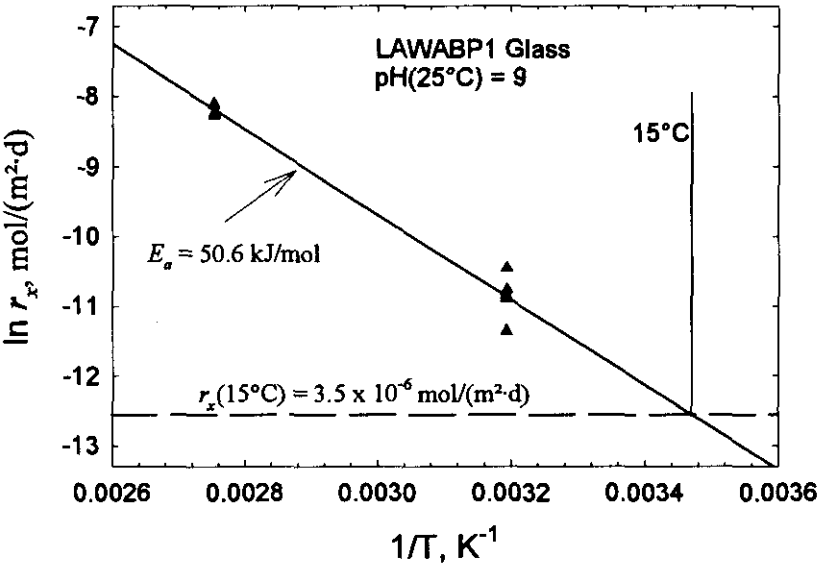


Figure 10. Plot of Excess Na Release via Ion-Exchange as a Function of Temperature From LAWABP1 glass at pH(25°C)=9

2.3.2.6 Future Experiments

The data presented in the foregoing sections demonstrates the utility of SPFT experiments for determining kinetic rate law parameters. Dissolution rate constants, pseudoequilibrium constants, and power law coefficients can all be obtained. Our next set of goals is to determine the dissolution rate as a function of pH and over a series of temperatures so that other parameters, such as the acti-

vation energy, can be obtained. We are also interested in further quantifying the effects of Si and Al in solution, especially over a range of temperatures. These data will allow us to determine the rate parameter values in a number of independent ways, which can then be used to check for internal consistency. We will be able to incorporate these variables into models that will bound the release rates over the expected composition region being considered by BNFL, Inc.

2.4 PRODUCT CONSISTENCY TEST RESULTS

2.4.1 Test Description

The Product Consistency Test (PCT) has been standardized as an ASTM standard procedure [17]. The ASTM standard includes two methods: PCT Method A was developed specifically for verifying process control of vitrified HLW forms and is conducted with specific values of test parameters; PCT Method B does not specify the values of test parameters. Because the PCT Method B encompasses commonly used variations of test parameters, we refer to all static dissolution tests with crushed glass generically as PCTs.

The PCTs are conducted by reacting an aliquot of crushed glass that has been sieved to isolate the desired size fraction with an aliquot of a solution in a sealed vessel at the desired temperature. There are three degrees of freedom for parameter variation in PCTs, temperature, glass surface area to solution volume ratio (S/V), and test duration. The glass surface area (S) is determined either by direct measurement with gas adsorption techniques such as Kr or Ar BET methods or as estimated from the size fraction of the glass [13]. Tests are conducted as batch tests wherein a separate test is run for each test duration. At the end of the test, the solution is analyzed for pH and the concentrations of dissolved glass components. The latter are used to calculate the amount of glass that has reacted and the dissolution rate. The reacted glass surface can also be analyzed to help characterize the reaction mechanism, such as when an alkali-depleted layer or alteration phases form.

2.4.2 ANL Test Results

Several PCTs are being conducted at glass surface/solution volume (S/V) ratios of about 2000 and 20,000 m^{-1} at temperatures of 40 and 90°C. The number of tests being conducted was limited by the amount of glass available. Test conditions were selected to allow direct comparison with test results for other glasses. Test solutions were passed through a 0.45 μm pore size filter, acidified

with nitric acid, then analyzed with inductively coupled plasma mass spectrometry (ICP-MS). Test results with LAWA33 glass are summarized in Table A.2. The results of blank tests give the detection limits for B, Na, and Si. Triplicate 7-day PCTs were conducted at 90°C; the results are compared in Table A.3 with 7-day PCT results with LD6-5412 glass, which was a low-level reference glass tested previously, and with SRL 51 and WV 6 glasses, which are non-radioactive reference glasses for waste forms made at the Defense Waste Processing Facility (DWPF) and the West Valley Demonstration Project (WVDP), respectively. Based on the 7-day PCT results, the LAWA33 glass is less durable than these other glasses. The LAWA33 glass is also less durable than LD6-5412 glass in PCTs conducted for longer durations. Alteration phases were not detected in any PCT with LAWA33. The average dissolution rate in the 7-day PCT is 0.025 g/(m^2·d) based on silicon.

Table A.2. PCT Results for LAWA33 Glass. Test Temperature is either 40 or 90°C as indicated by 40 or 90 in the Test No. column.

Test No.	Time, days	S/V, m^{-1}	pH	B, mg/L	†NL(B), g/m^2	Na, mg/L	NL(Na), g/m^2	Si, mg/L	NL(Si), g/m^2
PB2-40-1	7	2000	10.02	2.63	0.0479	20.3	0.0687	9.57	13.6
PB2-40-B1	7	blank	<7	0.23		<0.01		<0.6	
PB2-40-10	36	20000	11.23	11.9	0.217	129	0.436	41.9	0.117
PB2-40-11	98	20000	11.34	17.4	0.317	170	0.576	48.9	0.137
PB2-90-1a	7	2000	10.95	26.4	0.477	140	0.472	63.5	0.178
PB2-90-1b	7	2000	10.97	26.6	0.481	140	0.474	63.5	0.177
PB2-90-1c	7	2000	10.96	25.6	0.463	136	0.461	62.8	0.176
PB2-90-B1	7	blank	<7	0.08		<0.1		<0.6	
PB2-90-B2	7	blank	<7	0.16		<0.1		<0.6	
PB2-90-3	IP*	20000							
PB2-90-10	63	20000	11.82	325	0.590	1360	0.459	472	0.132
PB2-90-11	98	20000	11.97	395	0.719	1630	0.551	529	0.148
PB2-90-12	IP	20000							

*In Progress; †NL = Normalized mass loss

Table A.3. Comparison of PCT Results for LAWA33 and Other Glasses

Test No.	Glass	Time, days	S/V, m^{-1}	pH	NL(B), g/m^2	NL(Na), g/m^2	NL(Si), g/m^2
PB2-90-1a, b, c	LAWA33	7	2000	10.96±0.01	0.474±0.009	0.469±0.007	0.177±0.001
P-LD6-1, 2, 3	LD6-5412	7	2000	11.20±0.02	0.0880±0.0007	0.312±0.001	0.099±0.0004
51S-0, 1, 2	SRL 51S	7	2000	10.66±0.02	0.268±0.003	0.305±0.004	0.203±0.002
WV6-21, 22, 23	WV 6	7	2000	9.98±0.02	0.270±0.010	0.283±0.008	0.126±0.003
PB2-40-11	LAWA33	98	20000	11.34	0.317	0.576	0.137
PA4-9, 10[a]	LD6-5412	98	20000	11.53	0.013	0.054	0.014
PB2-90-10	LAWA33	63	20000	11.82	0.590	0.459	0.132
PA9-9, 10[a]	LD6-5412	56	20000	11.31	0.051	0.29	0.043
PB2-90-11	LAWA33	98	20000	11.97	0.719	0.551	0.148
PA9-11	LD6-5412	100	20000	12.64	0.065	0.34	0.051
PA9-12[b]	LD6-5412	100	20000	11.40	0.26	0.42	0.11

[a] Average values for duplicate tests. [b] Alteration phases formed in test.

2.4.3 PNNL Test Results

To date, only very limited PCT solution analytical data are available on BNFL, Inc. relevant ILAW glasses. All tests were run in Teflon PFA containers at 99°C. This temperature was selected to be consistent with PUF experiments that are also being run at 99°C. No solids analyses have been completed from these tests. A plot of normalized B release data for these glasses is given in Figure 11. Please see Section 3.2.4 for a discussion on how these data are used to derive input for STORM code calculations.

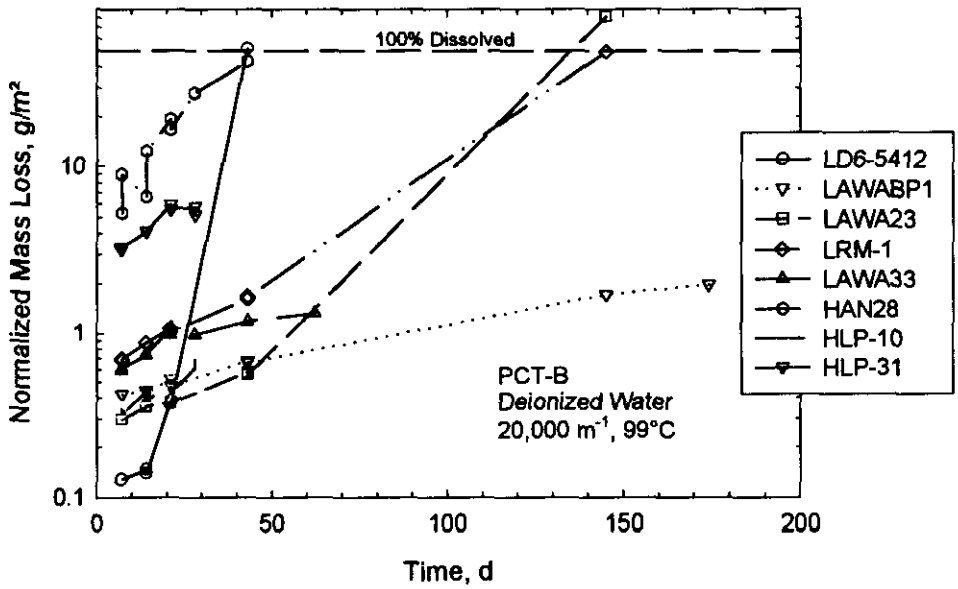


Figure 11. PCT Data for Selected ILAW Glasses

2.5 VAPOR HYDRATION TEST RESULTS

In the vapor-phase hydration test, VHT, monolithic samples are exposed to saturated water vapor at elevated temperatures (typically 100°C to 300°C) in a sealed vessel as shown in Figure 12. At relative humidity (RH) above about 80%, a thin film of water condenses on the sample. The thickness of the film increases with the RH, and it is in this film that the glass corrodes. The thickness of the film determines the effective S/V ratio of the system; for a uniform layer, the S/V ratio is simply the inverse of the thickness of the film. Most VHTs have been performed in 100% relative humidity at temperatures above 100°C, although tests have been conducted at lower humidities and temperatures. At the completion of a test, the sample is removed from the vessel, and the reacted surface is analyzed. Discrete precipitated crystalline phases usually form when the sample corrodes. The solution evaporates from the sample when the test is terminated and is not available for analysis. This precludes using the test to evaluate and test models of glass corrosion behavior, which require detailed measurements of the solution composition in contact with the glass.

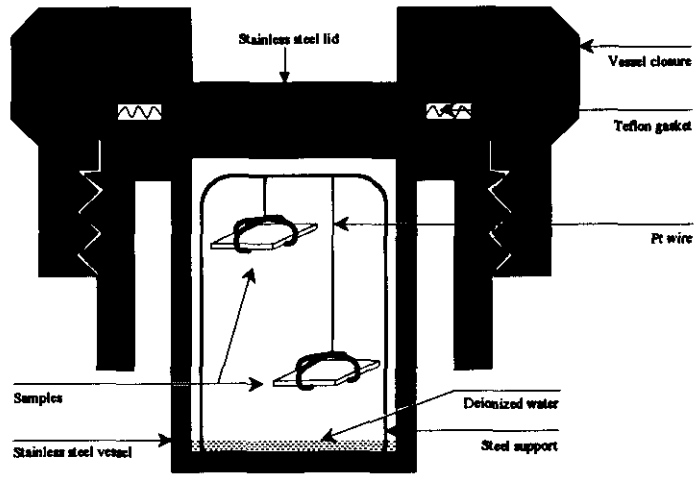


Figure 12. Schematic of Apparatus for conducting Vapor-phase Hydration Test

The VHT environment greatly accelerates the progression of glass corrosion by water. The VHT is the simplest accelerated test used in this testing program because there is only two degrees of freedom in test parameters that can be varied, temperature and test duration (excluding relative humidity). The principal uses of the test are 1) as a screening tool to quickly determine if a glass is likely to corrode at an extreme rate, 2) as a convenient means of generating alteration phases for analysis within a short period, and 3) for a measure of the corrosion rate at elevated temperatures. Vapor hydration has been used by archaeologists to replicate the weathering observed on obsidian artifacts recovered from terrestrial sites [18]. The method has also been used to simulate the long-term weathering of tektite [19] and basaltic glasses [20]. Because the test method produces the same alteration phases that form during the weathering of natural glasses over long periods, the test

has also been used to accelerate the corrosion of waste glasses. High-level waste glasses commonly form clay layers in VHTs. Glasses having compositions relevant to anticipated LAW for Hanford form zeolite phases similar to analcime, gobbinsite, and phillipsite.

2.5.1 ANL VHT Results

A small number of VHTs have been conducted at 150 and 175°C with LAWA33 glass to promote the formation of alteration phases. The tests that have been completed are summarized in Table 3. The glass alters to form a layer of clay (which is probably a smectite clay, based on preliminary analyses) initially and then an assortment of other phases at longer test durations. Analysis of these phases is in progress. Zeolites including analcime and a potassium-bearing analcime appear to be the most abundant phases, besides the clay. Whereas the alteration layers formed on samples reacted for short durations at both temperatures appeared homogeneous, those formed in the longer test durations have a complex microstructures with alteration phases both on top of and within a layer we presume to be clay. The layers and alteration phases are currently being characterized. The approximate thickness of the layers formed under different test conditions are summarized in Table 3. As expected, the glass reacts faster at 175°C than at 150°C, although significant alteration occurs at both temperatures. Not enough tests were conducted to determine the alteration rates after alteration phases formed at these temperatures, although the tests run for the longest durations provide lower bounds to the dissolution rates. Dividing the layer thickness of the 77-day tests at 150°C and the 28-day tests at 175°C by the duration, the minimum rates are 3.9 and 8.9 μm/day at 150 and 175°C, respectively. Assuming the density of the glass is about 2.5 g/cm^3, these rates are 9.8 and 22 g/(m^2·d) at 150 and 175°C, respectively. Assuming an activation energy of 80 kJ/mol, these rates extrapolate to 0.21 and 0.13 g/(m^2·d), respectively, at 90°C. These are lower than the forward rate estimated from the MCC-1 tests and higher than the average rate measured in the 7-day PCTs.

Table 3. Matrix of VHTs with LAWA33 Glass

Test No.	Temp., °C	Date In	Date Out	Time, days	Layer Thickness, μm	Alteration Phases
VB2-150-1	150	03/11/1999	03/25/1999	14	<1	clay
VB2-150-2	150	03/11/1999	04/08/1999	28	5	clay
VB2-150-3	150	03/11/1999	05/27/1999	77	300	clay + zeolites
VB2-150-4	150	03/11/1999	05/07/1999	57	40	clay + zeolites
VB2-175-1	175	03/11/1999	03/17/1999	6	1	clay
VB2-175-2	175	03/11/1999	03/25/1999	14	50	clay + zeolites
VB2-175-4	175	03/11/1999	04/08/1999	28	250	clay + zeolites

2.5.2 PNNL VHT Results

In addition to the eight glasses discussed in Section 2.4, four additional glasses (HLP-09, HLP-12, HLP-33, and HLP-56) were selected for detailed testing under the ILAW program. As PCT and PUF experiments with these glasses have only just been initiated, details regarding the test results have not been provided in this revision of the Waste Form Release Data Package. However, preliminary VHT results are available and will be discussed in this section. The VHTs were performed according to a PNNL technical procedure.[1] Samples with dimensions 10x10x1.5 mm are prepared from heat-treated glass bars using diamond impregnated saw. All sides are polished to 600 grit surface finish using SiC paper. Samples, stainless steel vessels, lids, and supports are cleaned and samples are suspended from a stainless steel supports on Pt wire. The amount of deionized water needed to saturate the inside of the vessel at given temperature (plus 0.05 ml excess of water, which is allowed to condense on samples surface) is added to the vessel. The sealed vessel is held at constant temperature in a convection oven for a preset time. After the test termination,

[1]Vapor-phase Hydration Test Procedure, GDL-VHT, Rev. 1, Pacific Northwest National Laboratory, Richland, WA (1999)

samples are removed from the vessel and examined for presence of secondary phases first by visual observation and optical microscopy. Amount of glass dissolved is determined by measuring the thickness of remaining unaltered glass as viewed in cross section with an optical microscope equipped with image analysis software. The alteration products are identified with X-ray diffraction (XRD) and scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS).

A matrix of 55 glasses was developed and tested with the aim to identify the impact of glass composition on the long-term corrosion behavior and to develop acceptable glass composition region [21]. Of the 55 glasses, 45 were designed to systematically vary the glass composition and 10 were selected because of large and growing databases on their corrosion characteristics had accumulated. The testing results of all 55 glasses are reported in detail by Vienna et al. [21]. The results for 12 of these glasses, pertinent to the ILAW testing program, are briefly discussed below.

Corrosion rates for each of the 12 glasses, including apparent activation energy (E_a) are summarized in Table 4. Note that these results represent the current status of testing and some rates/E_a may change significantly as new data become available.

Table 4. VHT Corrosion Rate Summary, (rates in g m^{-2} d^{-1}, E_a in kJ/mol)

Glass ID	Name	300°C	250°C	200°C	175°C	150°C	E_a
HLP-09		324.7*		1.0*			
HLP-10		393.7*		2.7*			
HLP-12		867.0		11.1			
HLP-31				60.6			
HLP-33				11.8*			
HLP-46	LD6-5412			195.7	65.6	14.7	86.4
HLP-47	LRM-1			28.2			
HLP-48	LAW-A33		397.1	39.5	11.1	2.9	90.7
HLP-51	LAW-ABP1	255.3		3.6*			
HLP-52	HAN-28			929.8*			
HLP-53	LAW-A23 quenched			411.5*			
HLP-56	LAW-A44	270.3*	61.3	10.2[a]			74.0*

(*) Marked values are preliminary and will be changed/updated in subsequent reports.
[a]200°C rate was extrapolated from higher temperature tests, measurements not yet complete.

Alteration products, identified by XRD, are summarized in Table 5. Phases are substituted by numbers according to the list in Table 6.

Table 5. Alteration Products on VHT Samples as Determined by XRD

Glass ID	Glass Name	Temp (°C)	Test duration (d)	Surf or Bulk	Phases (see Table 6)
HLP-09		300	5	B	2, 6, 16
HLP-10		300	3	B	2, 17
HLP-12		300	2	B	1, 2, 9, 13, 17
HLP-12		200	105	B	1, 2, 6, 17
HLP-31		200	2	S	18
HLP-31		200	10	B	2
HLP-33		300	5	B	1, 2, 9, 17
HLP-33		200	129	S	2, 6
HLP-46	LD6-5412	200	4	B	2, 16, 19
HLP-46	LD6-5412	175	11	B	2, 16, 19
HLP-46	LD6-5412	150	32	B	2, 4, 10, 16, 19
HLP-47	LRM-1	200	24	B	2
HLP-48	LAW-A33	250	2	B	2, 15, 16
HLP-48	LAW-A33	200	20	B	2, 15, 16
HLP-48	LAW-A33	175	29	B	2, 15, 16
HLP-51	LAW-ABP1	300	2	B	2, 3, 12, 15
HLP-51	LAW-ABP1	250	3	S	2, 16
HLP-51	LAW-ABP1	200	75	B	2, 16
HLP-51	LAW-ABP1	150	187	S	10, 16
HLP-52	HAN-28	200	13		12, 16
HLP-53	LAW-A23	200	3		15
HLP-56	LAW-A44	300	3	B	1, 2, 7, 17
HLP-56	LAW-A44	250	5	S	2

Table 6. List of all Alteration Products Identified on Hanford ILAW Glasses

#	Phase	JCPDF#	Formula
1	Acmite	71-1491	$NaFe(Si_2O_6)$
	Analcime	74-2219	$Na(AlSi_2O_6)H_2O$
	Analcime	76-0143	$NaAlSi_2O_6H_2O$
2	Analcime	76-0901	$Na(AlSi_2O_6)(H_2O)$
	Analcime-C	41-1478	$Na(Si_2Al)O_6{\cdot}H_2O$
	Analcime-O	19-1180	$Na(Si_2Al)O_6{\cdot}H_2O$
3	Annite-1M	26-0909	$K_2(Fe_5Al)Si_5Al_3O_{20}(OH)_4$
4	Gobbinsite	82-1867	$Na_4Ca_{0.94}(Si_{10.4}Al_{5.6}O_{32})(H_2O)_{16.185}$
5	Herschelite	19-1178	$NaAlSi_2O_6{\cdot}3H_2O$
6	Hydrogen Aluminum Silicate	80-1387	$H(AlSi_2O_6)$
7	Kingsmountite	35-0694	$Ca_4FeAl_4(PO_4)_6(OH)_4{\cdot}12H_2O$
8	Nosean	74-1736	$Na_8(SO_4)(Al_6Si_6O_{24})$
9	Omphacite	71-1403	$Fe_{0.5185}Al_{0.4815}Ca_{0.466}Na_{0.534}Si_2O_6$
10	Phillipsite	73-1419	$Na_4KAl_5Si_{11}O_{32}(H_2O)_{10}$
	Phillipsite	39-1375	$KCa(Si_5Al_3)O_{16.6}H_2O$

11 Potassium Chloride	77-2121 KCl
12 Sodalite Group	82-1812 $Na_8(AlSiO_4)_6(ClO_4)_2$
13 Sodium Aluminum Phosphate Silicate Hydrate	43-0136 $Na_{13}Al_{24}Si_{13}P_{11}O_{96}\cdot 16H_2O$
14 Sodium Aluminum Silicate	74-1787 $Na_6Al_6Si_{10}O_{32}$
15 Sodium Aluminum Silicate Boron Hydroxide Hydrate	83-0550 $Na_{7.55}(AlSiO_4)_6(B(OH)_4)_{1.685}(H_2O)_{1.97}$
Sodium Aluminum Silicate Hydrate	84-0590 $Na_3Al_3Si_3O_{12}(H_2O)_2$
16 Sodium Aluminum Silicate Hydrate	34-0524 $Na_{5.7}Al_{5.7}Si_{10.3}O_{32}\cdot 12H_2O$
Sodium Aluminum Silicate Hydrate	42-0216 $Na_6[AlSiO_4]_6\cdot 4H_2O$
17 Sodium Titanium Silicate	29-1280 $NaTiSi_2O_6$
18 Zeolite P (Na-exchanged)	80-0699 $Na_{3.552}(Al_{3.6}Si_{12.4}O_{32})(H_2O)_{10.656}$
19 Sodium Calcium Silicate	37-0282 $Na_4CaSi_3O_9$

As is evident from the data in Table 4, glass corrosion rates vary by nearly 3 orders of magnitude in 200°C VHTs for the range of glass compositions tested. HAN28 glass shows the highest corrosion rate, consistent with the results observed in PCTs (Figure 11) and as will be discussed in Section 2.6, PUF tests as well. The best performing glasses in the VHT are HLP-9, HLP-10, and LAWABP1. At the present time, it is not well understood what compositional factors control the long-term corrosion rate of these glasses. The corrosion rate results are essentially a direct measure of the stability of the glass with respect to a suite of alteration phases that form as a consequence of the glass/water reaction. However, because of incomplete or inaccurate thermodynamic data for many of the phases listed in Table 6, predictive modeling of long-term glass stability with geochemical reaction path codes remains limited to much simpler glass formulations than are being considered here.

2.6 PRESSURIZED UNSATURATED FLOW-THROUGH TESTS

The PUF test is a new technique developed at PNNL for testing waste forms [22,23]. The experimental design provides a novel way to study waste form corrosion behavior under unsaturated conditions, subject to open-system flow and transport. Like the SPFT test, the PUF test provides three degrees of freedom for parameter variation: temperature, glass surface area, and flow rate.

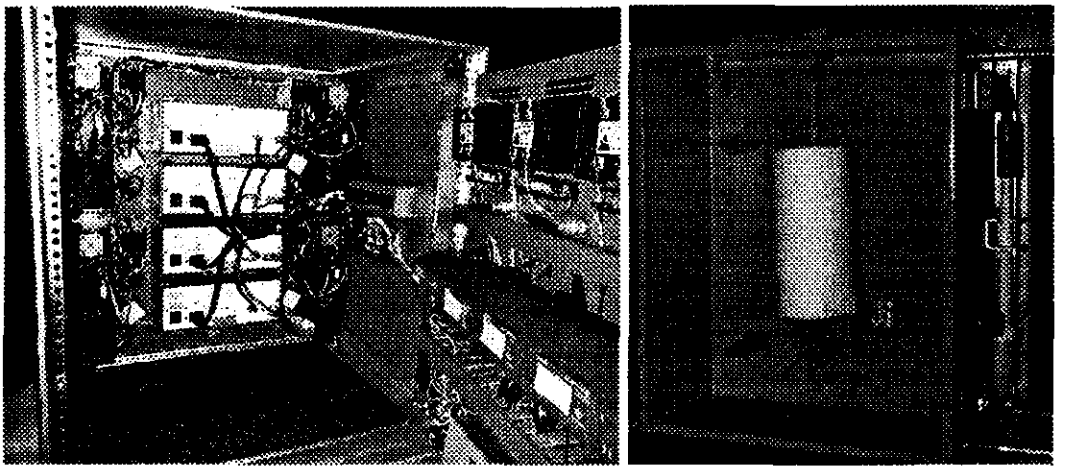


Figure 13. Picture of PUF System Hardware (Patent #5974859)

The basic test apparatus consists of a column packed with glass particles (or other material) of a known size and density, and a computer data acquisition and control system (see Figure 13). The column is fabricated from a chemically inert material so that dissolution reactions are not influenced by interaction with the column. A porous titanium plate with nominal pore diameter of 0.2 μm is sealed in the bottom of the column to ensure an adequate pressure differential for the conductance of fluid while operating under unsaturated conditions [24]. Titanium was chosen because it is highly corrosion resistant and has excellent wetting properties. When water saturated, the porous plate allows water but not air to flow through it, as long as the applied pressure differential does not exceed the air entry relief pressure or "bubble pressure" of the plate. The computer control system runs LabVIEW™ (National Instruments Corporation) software for logging test data to disk from several thermocouples, pressure sensors, inline sensors for effluent pH and conductivity, and column weight from an electronic balance to accurately track water mass balance and saturation level.

2.6.1 LAWA23 Glass

Three PUF experiments with LAWA23 glass (known also by the PNNL identifier BNFL-A-S98) have been completed. Details on these tests can be found in McGrail et al. [25]. Figure 14 shows the computer-monitored test metrics. Between 100 and 200 h, all three experiments exhibited a dramatic increase in effluent pH and electrical conductivity. The pH in all three experiments was tracked to values near or exceeding pH 14, whereupon sufficient corrosion of the solid-state pH electrode occurred to cause a loss of electrical signal. The computer-monitored test metrics in all three PUF experiments are now known as characteristic signatures of an autocatalytic acceleration

in glass corrosion rate that occurs after the formation of one or more alteration phases. Although we have observed similar rate excursions with other waste glasses, this was the first time that pH values in excess of 14 were ever monitored in a PUF experiment. The extreme pH values occur after the rate acceleration with BNFL-A-S98 glass because of the high alkali content of glass and the fact that a significant fraction of the SiO_2 in the glass has been replaced with metal oxides that increase solution pH when they dissolve.

XRD and TEM-SAED analysis of reacted solids (see SEM photos in Figure 15) removed from different positions in the PUF column showed diffraction peaks indicative of crystalline phases. Sodium aluminosilicate hydrate ($Na_{3.6}Al_{3.6}Si_{12.4}O_{32}\cdot 14H_2O$) zeolite was the major crystalline phase identified. Calcium silicate hydrate (CSH) was also found along with Na_2ZnSiO_4. The Na_2ZnSiO_4 phase is the round spheres scattered across the surface of the sample in Figure 15b.

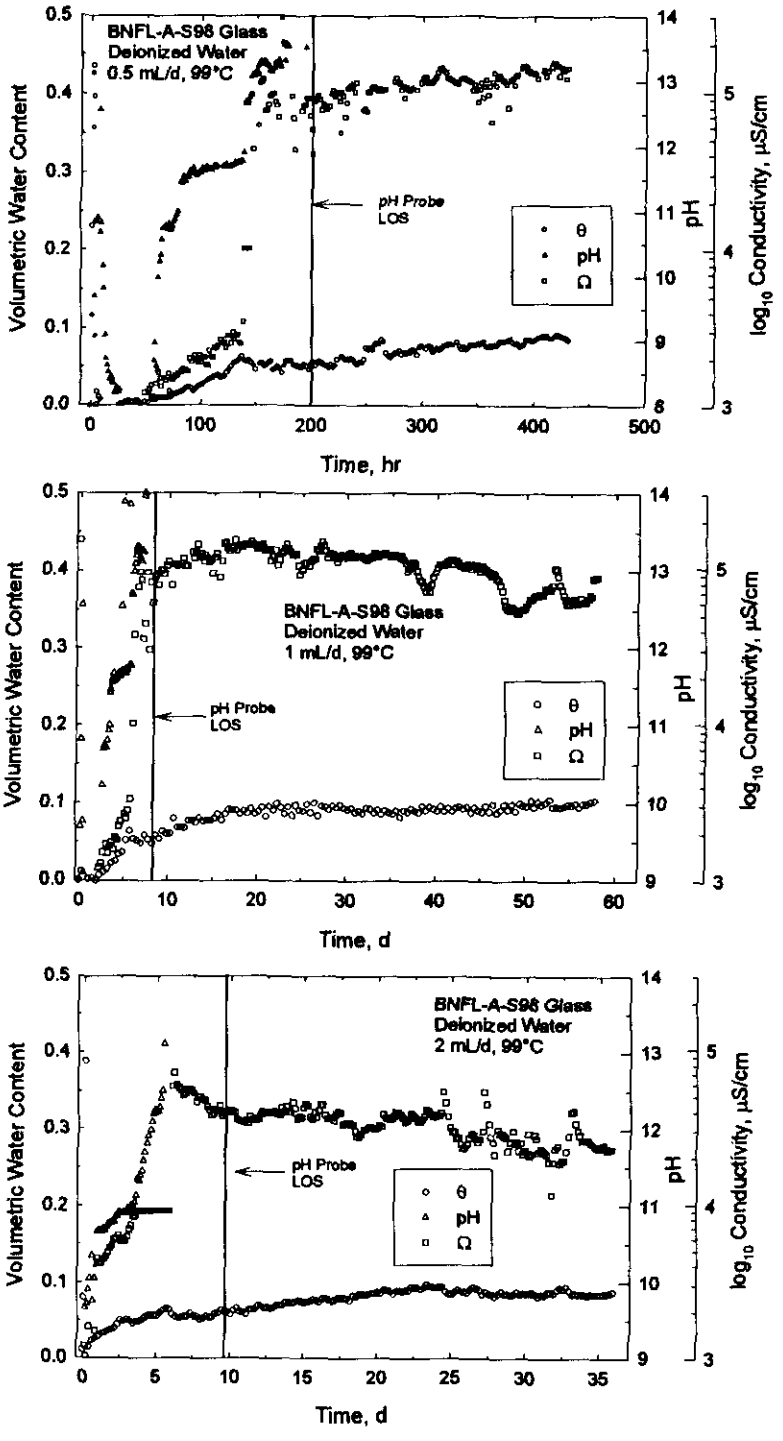
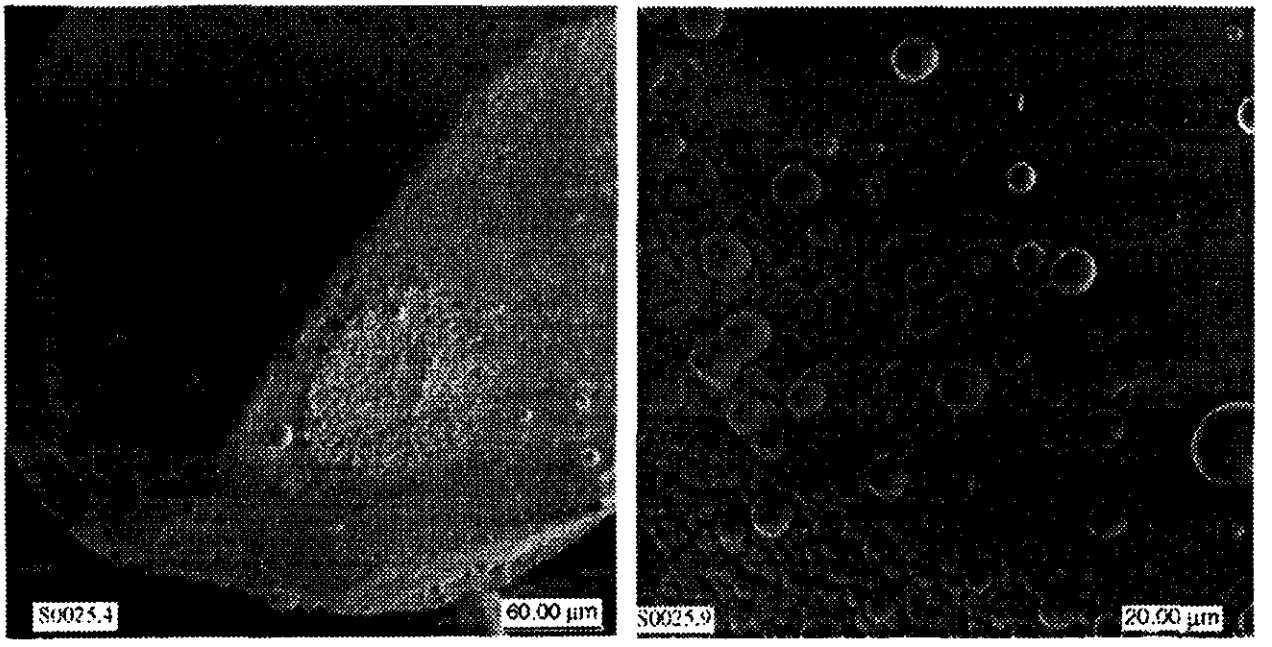


Figure 14. Test Metrics in PUF Tests with BNFL-A-S98 Glass (LOS = loss of electrical signal)



(a) (b)

Figure 15 Particle of BNFL-A-S98 Glass Reacted for 19 d at 99°C in PUF Test

Effluent samples from the same test were analyzed with ICP-MS and the results used to compute normalized release rates for the major glass components (see McGrail et al. [25] for details). The results are shown in Figure 16. The decline in the calculated rate with time is a consequence of the reduction in surface area due to extensive glass corrosion and mass loss after extended periods of time, which was not accounted for in the rate calculation. The calculated rate based on B release is very close to the expected forward rate of reaction of this glass at the test temperature and estimated effluent pH. A complete set of effluent chemical analyses for these tests is provided in Table 7 through Table 9.

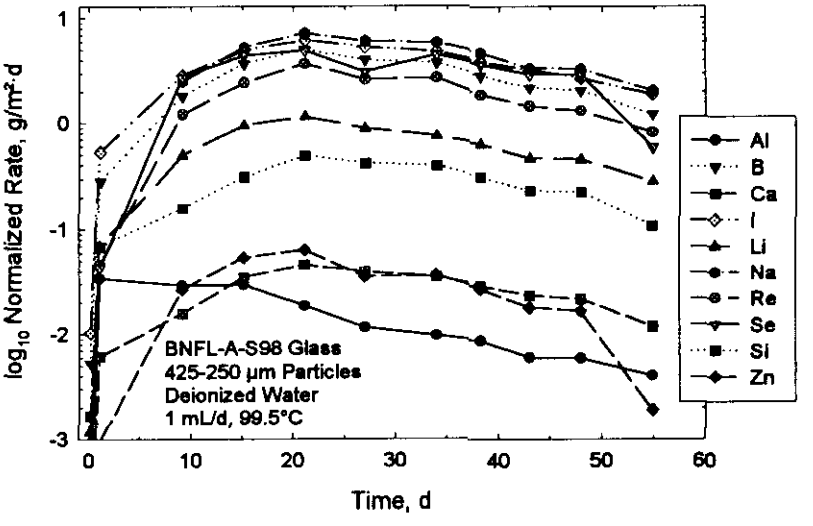


Figure 16. Normalized Release Rates in PUF Test with BNFL-A-S98 Glass

Table 7. Effluent Chemical Composition (mg/L) as a Function of Time in PUF Test at 0.5 mL/d and 99°C[a]

Time (d)	Al	B	Ca	I	Li	Fe	Mg	Na	Re	Se	Si	Zn
0.12	0.19	9.1	-0.50	0.99	0.68	0.02	0.02	-92	0.04	0.04	-5.0	0.05
1.06	13.65	21.5	0.66	1.19	10.83	0.37	0.37	297	0.31	0.28	40.9	0.36
12.93	11.59	5916.0	4.35	45.85	63.68	2.97	2.97	6431	1.22	3.71	245.1	7.36

Table 8. Effluent Chemical Composition (mg/L) as a Function of Time in PUF Test at 1.0 mL/d and 99°C[a]

Time (d)	Al	B	Ca	I	Li	Fe	Na	Re	Se	Si	Zn
0.12	1.49	9.1	0.24	0.75	1.46	17.16	-50	0.07	0.01	40.3	0.02
1.06	3.94	8.6	0.44	0.68	1.51	17.56	-50	0.09	0.02	29.3	0.06
9.11	33.37	545.8	11.16	36.73	107.50	10.88	8398	22.84	14.01	667.6	15.90
15.13	51.27	1691.7	37.61	95.89	313.25	2.66	26723	69.63	34.58	1997.3	49.41
21.09	34.91	2483.5	53.59	129.76	407.25	1.97	39418	113.02	41.13	3395.0	62.95
26.98	22.34	2030.0	47.41	113.98	323.00	0.36	34205	82.88	26.45	2954.5	35.49
33.95	18.73	1911.0	42.46	104.92	274.75	0.45	33100	86.29	38.76	2810.5	37.11
38.21	17.51	1498.7	35.98	87.69	239.75	2.41	27718	61.47	32.58	2338.0	28.36
42.95	12.51	1196.5	30.33	74.66	181.75	4.15	20305	49.55	26.90	1769.8	19.49
47.91	12.15	1100.7	27.46	61.54	174.75	4.69	19663	43.97	26.84	1703.5	17.82
54.87	8.97	709.0	16.37	46.67	120.00	8.28	13288	29.67	5.79	893.1	2.23

(a) Negative numbers signify values at or below detection limits.

Table 9. Effluent Chemical Composition (mg/L) as a Function of Time in PUF Test at 2.0 mL/d and 99°C[(a)]

Time	Al	B	Ca	I	Li	Fe	Mg	Na	Re	Se	Si	Zn	Zr
1.01	0.86	0.7	0.39	0.31	0.83	36.13	8.44	59	1.13	0.01	-5.0	0.02	0.03
3.17	6.69	8.5	0.67	0.64	2.74	33.50	12.10	243	1.44	0.09	-5.0	0.32	0.13
5.93	15.58	24.5	0.38	1.33	10.06	55.03	38.49	665	1.83	0.27	-5.0	0.73	0.01
9.07	32.07	420.2	5.85	7.61	85.33	52.28	4.41	3688	9.57	5.88	-5.0	3.82	0.03
12.86	48.65	1577.3	15.33	16.51	243.76	9.93	3.68	9243	27.59	17.75	151.4	11.27	0.09
15.08	43.05	1099.4	13.47	14.03	170.11	10.74	53.96	7572	21.48	13.27	267.2	5.59	0.02
17.19	16.72	1310.1	14.33	14.40	193.45	19.68	34.38	8597	24.55	21.52	227.3	2.38	0.02
19.88	42.34	1066.1	11.08	12.06	159.04	56.05	96.48	8386	18.58	13.48	329.5	4.67	0.03
22.85	17.92	1068.1	9.53	12.42	160.66	40.77	57.33	7442	18.38	11.68	227.3	0.69	0.02
25.91	30.27	1079.0	9.35	13.06	162.53	41.75	42.36	7071	18.19	11.85	85.10	3.54	0.02
27.88	10.44	931.5	8.90	6.72	149.92	42.37	14.28	6558	14.96	10.06	285.25	3.36	0.04
30.84	16.38	610.5	5.79	8.53	122.92	6.59	1.77	5059	11.93	8.68	5.22	2.76	0.31
33.90	14.16	455.2	5.27	6.92	97.87	6.55	1.35	3883	8.47	6.53	3.94	1.93	0.02
35.88	14.43	496.2	5.07	7.51	100.46	12.50	1.38	4052	9.90	7.27	4.32	1.92	0.01

2.6.2 LAWA33 Glass

Given the high reaction rates observed with the LAWA23 glass formulation, a new formulation (LAWA33) was provided by BNFL, Inc. that did not contain Ca, a contributor to zeolite formation that is thought to be the major cause of the reaction rate acceleration. The glass also contained TiO_2 and additional ZrO_2, both of which are considered neutral or stability-enhancing additives. This glass was manufactured and heat-treated according to a cooling curve provided by BNFL, Inc. staff. An examination of the microstructure of this glass in the TEM showed no evidence of phase separation or devitrification as a result of the heat treatment.

Approximately 250g of this glass was prepared but because of poor sample recovery in the size fraction used in the PUF tests, only one experiment was initiated. The results from the computer-monitored test metrics are shown in Figure 17. A problem developed in mass tracking with the electronic balance and so the indicated water content in this test is only approximate. The electrical conductivity and pH traces indicate a fairly rapid increase in the glass corrosion rate. Electrical conductivities reached over 20 mS/cm after only 7 days and after 18 d of reaction, effluent pH values are approaching pH 13. Both of these indicators suggest a rapid rate of glass corrosion in the test. The column became plugged after approximately 100 d of reaction time whereupon the test was terminated.

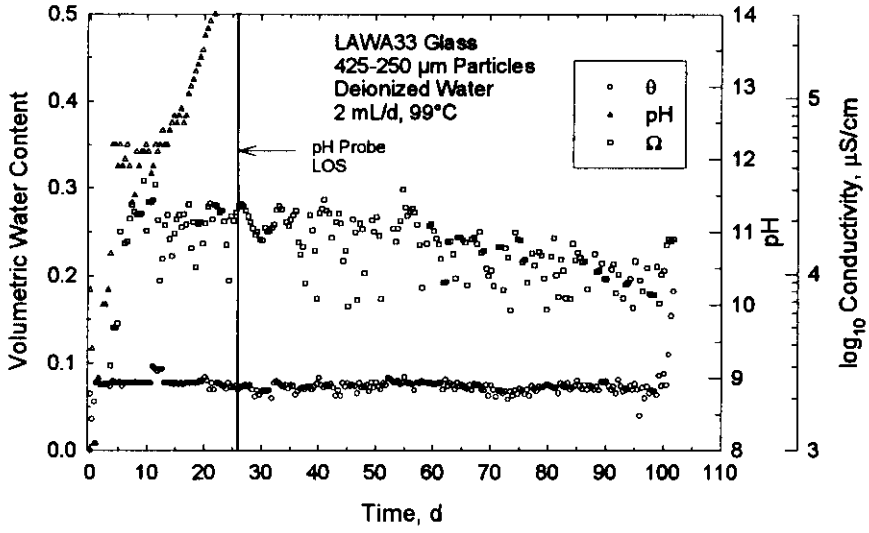


Figure 17. Electronically Monitored Test Metrics in PUF Test with LAWA33 Glass at 99°C and 2 mL/d Flow Rate

ICP-MS analyses of effluent samples were again converted to normalized release rates and the results are shown in Figure 18. The results confirm the high glass corrosion rate, again essentially at the forward rate of reaction at the temperature and estimated pH in the test. XRD and SEM analyses (see Figure 19) of reacted solids from the test showed that the major alteration phase was herschelite, $(Na,K)AlSi_2O_6 \cdot 3H_2O$, a sodium rich zeolite of the chabazite group.

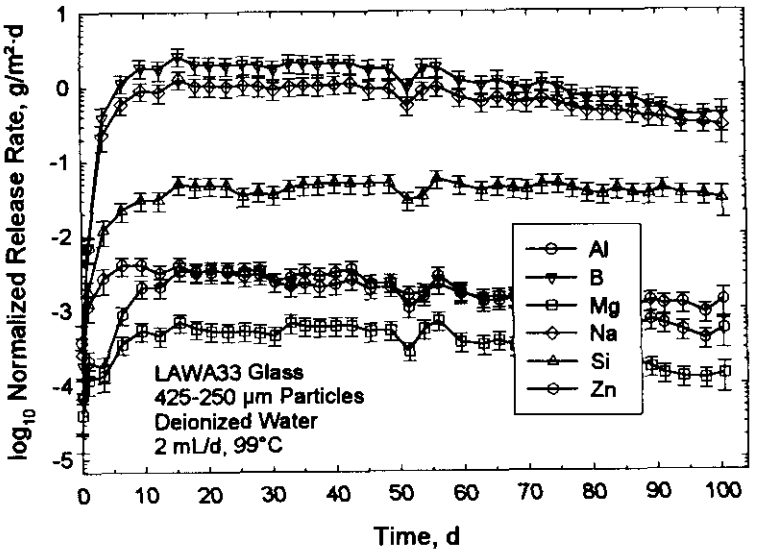


Figure 18. Normalized Release Rates in PUF Test with LAWA33 Glass

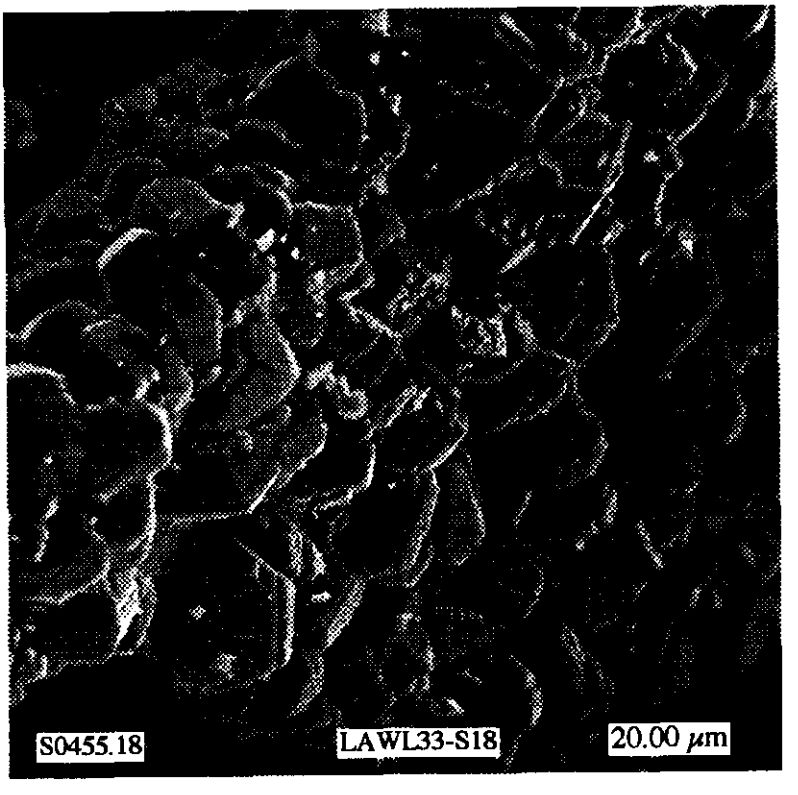


Figure 19. SEM Picture of Reacted Grain of LAWA33 Glass Densely Coated with Large Crystals of Herschelite, $(Na,K)AlSi_2O_6 \cdot 3H_2O$

2.6.3 LAWABP1 Glass

To ascertain whether improved long-term performance could be obtained by adjusting the additives in LAWA33 glass, a glass named LAWABP1 was formulated and manufactured. The composition of this glass is given in Table 2. A PUF experiment at 99°C and 2 mL/d flow rate was initiated with this glass and was terminated after 190 d. The results from the computer-monitored test metrics are shown in Figure 20. The electrical conductivity and pH data show that acceleration of the reaction rate has been delayed approximately three times longer than was observed for both LAWA23 and LAWA33 glasses. More importantly, the rate acceleration appears to be transient, with the rate relaxing back to a nominal value approximately 10X higher than before the acceleration occurred.

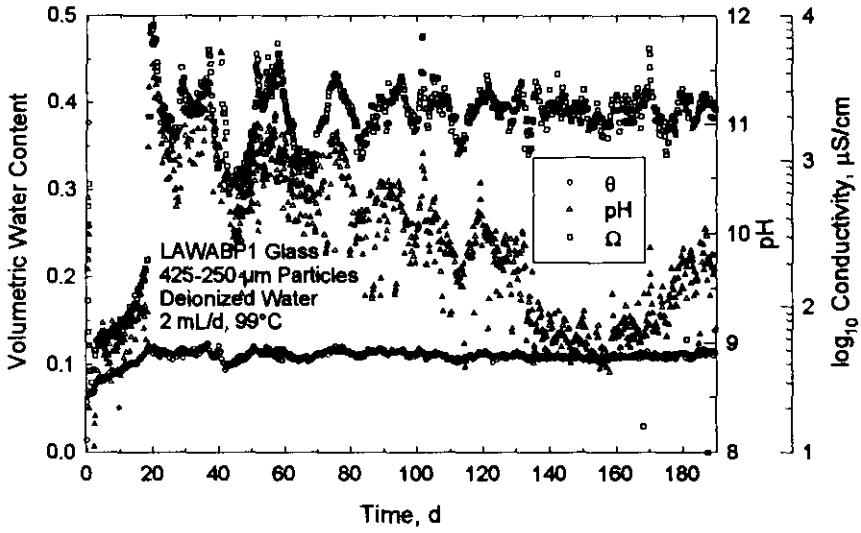


Figure 20. Electronically Monitored Test Metrics in PUF Test with LAWABP1 Glass at 99°C and 2 mL/d Flow Rate

ICP-AES analyses of effluent samples were converted to normalized release rates and the results are shown in Figure 21. There is a five order of magnitude spread in the release rates of the glass components. The soluble elements, such as B and Na, are released at the highest rates whereas highly insoluble elements, such as Ti and Zr, have the lowest release rates. An important difference in the effluent composition

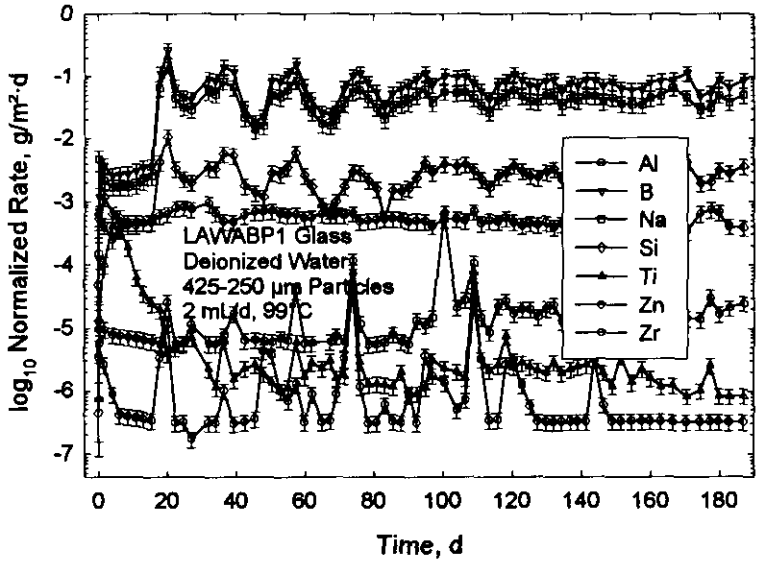


Figure 21. Normalized Release Rates in PUF Test with LAWABP1 Glass

from LAWABP1 glass as compared with LAWA33 glass is the ratio of the normalized B release to the normalized Si release. This value is approximately 60 for LAWA33 glass but only 25 for LAWABP1 glass, indicating that less of the Si is being incorporated into secondary phases, an important factor that slows the corrosion rate relative to LAWA33 glass.

A portion of the reacted solids removed from the LAWABP1 column were dried in glass vials at room temperature in a sealed can with $CaSO_4$ desiccant. Samples were dried until a constant mass was obtained. The observed mass loss was then used to compute the water mass fraction associated with the sample. The results are shown in Figure 22. The first three data points likely represent an imbibition profile as water drips from the fluid inlet onto the top of the porous glass bed. The water content peak observed at sample S9 is indicative of a precipitation front where water mass has accumulated in alteration products. A comparison of optical photo-

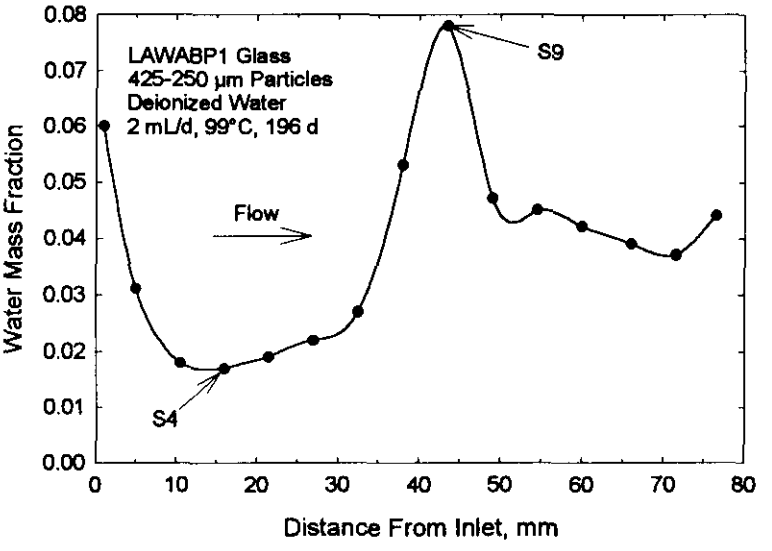


Figure 22. Water Mass Fraction as a Function of Position in Reacted Solids from PUF Test with LAWABP1 Glass. Samples labeled S4 and S9 were selected as representative of minimum and maximum water content samples.

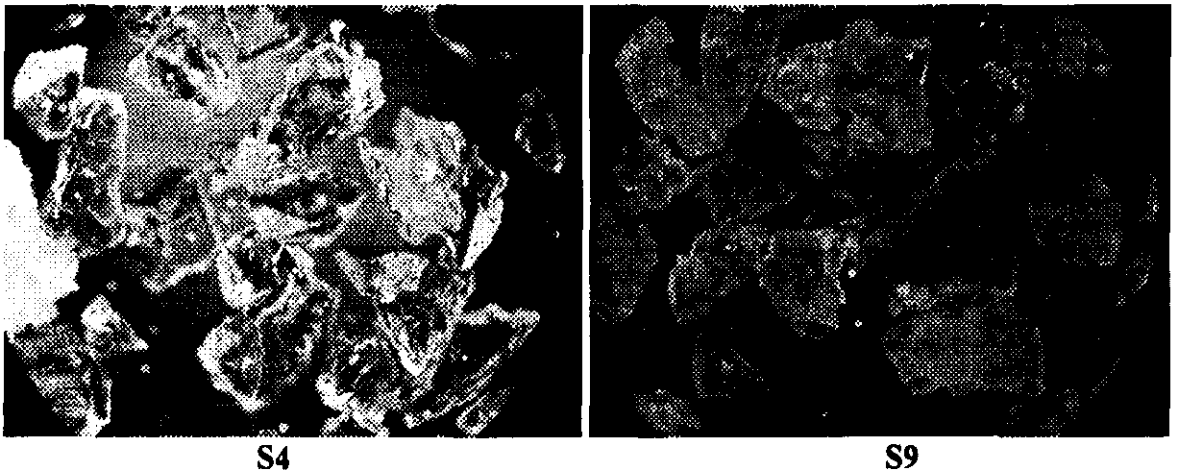


Figure 23. Optical Photos of LAWABP1 Glass Samples S4 and S9 After 190 d of Reaction in PUF Test at 99°C and 2 mL/d Flow Rate

graphs (Figure 23) taken on samples S4 and S9 clearly show this effect as the grains from sample S4 appear almost pristine whereas most of the grains from sample S9 are coated with alteration products.

SEM analyses of sample S9 reveals grains coated with an alteration layer (see highlighted area in Figure 24a) and several crystalline alteration phases. Energy dispersive spectroscopy (EDS) shows that Phase 1 is a mixed Na-K aluminosilicate and the crystal morphology clearly identifies it as herschelite. EDS analysis of Phase 2 shows it to be a pure Na-aluminosilicate and the crystal morphology is consistent with analcime. Phase 3 comprises the bulk of the alteration layer on the glass. EDS analysis indicates that the phase is enriched in Fe, Mg, Zn, and Ti and is most likely a nontronitic clay. Embedded in the clay layer were also small crystals with plate-like morphology (see inset of Figure 24b). This phase is enriched in Ti and Zn compared with the underlying clay layer. More detailed TEM analysis is underway to identify this phase.

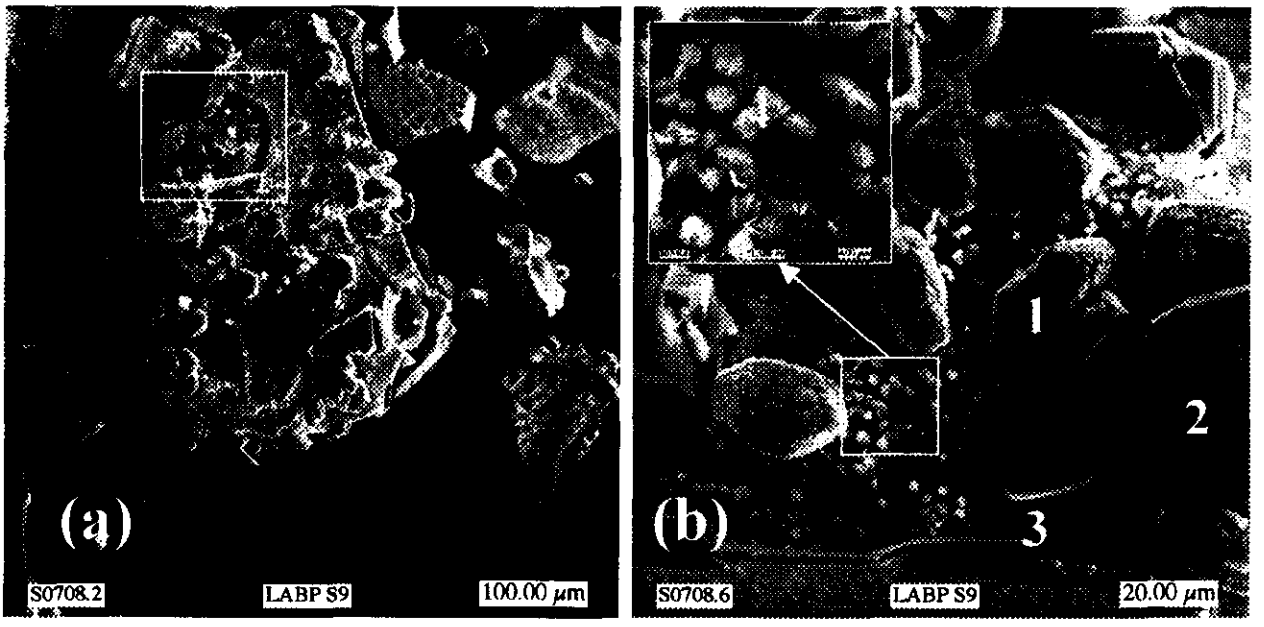


Figure 24. SEM Photos of Reacted LAWABP1 Glass Grains From Sample S9

2.6.4 HLP-10 Glass

The HLP-10 glass was one of two glasses (HLP-10 and HLP-31) selected from a much larger matrix of prototypic BNFL Inc. glasses whose corrosion behavior is being studied via vapor hydration tests [21]. The HLP-10 glass was selected because preliminary VHT data placed it

among the best performing glasses in the matrix while the HLP-31 glass was selected because it ranked as one of the poorer performing glasses in VHTs. The intent here was to ascertain whether similar behavior would be observed in PUF tests with these glasses. PUF tests with these glasses are still in progress at this time so only preliminary results are available.

Results from the computer monitored test metrics for the HLP-10 glass are provided in Figure 25. As was observed for LAWABP1 glass, periodic excursions in pH and conductivity have been monitored after about 20 d test duration. This glass also behaves similar to LAWABP1 in that it does not undergo a sustained acceleration in reaction rate as was observed for LAWA23 and LAWA33 glasses. Results from chemical analysis of the effluent samples are consistent with the data from the inline sensors, as illustrated in Figure 26. A comparison of the B release data for LAWABP1 and HLP-10 glasses suggests that on average, the corrosion rate of HLP-10 is equivalent to or slightly less than LAWABP1 glass under these test conditions.

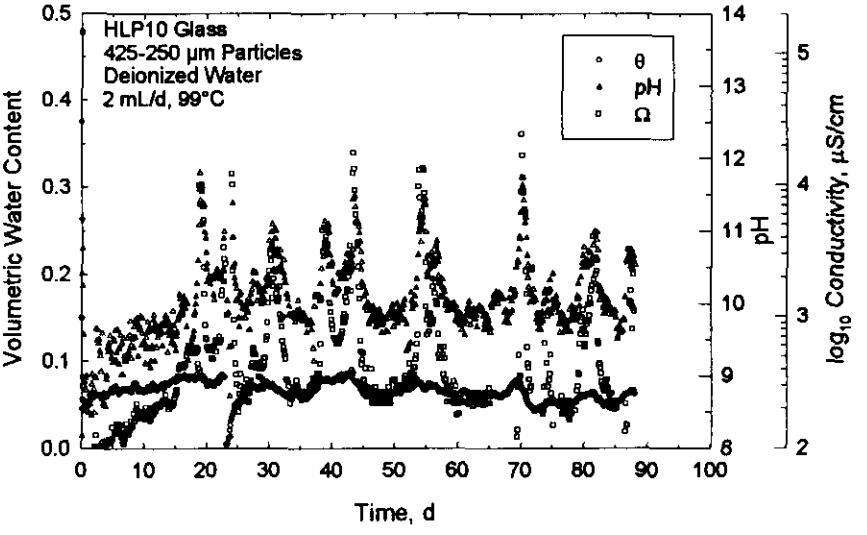


Figure 25. Electronically Monitored Test Metrics in PUF Test with HLP-10 Glass at 99°C and 2 mL/d Flow Rate

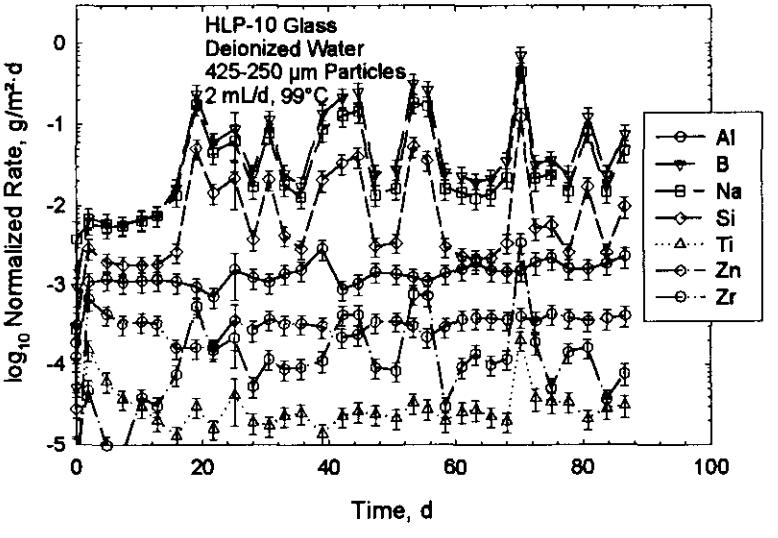


Figure 26. Normalized Release Rates in PUF Test with HLP-10 Glass

2.6.5 HLP-31 Glass

Results from the computer monitored test metrics for the HLP-31 glass are provided in Figure 27. The data show a very complex behavior with rapid swings in effluent pH and electrical conductivity. Volumetric water content also exhibits unstable oscillations that are the most intense we have ever observed in a PUF experiment. The effluent chemical composition again mirrors the data from the inline sensors, at least after approximately 25 days (Figure 28). The excursions are so rapid in first 25 days that the 3 day nominal collection period effectively smooths the data.

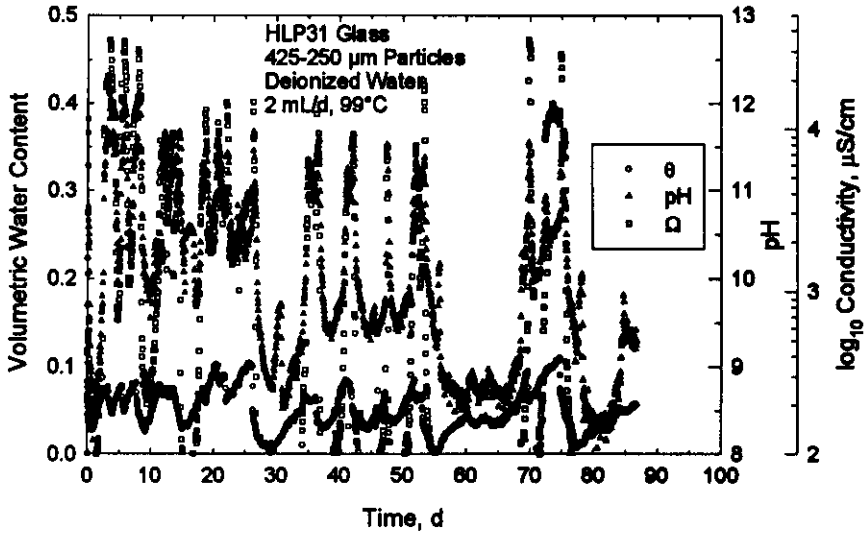


Figure 27. Electronically Monitored Test Metrics in PUF Test with HLP-31 Glass at 99°C and 2 mL/d Flow Rate

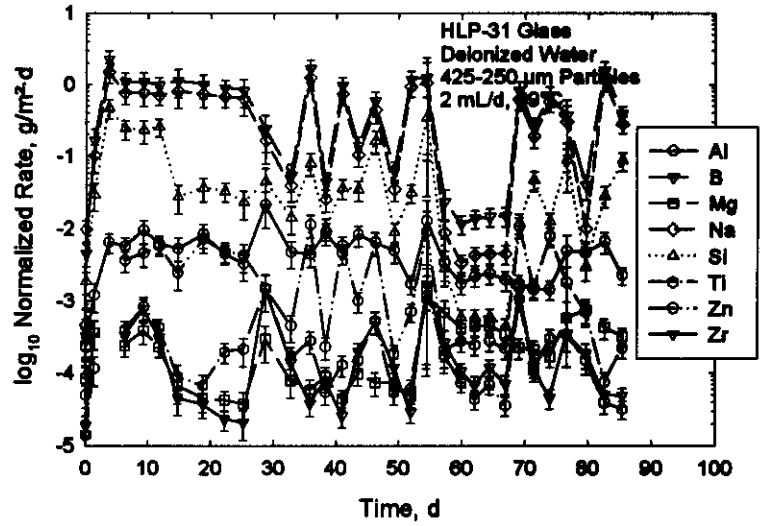


Figure 28. Normalized Release Rates in PUF Test with HLP-31 Glass

Still, the results indicate a very rapid rate of reaction on the order of 1 g m^{-2} d^{-1}, which is approximately a factor of 2-3 less than the expected forward reaction rate of this glass at 99°C and the average pH during the test.

2.7 CORRELATION BETWEEN TEST METHODS

In Sections 2.3 through 2.6, a large data set was presented covering a variety of different test methods and wide range of prototypic glass formulations for low-activity waste. The reader

should be aware that this data set is unique in the world in that it covers more test methods more thoroughly than has ever been done before for any waste form, including borosilicate waste glasses. The purpose of this section then is to examine this data set as a whole to determine what correlations, if any may exist between results from the various test methods.

The SPFT experiments stand alone in this data set as the test method is not designed to elucidate differences in the long-term behavior of glasses, as are the other test methods. As illustrated in Figure 29, the forward dissolution rate among a wide range of glass compositions varies very little. Consequently, the forward reaction rate for almost any reasonable BNFL, Inc. glass can be predicted with confidence. However, considerable uncertainty still exists regarding the form of the affinity term in the kinetic rate law for glass dissolution, especially regarding the role, if any, of Al. Insufficient data exist to draw definitive conclusions at this time except that the aluminate ion does appear to have an important role in regulating the kinetics of the glass corrosion reaction.

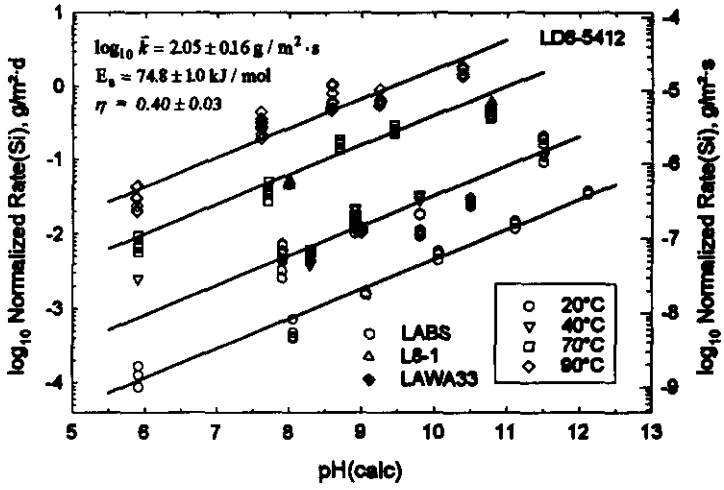


Figure 29. Forward Reaction Rate as a Function of Temperature and Solution pH for Four Different Glass Compositions

In Figure 30, we plot the normalized B and Na release data at 1000 h in the PCT versus the VHT corrosion rate at 200°C for the TFA matrix of 55 ILAW glasses. From the resulting random scatter in the data, we conclude that there is no correlation between the test results. This is not surprising because a 1000 h test duration in the PCT, even at a S/V ratio of 20,000 m^{-1}, is not sufficient to enter an accelerated reaction stage for many glasses, as was clearly demonstrated by the PCT results in Figure 11. Normalized releases prior to rate acceleration remain quite low but this does not mean that the glass will maintain good long-term stability. There are also technical difficulties in assessing normalized release (or glass corrosion rates) with the PCT method. Once a rate acceleration occurs, sufficiently large amounts of glass react that changes in surface area can be significant. Water consumption from hydrolysis of the glass and incorporation into secondary phases results in a time varying and essentially unknown S/V ratio. The stochastic nature

of rate accelerations often means that few data points are available from which to compute a rate once a rate acceleration does occur. For these reasons and the higher degree of acceleration available with the VHT and PUF test methods, they are preferred methods for evaluating long-term glass stability. Qualitatively however, the longer-term PCT data shown in Figure 11 are consistent with the results from PUF and VHT tests. The poorest performing glass is clearly HAN28, which also ranked lowest in VHT and PUF tests, and the best performing glass is LAWABP1. However, PCT data with HLP-31 show high initial release values, which would rank it poorer when compared with LAWA23. This is opposite from VHT and PUF test results with these glasses. Still, at longer test durations in the PCT, a rate acceleration is observed with LAWA23 glass, just as it was observed in PUF tests, which would change its relative ranking.

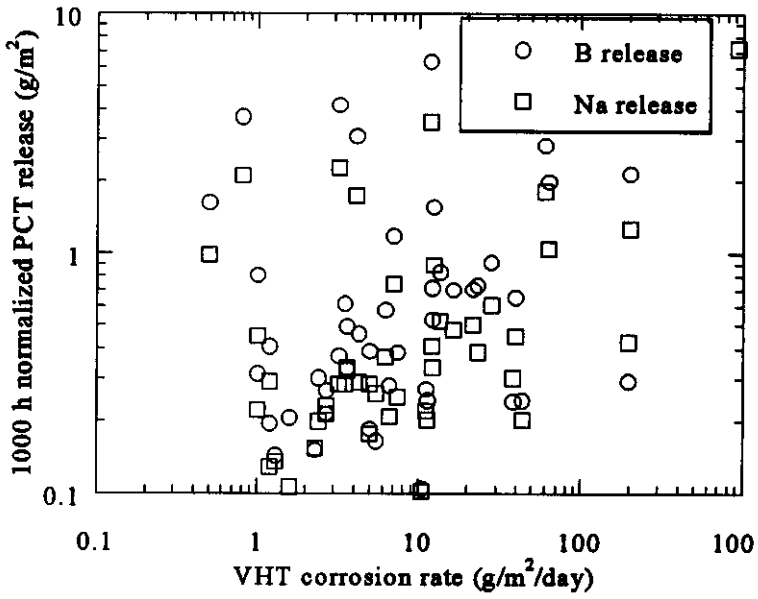


Figure 30. Comparison of 1000 h PCT Normalized Release With 200°C VHT Corrosion Rate

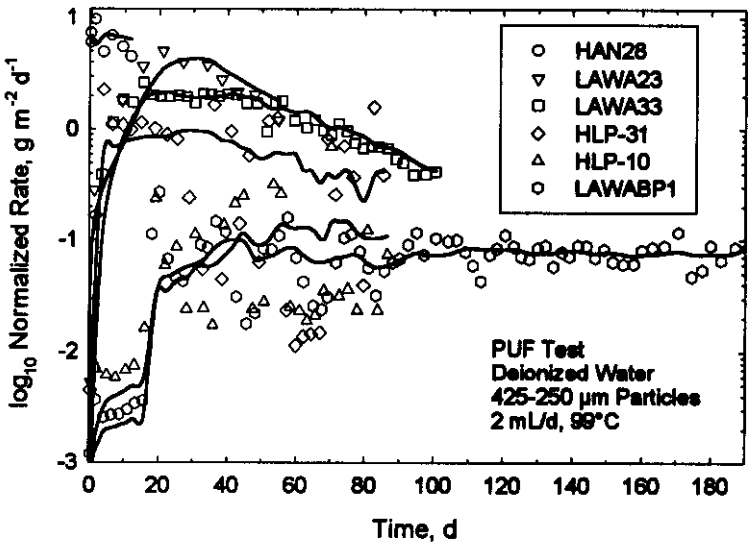


Figure 31. Comparison of Glass Corrosion Rate in PUF Tests at 99°C and 2 mL/d

In Figure 31, the normalized release rate of B in PUF tests with six different ILAW glass formulations are compared (Na was used for HAN28 as this glass does not contain B). The lines on the figure were computed by using a 4-point moving average for the HAN28, LAWA23, and LAWA33 glasses and a 10-point moving average for the HLP-10, HLP-31, and LAWABP1

glasses. The difference in dissolution rate as a function of composition and time become immediately obvious with the order being HAN28>LAWA23>LAWA33≥HLP-31> HLP-10≈LAWABP1.

A comparison of the peak dissolution rate observed in PUF tests versus the dissolution rate estimated in VHTs at 200°C is plotted in Figure 32. The peak dissolution rate was used from the PUF tests because for the glasses with high dissolution rates, the apparent corrosion decreases with time as the total unreacted glass surface area decreases and this is not taken into account in the corrosion rate calculation. The results suggest a good correlation between the VHT and PUF test results ($R^2 = 0.91$). Given that similar secondary phases formed in both types of tests, a correlation between the results from these highly accelerated tests might be expected. We conclude that when the results from all three accelerated test methods, VHT, PCT, and PUF are viewed as whole, a remarkably consistent picture about the long-term performance of ILAW glasses emerges.

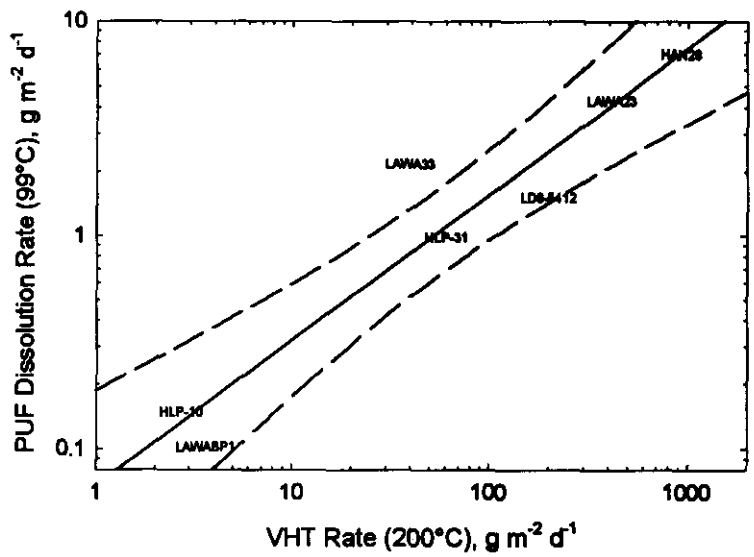


Figure 32. Comparison of Glass Corrosion Rate in PUF Tests at 99°C and VHT Tests at 200°C. Solid line is the regressed fit and the dashed lines are the 95% confidence interval.

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3.0 STORM CODE INPUTS

3.1 MULTIPHASE FLOW INPUT

Multiphase flow input data to STORM consists of entries for 1) lithographic units, 2) hydraulic properties, 3) hydraulic initial conditions, and 3) hydraulic boundary conditions. These data are to be principally defined from facility design documents, the near-field hydraulic properties data package, or the far-field hydraulic properties data package [3]. STORM will be used to compute the flow-field in the near-field region based upon hydraulic properties for the materials, specified initial and boundary conditions, and water consumption/release from chemical reactions.

3.1.1 Material Zonation

To establish a consistent framework for overlaying a computational grid on the spatial domain of interest, a set of material zones or lithographic units are established with similar hydrogeological and geochemical properties. These zones are usually related to disposal design components, geologic formations, or geologic facies determined from borehole analyses. However, because limited information is available on physical properties at a given spatial resolution, material zones may also include combinations of materials that are assigned uniform hydraulic and/or chemical properties. Classification of these materials into appropriate zones will be performed as a part of the near-field hydraulics data package [3]. The material zones that will be considered are:

- Waste glass
- Waste package container
- Filler material between waste packages
- Portland concrete
- Back-filled soil
- Glass conditioning layer
- Hanford sands
- Hanford gravels
- Ringold formation

3.1.2 Material Hydraulic Properties

The hydraulic properties for each material zone in the simulation will be determined as a part of the near-field hydraulics data package [3]. For each defined rock/soil type, the following data is needed:

- Nonhysteretic van Genuchten parameters
  - "α" parameter, units (1/m)
  - "n" parameter
  - Minimum saturation
  - "m" parameter
- Particle density
- Porosity
- Specific storativity
- Compressibility
- Tortuosity
- Intrinsic permeability
- Intrinsic permeability function options:
  - Constant
  - Kozeny and Carmen
  - Fair and Hatch
- Aqueous Permeability function options:
  - Constant
  - Mualem or Burdine parameter
  - Van Genuchten "m" parameter
  - Tabular w/ water content
- Gas Permeability function options:
  - Constant
  - Mualem or Burdine parameter
  - Van Genuchten "m" parameter
  - Tabular

3.1.3 Hydraulic Initial Conditions

Initial hydraulic conditions for each material zone will be provided from either the near-field or far-field hydraulics data package [3] as follows:

- Water content
- Water flux
- Dissolved gas content of aqueous phase
- Gas pressure

- Relative humidity of gas phase
- Temperature

3.1.4 Hydraulic Boundary Conditions

The hydraulic conditions of the upper boundary will be determined as a part of the recharge data package [26]. For the base analysis case, the upper boundary will be defined just below the capillary break. Sensitivity cases examining the effects of mass redistribution on the hydraulic properties of the capillary barrier will require setting the upper boundary above the barrier. The following data is needed as a function of time and space along the boundary:

- Water content
- Water flux
- Dissolved gas content of aqueous phase
- Gas pressure
- Relative humidity of gas phase
- Temperature

The side boundaries will be placed at axes of symmetry so that they can be assumed to be no-flow boundaries. The lower boundary will be placed far enough below the waste form so that vertical concentration gradients are small. For hydraulic boundary conditions at this lower boundary, free drainage under gravity will be assumed.

3.2 REACTIVE TRANSPORT INPUT

3.2.1 Lithology

For each material zone, a list of the solid species that comprise that material is required. For each of these solid species in each material zone, the following data is needed:

- Relative volume
- Particle radius

Values for these variables are listed in Table 10 and Table 11. The waste package is assumed to consist of 304L Stainless Steel container filled with LAWABP1 waste glass. For Hanford sands and backfill soil, petrologic and particle size data was obtained from the near-field hydrology data package [3]. The filler material between waste packages is assumed to be quartz sand. The vault concrete is assumed to consist of back-filled soil mixed with 15% Portland cement.

Table 10. Relative Volume of Solid Species in Material Zones

	ILAW Glass	304L SS	Quartz	Albite High	K-Feldspar	Illite	Portlandite
Waste Package	0.99	0.01					
Filler			1				
Vault Concrete			0.34	0.34	0.085	0.085	0.15
Back-filled Soil			0.4	0.4	0.100	0.100	
Hanford Sands			0.4	0.4	0.100	0.100	

Table 11. Particle Radius (m) of Solid Species in Material Zones

	ILAW Glass	304L SS	Quartz	Albite High	K-Feldspar	Illite	Portlandite
Waste Package	5.00E-02	5.00E-02					
Filler			1.00E-04				
Vault Concrete			1.00E-04	1.00E-04	1.00E-04	5.00E-06	1.00E-04
Back-filled Soil			1.00E-04	1.00E-04	1.00E-04	5.00E-06	
Hanford Sands			1.00E-04	1.00E-04	1.00E-04	5.00E-06	

The assumed particle radius values for Hanford sediments and backfill soil are consistent with petrologic and particle size data obtained from laboratory-measured values [27]. The composition of the filler material between waste packages is assumed to be the same as that for the backfill soil. For the Portland cement, we have simply assumed that the material is heavily degraded into a rubble [28] with consistency similar to surrounding soil. Comparatively, the glass is assumed to have an average 500 times larger radius. This is consistent with the expected sparse degree of glass fracturing in the waste package based on prior experience with high-level waste glasses [29,30]. Fracturing is expected to increase the glass surface area a maximum of 10X over geometric.

3.2.2 Aqueous Species

Aqueous species are the cations, anions, or neutral complexes present in the aqueous phase. For each aqueous species, the following data is needed:

- Molecular Weight
- Charge
- Hard core diameter
- Number of elements in aqueous species
- Stoichiometric coefficient of each element

The aqueous species listed in Table 12 were identified by simulating the dissolution of LAWABP1 glass (along with a trace amount of calcite) in deionized water at 15°C with the EQ3/6 code package [31]. All data were obtained from the EQ3/6 data0.com.R8 database [32]. The simulations were not intended to be representative of disposal system conditions. The intent here was only to make use of the EQ3/6 software to extract a subset of aqueous (and solid) species from the large thermodynamic database that were relevant for ILAW simulations. Since LAWABP1 glass contains all of the elements that are currently expected to be part of the final ILAW product produced by BNFL, Inc, and adding calcite caused the software to load Ca species that might be important in a disposal system with a concrete vault, the list of aqueous species given in Table 12 is expected to be reasonably complete. However, for conducting actual disposal system simulations, it will be possible to exclude a number of these species from the simulation because their concentration will be extremely small over the range of chemical conditions anticipated for the ILAW disposal system.

Table 12. Aqueous Species Produced by the Dissolution of Calcite and LAWABP1 Glass Containing Trace Amounts of Tc, Se, U and Pu in Deionized Water

Species	Mol.Wt.	Charge	Hard Core Diameter	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element
Al(OH)2+	60.996	1	4	3	1	Al	2	H	2	O		
Al13O4(OH)24(7+)	822.934	7	6	3	13	Al	24	H	28	O		
AlO2-	58.98	-1	4	2	1	Al	2	O				
B(OH)3(aq)	61.833	0	3	3	1	B	3	H	3	O		
BO2-	42.81	-1	4	2	1	B	2	O				
Ca++	40.08	2	6	1	1	Ca	1					
CaB(OH)4+	118.92	1	4	4	1	B	1	Ca	4	H	4	O
CaCO3(aq)	100.087	0	0	3	1	C	1	Ca	3	O		
CaCl+	75.53	1	4	2	1	Ca	1	Cl				
CaF+	59.076	1	4.0	2	1	Ca	1	F				
CaHCO3+	101.095	1	4.0	4	1	C	1	Ca	1	H	3	O
CaHPO4(aq)	136.057	0	3.0	4	1	Ca	1	H	4	O	1	P
CaOH+	57.085	1	4.0	3	1	Ca	1	H	1	O		
CaPO4-	135.049	-1	4.0	3	1	Ca	4	O	1	P		
CaSO4(aq)	136.142	0	0.0	3	1	Ca	4	O	1	S		
H2SiO4--	94.099	-2	4	3	2	H	4	O	1	Si		
H4(H2SiO4)4----	380.428	-4	4	3	12	H	16	O	4	Si		
H6(H2SiO4)4--	382.444	-2	4	3	14	H	16	O	4	Si		
HAlO2(aq)	59.988	0	3	3	1	Al	1	H	2	O		
HCO3-	61.017	-1	4	3	1	C	1	H	3	O		
HCrO4-	117.002	-1	4	3	1	Cr	1	H	4	O		
HF(aq)	20.006	0	3	2	1	F	1	H				
HPO4--	95.979	-2	4	3	1	H	4	O	1	P		
HSiO3-	77.092	-1	4	3	1	H	3	O	1	Si		
K+	39.098	1	3	1	1	K						
KCl(aq)	74.551	0	0	2	1	Cl	1	K				
KHPO4-	135.078	-1	4	4	1	H	1	K	4	O	1	P
KOH(aq)	56.106	0	0	3	1	H	1	K	1	O		
KSO4-	135.162	-1	4	3	1	K	4	O	1	S		
La+++	138.905	3	9	1	1	La						
Mg++	24.305	2	8	1	1	Mg						
MgB(OH)4+	103.145	1	4	4	1	B	4	H	1	Mg	4	O
MgCl+	59.758	1	4	2	1	Cl	1	Mg				
MgCO3(aq)	84.314	0	0	3	1	C	1	Mg	3	O		

Table 12. Aqueous Species Produced by the Dissolution of Calcite and LAWABP1 Glass Containing Trace Amounts of Tc, Se, U and Pu in Deionized Water

Species	Mol.Wt.	Charge	Hard Core Diameter	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element
MgF+	43.303	1	4	2	1	F	1	Mg				
MgHCO3+	85.322	1	4	4	1	C	1	H	1	Mg	3	O
MgHPO4(aq)	120.284	0	3	4	1	H	1	Mg	4	O	1	P
MgPO4-	119.276	-1	4	3	1	Mg	4	O	1	P		
MgSO4(aq)	120.369	0	3	3	1	Mg	4	O	1	S		
Na+	22.99	1	4	1	1	Na						
NaAlO2(aq)	81.97	0	3	3	1	Al	1	Na	2	O		
NaB(OH)4(aq)	101.83	0	3	4	1	B	4	H	1	Na	4	O
NaCl(aq)	58.442	0	3	2	1	Cl	1	Na				
NaCO3-	82.999	-1	4	3	1	C	1	Na	3	O		
NaF(aq)	41.988	0	0	2	1	F	1	Na				
NaHCO3(aq)	84.007	0	3	4	1	C	1	H	1	Na	3	O
NaHPO4-	118.969	-1	4	4	1	H	1	Na	4	O	1	P
NaHSiO3(aq)	100.081	0	0	4	1	H	1	Na	3	O	1	Si
NaOH(aq)	39.997	0	3	3	1	H	1	Na	1	O		
NaSO4-	119.053	-1	4	3	1	Na	4	O	1	S		
O2(aq)	31.999	0	3	1	2	O						
OH-	17.007	-1	3	2	1	H	1	O				
PO4---	94.971	-3	4	2	4	O	1	P				
PuO2(CO3)2--	396.017	-2	4	3	2	C	8	O	1	Pu		
SeO4--	142.958	-2	4	2	4	O	1	Se				
SiO2(aq)	60.084	0	3	2	2	O	1	Si				
SO4--	96.064	-2	4	2	4	O	1	S				
TcO4-	161.998	-1	4	2	4	O	1	Tc				
Ti(OH)4(aq)	115.909	0	3	3	4	H	4	O	1	Ti		
UO2(CO3)3----	450.055	-4	4	3	3	C	11	O	1	U		
Zn(OH)3-	116.412	-1	4	3	3	H	3	O	1	Zn		
Zn(OH)4--	133.419	-2	4	3	4	H	4	O	1	Zn		
Zn++	65.39	2	6	1	1	Zn						
ZnCl+	100.843	1	4	2	1	Cl	1	Zn				
ZnCl2(aq)	136.295	0	0	2	2	Cl	1	Zn				
ZnCl3-	171.748	-1	4	2	3	Cl	1	Zn				
ZnF+	84.388	1	4	2	1	F	1	Zn				

Table 12. Aqueous Species Produced by the Dissolution of Calcite and LAWABP1 Glass Containing Trace Amounts of Tc, Se, U and Pu in Deionized Water

Species	Mol.Wt.	Charge	Hard Core Diameter	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element
ZnHCO3+	126.407	1	4	4	1	C	1	H	3	O	1	Zn
ZnHPO4(aq)	161.369	0	3	4	1	H	4	O	1	P	1	Zn
ZnOH+	82.397	1	4	3	1	H	1	O	1	Zn		
ZnPO4-	160.361	-1	4	3	4	O	1	P	1	Zn		
ZnSO4(aq)	161.454	0	0	3	4	O	1	S	1	Zn		
Zr(OH)4(aq)	159.253	0	3	3	4	H	4	O	1	Zr		

3.2.3 Gas Species

Gas species are compounds such as CO_2 and O_2 that make up the air phase in STORM simulations. For each gas species, the following data is needed:

- Molecular Weight
- Number of elements in gaseous species
- Stoichiometric coefficient of each element

The gaseous species listed in Table 13 are the only ones currently expected to significantly influence the chemical environment in the near and far field. The listed data were obtained from the EQ3/6 data0.com.R8 database [32].

Table 13. Gaseous Species Important for Conducting STORM Code Simulations

Species	*Mol.Wt. g mol^{-1}*	*No. Elements*	*Moles*	*Element*	*Moles*	*Element*
CO2(g)	44	2	1	C	2	O
O2(g)	31.999	1	2	O		

3.2.4 Secondary Mineral Phases

3.2.4.1 Mineral Selection

Secondary minerals are solid phases that precipitate from a supersaturated aqueous solution. For each secondary mineral species, the following data is needed:

- Mass Density (mg m^{-3})
- Stoichiometric coefficient of each element

The mass density is obtained by dividing the molecular weight by the molar volume of the species. A list of potential secondary minerals was identified (see Table 14) by simulating the dissolution of LAWABP1 glass in deionized water at 15°C with the EQ3/6 code package [31] and the data0.com.R8 database [32]. Because LAWABP1 glass contains all of the elements that are currently expected to be part of the final ILAW product produced by BNFL, Inc, the list of secondary phases given in Table 14 is expected to be reasonably complete. However, further testing with BNFL Inc. glasses will likely reveal other secondary phases that will need to be added.

A large number of the phases listed in Table 14 can be eliminated from consideration in STORM simulations because: 1) formation of the phase is kinetically prohibited at the disposal system temperature of 15°C, 2) selection of the phase would violate the Gibbs phase rule, 3) simulations show that allowing the phase to form is inconsistent with a large body of laboratory test data with borosilicate glasses, or 4) the phase is unstable over the range of chemical environments expected for the ILAW disposal system. A final set of phases to be included in STORM simulations with LAWABP1 glass was determined by modeling the solution chemistry observed in PCT experiments with the EQ3/6 code. The results are shown in Figure 33. The agreement with the experimental data is extraordinarily good. The predicted secondary phase paragenesis is provided in Figure 34. However, it was necessary to adjust the log K upward for several of the phases [labeled as amorphous, e.g. $La(OH)_3(am)$] to match the observed solution concentration values. This is a consequence of the fact that amorphous solids rather than their crystalline analogs often form in laboratory experiments with waste glasses. The amorphous solids are typically much more soluble and this is reflected in the equilibrium constant. The final secondary phase reaction network and the associated log K values are provided in Table 15.

Herschelite has been identified as a ubiquitous reaction product in PUF and VHT tests with a large number of BNFL, Inc. glass formulations, including LAWABP1. Because this phase is thought to be principally responsible for dissolution rate accelerations observed during testing, inclusion of this phase in the reaction network is mandatory. However, a solubility product for this phase is not included in the current thermodynamic database for EQ3/6 nor has a measured value been reported. Consequently, it was necessary to estimate a log K for herschelite. The estimation method we used is discussed in the next section.

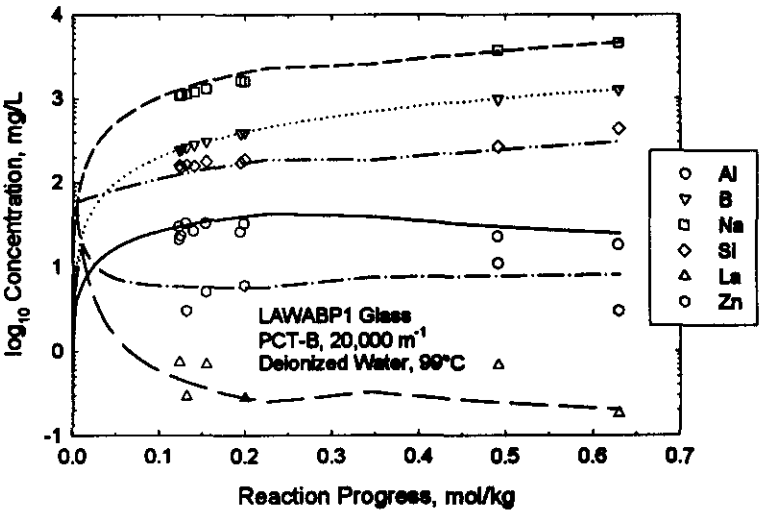

Figure 33. Comparison of PCT Solution Concentration Data with the Solution Composition Calculated with the EQ3/6 Code

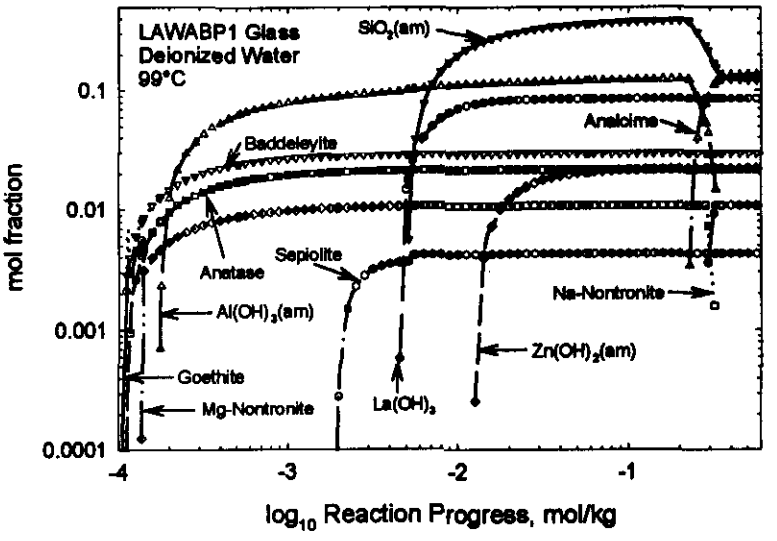

Figure 34. Predicted Paragenetic Sequence of Alteration Phases Formed During the Reaction of LAWABP1 Glass in Deionized Water. PuO_2 and soddyite were also predicted to form. However, they are not shown because of the very small mol fractions associated with these phases.

3.2.4.2 Solubility Product for Herschelite

The composition of herschelite forming from corrosion of a sample of LAWA33 glass was determined using EDS coupled to a SEM. From these data the chemical formula for herschelite was calculated to be $Na_{1.62}K_{0.50}Al_{2.26}Si_{4.00}O_{12.45}$ $6H_2O$. The temperature dependent solubility product was calculated using the approach outlined by Mattigod and Kittrick [33]. In this approach the temperature dependence of solubility of a mineral is expressed in the form:

Table 14. Secondary Minerals of Potential Importance in Simulating the Dissolution of LAWABP1 Glass in Deionized Water at 15°C

Species	Mol.Wt.	Molar Volume	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element
Albite	262.2	100.2	4	1	Al	1	Na	8	O	3	Si				
Albite high	262.2	100.4	4	1	Al	1	Na	8	O	3	Si				
Albite low	262.2	100	4	1	Al	1	Na	8	O	3	Si				
Alunite	414.2	293.6	5	3	Al	6	H	1	K	14	O	2	S		
Ameslte-14A	557.3	205.4	5	4	Al	8	H	4	Mg	18	O	2	Si		
Analcime	201.2	89.1	4	0.96	Al	0.96	Na	6	O	2.04	Si				
Andalusite	162	51.5	3	2	Al	5	O	1	Si						
Anthophyllite	780.8	264.4	4	2	H	7	Mg	24	O	8	Si				
Antigorite	4535.9	1749.1	4	62	H	48	Mg	147	O	34	Si				
Arcanite	174.2	500	3	2	K	4	O	1	S						
Artinite	196.6	96.9	4	1	C	8	H	2	Mg	8	O				
Baddeleyite	123.2	500	2	2	O	1	Zr								
Beidellite-H	360.2	130.7	4	2.33	Al	2.33	H	12	O	3.67	Si				
Beidellite-K	372.8	133.7	5	2.33	Al	2	H	0.33	K	12	O	3.67	Si		
Beidellite-Mg	363.9	123.1	5	2.33	Al	2	H	0.165	Mg	12	O	3.67	Si		
Beidellite-Na	367.5	130.5	5	2.33	Al	2	H	0.33	Na	12	O	3.67	Si		
Berlinite	121.9	500	3	1	Al	4	O	1	P						
Boehmite	59.9	19.5	3	1	Al	1	H	2	O						
Borax	381.3	222.6	4	4	B	20	H	2	Na	17	O				
Boric acid	61.8	43	3	1	B	3	H	3	O						
Brucite	58.3	24.6	3	2	H	1	Mg	2	O						
Celadonite	396.7	157.1	6	1	Al	2	H	1	K	1	Mg	12	O	4	Si
Chalcedony	60	22.6	2	2	O	1	Si								
Chrysotile	277.1	108.5	4	4	H	3	Mg	9	O	2	Si				
Clinochlore-14A	555.7	207.1	5	2	Al	8	H	5	Mg	18	O	3	Si		
Clinochlore-7A	555.7	211.5	5	2	Al	8	H	5	Mg	18	O	3	Si		
Clinoptilolite-K	1410.4	500	6	3.45	Al	0.017	Fe	21.844	H	3.467	K	46.922	O	14.533	Si
Clinoptilolite-Na	1354.6	500	6	3.45	Al	0.017	Fe	21.844	H	3.467	Na	46.922	O	14.533	Si
Clinoptilolite-dehy-K	1213.7	544.7	5	3.45	Al	0.017	Fe	3.467	K	36	O	14.533	Si		
Clinoptilolite-dehy-Na	1157.8	544.7	5	3.45	Al	0.017	Fe	3.467	Na	36	O	14.533	Si		
Clinoptilolite-hy-K	1348.8	500	6	3.45	Al	0.017	Fe	14.998	H	3.467	K	43.499	O	14.533	Si
Clinoptilolite-hy-Na	1353.8	500	6	3.45	Al	0.017	Fe	21.754	H	3.467	Na	46.877	O	14.533	Si

Table 14. Secondary Minerals of Potential Importance in Simulating the Dissolution of LAWABP1 Glass in Deionized Water at 15°C

Species	Mol.Wt.	Molar Volume	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element
Coesite	60	20.6	2	2	O	1	Si								
Cordierite anhyd	584.9	233.2	4	4	Al	2	Mg	18	O	5	Si				
Cordierite hydr	602.9	241.2	5	4	Al	2	H	2	Mg	19	O	5	Si		
Corundum	101.9	25.5	2	2	Al	3	O								
Cristobalite(alpha)	60	25.7	2	2	O	1	Si								
Cristobalite(beta)	60	27.3	2	2	O	1	Si								
Cronstedtite-7A	399.5	500	4	4	Fe	4	H	9	O	1	Si				
Dawsonite	143.9	500	5	1	Al	1	C	2	H	1	Na	5	O		
Diaspore	59.9	17.7	3	1	Al	1	H	2	O						
Enstatite	100.3	31.2	3	1	Mg	3	O	1	Si						
Epsomite	246.4	146.8	4	14	H	1	Mg	11	O	1	S				
Fe(OH)3	106.8	34.3	3	1	Fe	3	H	3	O						
Ferrite-Mg	199.9	44.5	3	2	Fe	1	Mg	4	O						
Ferrite-Zn	241	45.2	3	2	Fe	4	O	1	Zn						
Forsterite	140.6	43.7	3	2	Mg	4	O	1	Si						
Gibbsite	78	31.9	3	1	Al	3	H	3	O						
Goethite	88.8	20.8	3	1	Fe	1	H	2	O						
Halite	58.4	27	2	1	Cl	1	Na								
Hematite	159.6	30.2	2	2	Fe	3	O								
Hercynite	173.8	40.7	3	2	Al	1	Fe	4	O						
Herschelite	259.4	-	6	2.26	Al	12	H	0.5	K	1.62	Na	18.45	O	4	Si
Hexahydrite	228.4	132.5	4	12	H	1	Mg	10	O	1	S				
Hopeite	458.1	150.7	4	8	H	12	O	2	P	3	Zn				
Hydromagnesite	467.6	208.8	4	4	C	10	H	5	Mg	18	O				
Hydrozincite	549	0	4	2	C	6	H	12	O	5	Zn				
Ice	18	19.6	2	2	H	1	O								
Illite	383.9	500	6	2.3	Al	2	H	0.6	K	0.25	Mg	12	O	3.5	Si
Ilmenite	151.7	500	3	1	Fe	3	O	1	Ti						
Jadeite	202.1	60.4	4	1	Al	1	Na	6	O	2	Si				
Jarosite	500.8	156.7	5	3	Fe	6	H	1	K	14	O	2	S		
Jarosite-Na	484.7	168.4	5	3	Fe	6	H	1	Na	14	O	2	S		
K-Feldspar	278.3	108.8	4	1	Al	1	K	8	O	3	Si				

Table 14. Secondary Minerals of Potential Importance in Simulating the Dissolution of LAWABP1 Glass in Deionized Water at 15°C

Species	Mol.Wt.	Molar Volume	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element
KNaCO3:6H2O	230.1	500	5	1	C	12	H	1	K	1	Na	9	O		
KTcO4	201	500	3	1	K	4	O	1	Tc						
Kalicinite	100.1	46.1	4	1	C	1	H	1	K	3	O				
Kalsilite	158.1	59.8	4	1	Al	1	K	4	O	1	Si				
Kaolinite	258.1	99.5	4	2	Al	4	H	9	O	2	Si				
Kieserite	138.3	56.6	4	2	H	1	Mg	5	O	1	S				
Kyanite	162	44	3	2	Al	5	O	1	Si						
Lansfordite	174.3	100.8	4	1	C	10	H	1	Mg	8	O				
Magnesite	84.3	28	3	1	C	1	Mg	3	O						
Magnetite	231.5	44.5	2	3	Fe	4	O								
Maximum Microcline	278.3	108.7	4	1	Al	1	K	8	O	3	Si				
Mirabilite	322.1	500	4	20	H	2	Na	14	O	1	S				
Montmor-K	372.3	500	6	1.67	Al	2	H	0.33	K	0.33	Mg	12	O	4	Si
Montmor-Mg	363.4	500	5	1.67	Al	2	H	0.495	Mg	12	O	4	Si		
Montmor-Na	367	500	6	1.67	Al	2	H	0.33	Mg	0.33	Na	12	O	4	Si
Muscovite	398.3	140.7	5	3	Al	2	H	1	K	12	O	3	Si		
Na2CO3	105.9	41.8	3	1	C	2	Na	3	O						
Na2CO3:7H2O	232	153.7	4	1	C	14	H	2	Na	10	O				
Na2SiO3	122	50.8	3	2	Na	3	O	1	Si						
Na4UO2(CO3)3	542	500	4	3	C	4	Na	11	O	1	U				
NaFeO2	110.8	33.4	3	1	Fe	1	Na	2	O						
Na_2ZnSiO_4	203.4	-	4	4	O	2	Na	1	Si	1	Zn				
Nahcolite	84	38.6	4	1	C	1	H	1	Na	3	O				
Natrolite	380.2	169.2	5	2	Al	4	H	2	Na	12	O	3	Si		
Natron	286.1	195.9	4	1	C	20	H	2	Na	13	O				
Natrosilite	182.1	72.5	3	2	Na	5	O	2	Si						
Nepheline	142	54.1	4	1	Al	1	Na	4	O	1	Si				
Nesquehonite	138.3	74.7	4	1	C	6	H	1	Mg	6	O				
Nontronite-H	418	500	5	0.33	Al	2	Fe	2.33	H	12	O	3.67	Si		
Nontronite-K	430.5	500	6	0.33	Al	2	Fe	2	H	0.33	K	12	O	3.67	Si
Nontronite-Mg	421.6	500	6	0.33	Al	2	Fe	2	H	0.165	Mg	12	O	3.67	Si
Nontronite-Na	425.2	500	6	0.33	Al	2	Fe	2	H	0.33	Na	12	O	3.67	Si

Table 14. Secondary Minerals of Potential Importance in Simulating the Dissolution of LAWABP1 Glass in Deionized Water at 15°C

Species	Mol.Wt.	Molar Volume	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element
Oxychloride-Mg	207.1	500	4	1	Cl	11	H	2	Mg	7	O				
Paragonite	382.2	132.5	5	3	Al	2	H	1	Na	12	O	3	Si		
Pentahydrite	210.4	110.7	4	10	H	1	Mg	9	O	1	S				
Periclase	40.3	11.2	2	1	Mg	1	O								
Phlogopite	417.2	149.6	6	1	Al	2	H	1	K	3	Mg	12	O	3	Si
Pu(OH)4	312	500	3	4	H	4	O	1	Pu						
PuO2	275.9	23.8	2	2	O	1	Pu								
PuO2(OH)2	310	500	3	2	H	4	O	1	Pu						
Pyrophyllite	360.3	126.6	4	2	Al	2	H	12	O	4	Si				
Quartz	60	22.6	2	2	O	1	Si								
Ripidolite-14A	618.8	209.6	6	2	Al	2	Fe	8	H	3	Mg	18	O	3	Si
Ripidolite-7A	618.8	215.3	6	2	Al	2	Fe	8	H	3	Mg	18	O	3	Si
Rutile	79.8	18.8	2	2	O	1	Ti								
Sanidine high	278.3	109	4	1	Al	1	K	8	O	3	Si				
Saponite-H	379.2	136.8	5	0.33	Al	2.33	H	3	Mg	12	O	3.67	Si		
Saponite-K	391.8	139.8	6	0.33	Al	2	H	0.33	K	3	Mg	12	O	3.67	Si
Saponite-Mg	382.9	133.6	5	0.33	Al	2	H	3.165	Mg	12	O	3.67	Si		
Saponite-Na	386.4	136.6	6	0.33	Al	2	H	3	Mg	0.33	Na	12	O	3.67	Si
Sellaite	62.3	19.6	2	2	F	1	Mg								
Sepiolite	647.8	285.6	4	14	H	4	Mg	23	O	6	Si				
SiO2(am)	60	29	2	2	O	1	Si								
Sillimanite	162	49.9	3	2	Al	5	O	1	Si						
Smithsonite	125.3	28.2	3	1	C	3	O	1	Zn						
Spinel	142.2	39.7	3	2	Al	1	Mg	4	O						
Starkeyite	192.4	95.7	4	8	H	1	Mg	8	O	1	S				
Strengite	186.8	500	4	1	Fe	4	H	6	O	1	P				
Sylvite	74.5	37.5	2	1	Cl	1	K								
Talc	379.2	136.2	4	2	H	3	Mg	12	O	4	Si				
Thenardite	142	53.3	3	2	Na	4	O	1	S						
Thermonatrite	124	54.9	4	1	C	2	H	2	Na	4	O				
Tridymite	60	500	2	2	O	1	Si								
Zincite	81.3	500	2	1	O	1	Zn								

Table 14. Secondary Minerals of Potential Importance in Simulating the Dissolution of LAWABP1 Glass in Deionized Water at 15°C

Species	Mol.Wt.	Molar Volume	No. Elements	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element	Moles	Element
Zircon	183.3	500	3	4	O	1	Si	1	Zr						
Zn(OH)2(beta)	99.4	500	3	2	H	2	O	1	Zn						
Zn(OH)2(epsilon)	99.4	500	3	2	H	2	O	1	Zn						
Zn(OH)2(gamma)	99.4	500	3	2	H	2	O	1	Zn						
ZnSO4:6H2O	269.5	500	4	12	H	10	O	1	S	1	Zn				
ZnSO4:7H2O	287.5	500	4	14	H	11	O	1	S	1	Zn				
ZnSO4:H2O	179.4	500	4	2	H	5	O	1	S	1	Zn				

Table 15: Secondary Phase Reaction Network for LAWABP1 Glass

Reaction	log K (15°C)
$Al(OH)_3(am)$ Φ $AlO_2^- + H^+ + H_2O$	-13.10
Analcime Φ $0.96AlO_2^- + 0.96Na^+ + 2.04SiO_2(aq)$	-9.86
Anatase + $2H_2O$ Φ $Ti(OH)_4(aq)$	-6.64
Baddeleyite + $2H_2O$ Φ $Zr(OH)_4(aq)$	-9.29
Goethite + H_2O Φ $Fe(OH)_3(aq)$	-11.09
Herschelite Φ $1.62Na^+$ (aq) + $0.50K^+$ (aq) + $2.26AlO_2^-$ + $4SiO_2(aq)$ + $0.14H^+$ + $5.93H_2O$	-40.94
$La(OH)_3(am) + 3H^+$ Φ $3H_2O + La^{3+}$	22.55
Nontronite-K + $2H_2O$ Φ $0.330AlO_2^- + 2Fe(OH)_3(aq) + 0.330K^+ + 3.67SiO_2(aq)$	-43.70
Nontronite-Mg + $2H_2O$ Φ $0.330AlO_2^- + 2Fe(OH)_3(aq) + 0.165Mg^{2+} + 3.67SiO_2(aq)$	-43.36
Nontronite-Na + $2H_2O$ Φ $0.330AlO_2^- + 2Fe(OH)_3(aq) + 0.330Na^+ + 3.67SiO_2(aq)$	-43.33
$PuO_2 + H^+ + 0.25O_2(g)$ Φ $PuO_2^+ + 0.5H_2O$	-5.18
Sepiolite + $8H^+$ Φ $4Mg^{2+} + 6SiO_2(aq) + 11H_2O$	31.29
$SiO_2(am)$ Φ $SiO_2(aq)$	-2.85
Soddyite Φ $2UO_2(OH)_2(aq) + SiO_2(aq)$	-20.24
$Zn(OH)_2(am) + 2H^+$ Φ $2H_2O + Zn^{2+}$	14.44

$$\log K_T = 1/2.303\ R[A \ln T + BT + C/T^2 + D/T + E) \quad (5)$$

where K_T is the solubility product at temperature T (°K), R is the gas constant, $A = \Delta a$, $B = \Delta b/2$, $C = \Delta c/2$, $D = [\Delta a\ T_r + (\Delta b/2)\ T_r^2 - \Delta c/T_r - \Delta S^0\ T_r + RT \ln K_{Tr}]$, and $E = [-\Delta a - \Delta a \ln T_r - \Delta b\ T_r + (\Delta c/2\ T_r^2) + \Delta S^0]$, and Δa, Δb, and Δc are the heat capacity of reaction coefficients from Meier-Kelly equation

$$\Delta C_p = \Delta a + \Delta b\ T + \Delta c/T^2 \quad (6)$$

where ΔS^0 = entropy of reaction
K_{Tr} = solubility product at a reference temperature (298.15 ^{0}K).

The dissolution/precipitation reaction of herschelite is expressed in the form:

$$Na_{1.62}K_{0.50}Al_{2.26}Si_{4.00}O_{12.45}\ 6H_2O\ (solid) + 8.9H^+(aq) = 1.62Na^+(aq) + 0.50K^+(aq) + 2.26Al^{3+}(aq) + 4Si(OH)_4^0(aq) + 2.45H_2O \quad (7)$$

The solubility product for this reaction is expressed as:

$$\log K_T = 1.62 \log Na^+ + 0.50 \log K^+ + 2.26 \log Al^{3+} + 4 \log Si(OH)_4^0 + 8 \log H^+ = 1/2.303\ R[A \ln T + BT + C/T^2 + D/T + E) \quad (8)$$

The sources of thermochemical data used in the calculations are listed in Table 16. The solubility product at reference temperature (298.15 ^{0}K) was calculated from the free energy of formation values listed in Table 1 using the expression

$$\ln K_{298.15} = -\Delta G^o/2.479 \quad (9)$$

where ΔG^o is the free energy of reaction.

Using the data listed in Table 16, the solubility product of herschelite was computed as

$$\log K_T = -11.5438 \ln T + 0.071779T + 8.8225x10^4/T^2 + 1.1881x10^4/T + 15.654 \quad (10)$$

The solubility product for herschelite was calculated at 10 degree temperature intervals starting from 15°C to 95°C. The results are tabulated in Table 2 and graphically represented in Figure 1. The computations showed that the solubility product of herschelite changes by about six orders of magnitude between 15^0 to 95^{0}C indicating significantly higher solubility at higher temperature as compared to its solubility at ambient temperature.

Table 16. Thermochemical Data used in the Calculations

Species	ΔG_f^0 (kJ/mol)	$S^0_{298.15}$ (J/mol deg)	$C_p = a + bT + c/T^2$ (J/mol deg)		
			a	b x10^3	c x 10^{-5}
$Na_{1.62}K_{0.50}Al_{2.26}Si_{4.00}O_{12.45}$ $6H_2O$ (herschelite)	-7405.40	691.41	342.68	841.05	13.10
H_2O (liq)	-237.14	69.91	49.66	54.31	8.44
Na^+ (aq)	-261.90	59.00	0	155.64	0
K^+ (aq)	-282.49	102.50	0	72.80	0
Al^{3+} (aq)	-485.00	-321.70	0	128.03	0
$Si(OH)_4^0$ (aq)	-1308.00	180.00	0	719.65	0

ΔG_f^0 values: herschelite estimated by the method of Mattigod and McGrail [34], for all other species from Robie et al. [35].

$S^0_{298.15}$ values: herschelite estimated by the method of Robinson and Haas [36], for all other species from Wagman et al. (1982).

C_p coefficients: herschelite estimated by the method of Robinson and Haas [36] and fit to MK equation, H_2O from Mattigod and Kittrick [33], for all other aqueous species from Naumov [37].

Table 17. Computed Solubility Product Values of Herschelite as a Function of Temperature

Temp (°K)	Temp (°C)	log K
288.15	15	13.26
298.15	25	12.13
308.15	35	11.11
318.15	45	10.19
328.15	55	9.36
338.15	65	8.61
348.15	75	7.94
358.15	85	7.34
368.15	95	6.80

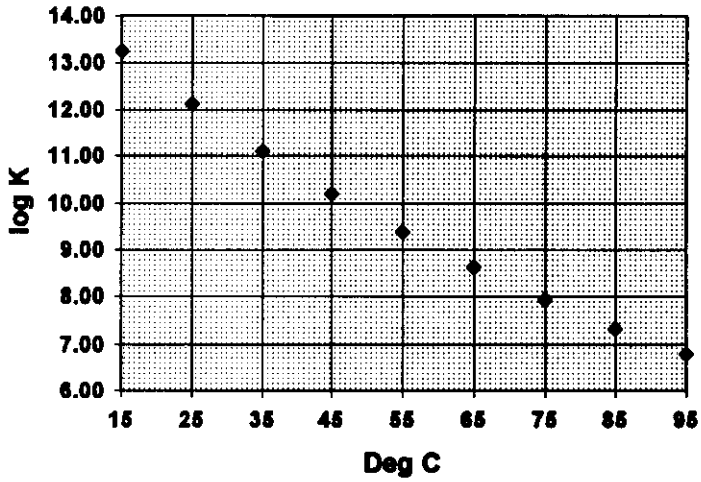

Figure 35. The Temperature Dependence of Solubility Product of Herschelite

3.2.5 Solute Transport Coefficients

For each gaseous and aqueous species, the following data is needed:

- Aqueous diffusion coefficient (m^2 s^{-1})
- Gas diffusion coefficient (m^2 s^{-1})

The diffusion coefficients will be determined as a part of the near-field hydraulics data package [3].

3.2.6 Solute/Solid Interaction

For each gaseous and aqueous species, the following data is needed:

- Solute/solid partitioning coefficient (m^3 kg^{-1})

This coefficient is related to the distribution coefficients (K_d) being provided by the near- and far-field geochemistry data package [27].

3.2.7 Equilibrium Reactions

For each equilibrium reaction, the following data is needed:

- Stoichiometric coefficient of each aqueous species in each reaction
- Equilibrium constant at a temperature of 15°C.

The equilibrium reactions in Table 18 were identified by simulating the dissolution of *LAWABP1 glass in deionized water at 15°C with the EQ3/6 code package* [31] and the data0.com.R8 database [32]. As discussed in Section 3.2.2, it will be possible to exclude a significant number of these species from the simulations because their concentration will be extremely small over the range of chemical conditions anticipated for the ILAW disposal system. Simulations with the STORM code will be performed to define this range of conditions and to justify elimination of an equilibrium reaction. However, because simulations are required, justification for elimination of an equilibrium reaction must be provided in the ILAW PA and not in this data package.

Table 18. Equilibrium reactions of Potential Importance From Dissolution of LAWABP1 Glass Containing Trace Amounts of Tc, Se, U and Pu in Deionized Water at 15°C

log K	Source	Extrapolation Algorithm	Moles	Species	Moles	Species	Moles	Species	Moles	Species	Moles	Species
11.188	[94pok/hel]	supcrt92 [92joh/oel]	-1	Al(OH)2+	-2	H+	1	Al+++				
98.73	[76bae/mes]		-1	Al13O4(OH)24(7+)	-32	H+	28	H2O	13	Al+++		
23.987	[94pok/hel]	supcrt92 [92joh/oel]	-1	AlO2-	-4	H+	1	Al+++				
9.351	[88sho/hel]	supcrt92 [92joh/oel]	-1	BO2-	-1	H2O	-1	H+				
-6.417	[89sho/hel]	supcrt92 [92joh/oel]	-1	CO2(aq)	-1	H2O	1	HCO3-				
-7.755	[82wag/eva, 60kel]	supcrt92 [92joh/oel]	-1	CO2(g)	-1	H2O	1	HCO3-				
10.429	[88sho/hel]	supcrt92 [92joh/oel]	-1	CO3--	-1	H+						
-2.703	[76bae/mes]		-1	Fe(OH)2+	-1	H+	1	Fe++	0.25	O2(g)		
3.627	[76bae/mes]		-1	Fe(OH)3(aq)	-2	H+	1	Fe++	0.25	O2(g)		
13.227	[76bae/mes]		-1	Fe(OH)4-	-3	H+	1	Fe++	0.25	O2(g)		
-7.24	[88sho/hel]	supcrt92 [92joh/oel]	-1	H2PO4-	1	HPO4--						
22.96	[76smi/mar]		-1	H2SiO4--	-2	H+	1	SiO2(aq)				
35.94	[76smi/mar]		-1	H4(H2SiO4)4----	-4	H+	4	SiO2(aq)				
13.64	[76smi/mar]		-1	H6(H2SiO4)4--	-2	H+	4	SiO2(aq)				
17.308	[94pok/hel]	supcrt92 [92joh/oel]	-1	HAlO2(aq)	-3	H+	1	Al+++				
-6.491	[88sho/hel]	supcrt92 [92joh/oel]	-1	HCrO4-	1	H+						
-3.09	[89sho/hel]	supcrt92 [92joh/oel]	-1	HF(aq)	1	H+						
10.101	[94sve]	supcrt92 [92joh/oel]	-1	HSiO3-	-1	H+	1	SiO2(aq)				
1.579	[94sve]	supcrt92 [92joh/oel]	-1	KCl(aq)	1	K+						
-0.78	[89mar/smi]		-1	KHPO4-	1	K+						
14.46	[76bae/mes]		-1	KOH(aq)	-1	H+	1	K+				
-0.871	[94sve]	supcrt92 [92joh/oel]	-1	KSO4-	1	SO4--						
7.347	[80bas]		-1	MgB(OH)4+	-1	H+	1	B(OH)3(aq)	1	Mg++		
0.118	[94sve]	supcrt92 [92joh/oel]	-1	MgCl+	1	Mg++						
7.496	[94sve]	supcrt92 [92joh/oel]	-1	MgCO3(aq)	-1	H+	1	Mg++				
-1.351	[94sve]	supcrt92 [92joh/oel]	-1	MgF+	1	Mg++						
-1.036	[94sve]	supcrt92 [92joh/oel]	-1	MgHCO3+	1	Mg++						
-2.91	[76smi/mar]		-1	MgHPO4(aq)	1	Mg++						
5.733	[74tru/jon]		-1	MgPO4-	-1	H+	1	Mg++				
-2.299	[82mar/smi]	69hel	-1	MgSO4(aq)	1	SO4--						
24.78	[94pok/hel]	supcrt92 [92joh/oel]	-1	NaAlO2(aq)	-4	H+	1	Al+++	1	Na+		

Table 18. Equilibrium reactions of Potential Importance From Dissolution of LAWABP1 Glass Containing Trace Amounts of Tc, Se, U and Pu in Deionized Water at 15°C

log K	Source	Extrapolation Algorithm	Moles	Species	Moles	Species	Moles	Species	Moles	Species	Moles	Species
8.974	[80bas]		-1	NaB(OH)4(aq)	-1	H+	1	B(OH)3(aq)	1	Na+		
0.803	[87sve, 89sho]	supcrt92 [92joh/oel]	-1	NaCl(aq)	1	Na+						
9.821	[82wag/eva]	64cri/cob	-1	NaCO3-	-1	H+	1	Na+				
1.036	[94sve]	supcrt92 [92joh/oel]	-1	NaF(aq)	1	Na+						
-0.237	[82wag/eva]	69hel	-1	NaHCO3(aq)	1	Na+						
-0.92	[89mar/smi]		-1	NaHPO4-	1	Na+						
8.359	[94sve]	supcrt92 [92joh/oel]	-1	NaHSiO3(aq)	-1	H+	1	Na+	1	SiO2(aq)		
15.12	[94pok/hel]	supcrt92 [92joh/oel]	-1	NaOH(aq)	-1	H+	1	Na+				
-0.82	[82mar/smi]		-1	NaSO4-	1	SO4--						
2.816	[89sho/hel]	supcrt92 [92joh/oel]	-1	O2(aq)								
14.344	[88sho/hel]	supcrt92 [92joh/oel]	-1	OH-	-1	H+						
12.418	[88sho/hel]	supcrt92 [92joh/oel]	-1	PO4---	-1	H+						
-1.091	[80lem/tre]	64cri/cob	-1	PuO2(CO3)2--	-4	H+	2	HCO3-	1	Pu++++	0.5	O2(g)
-13.082	[88sho/hel]	supcrt92 [92joh/oel]	-1	SeO4--	0.5	O2(g)						
9.344	[92gre/fug]	64cri/cob	-1	UO2(CO3)3----	-3	H+	1	UO2++				
28.837	[82wag/eva]		-1	Zn(OH)3-	-3	H+	1	Zn++				
41.605	[82wag/eva]		-1	Zn(OH)4--	-4	H+	1	Zn++				
0.055	[94sve]	supcrt92 [92joh/oel]	-1	ZnCl+	1	Zn++						
-0.08	[94sve]	supcrt92 [92joh/oel]	-1	ZnCl2(aq)	1	Zn++						
0.077	[94sve]	supcrt92 [92joh/oel]	-1	ZnCl3-	1	Zn++						
-1.15	[76smi/mar]		-1	ZnF+	1	Zn++						
-1.371	[87bou/bar]		-1	ZnHCO3+	1	Zn++						
-3.26	[76smi/mar]		-1	ZnHPO4(aq)	1	Zn++						
9.29	[87bou/bar]		-1	ZnOH+	-1	H+	1	Zn++				
4.302	[79mat/spo]		-1	ZnPO4-	-1	H+	1	Zn++				
0.021	[82wag/eva]	69hel	-1	ZnSO4(aq)	1	Zn++						
1.228	[74nau/ryz]		-1	Zr(OH)4(aq)	-2	H+	1	Zr(OH)2++				

3.2.8 Kinetic Reactions

For each kinetic reaction, the following data is needed:

- Mass action law type: {full = 1} {reduced = -1} {glass = 0}
- Stoichiometric coefficient of aqueous species in each reaction
- Equilibrium constant at a temperature of 15°C.
- Rate constant of solid reaction

Also, for the glass dissolution reaction only, the following data is needed:

- Stoichiometric coefficient of aqueous species used in equilibrium calculations
- Activation energy of solid reaction
- Exponential factor of solid reaction
- Exponential factor of pH dependence of dissolution reaction

3.2.8.1 Secondary Minerals

A full mass action law type will be used for each mineral except the waste glass. A special glass mass action law type implemented in the STORM code will be used for the glass (see Section 3.2.8.2). Compilations of kinetic rate constants, equivalent to thermodynamic databases for important mineral phases, are not available. Also, the available kinetics data are much more limited as compared with thermodynamic data. For the expected case where kinetic rate constants are not available for an important solid, sufficiently large values will be used to approximate a state of thermodynamic equilibrium with the phase. Alternatively, the specific phase will need to be synthesized and the dissolution/precipitation kinetic rate constants measured. For most instances, we expect to use large enough rate constants to approximate equilibrium conditions, i.e. ensure that the phase will precipitate rapidly if the local chemical environment at a grid node is saturated with respect to the particular phase. This has an additional advantage in that uncertainty in the exact value of a particular rate constant will have little impact on the calculational results.

3.2.8.2 Glass

Because glass dissolution is an irreversible chemical reaction, a special type of mass action law has been implemented in the STORM code to simulate its dissolution [1]. The glass dissolution reaction is written as illustrated for LD6-5412 glass:

$$\text{Glass} + 0.5OH^- + 0.45H_2O = 0.0202K^+ + 0.4208Na^+ + 0.046Ca^{2+} + 0.094BO_2^- + 0.154Al(OH)_3(aq) + 0.2712HSiO_3^- + 0.3348H_2SiO_4^{2-} + 1.6172x10^{-6}TcO_4^{2-} \quad (11)$$

The pH-dependence of the glass dissolution rate is captured with the $0.5OH^-$ term on the left-hand side of Equation (11). The pH dependence for LAWA33 glass was also found to be of order 0.5 from a series of single-pass flow-through experiments, discussed in Section 2.3.2.3. Most glasses exhibit pH-dependence dissolution rates between 0.4 and 0.5 [13]. Consequently, we expect similar behavior for LAWABP1 glass.

The forward dissolution rate constant at 90 and 40°C has been determined by SPFT experiments for LAWABP1 glass (see Section 2.3.2). However, two data points are insufficient to calculate a reliable activation energy. To estimate the intrinsic rate constant at the disposal system temperature of 15°C, we will assume an activation energy of 75 kJ/mol determined by McGrail et al. [13] for LD6-5412 glass and make use of the Arrhenius equation:

$$k_0(T) = \overset{v}{k} 10^{\eta \cdot pH} e^{-E_a/RT} \quad (12)$$

where k_0 is the forward dissolution rate, $\overset{v}{k}$ is the intrinsic rate constant, E_a is the activation energy, R is the gas constant, and T is the temperature. The forward rate constant for LAWABP1 glass at 40°C is 3.4×10^{-3} g m^{-2} d^{-1} (see Section 2.3.2.2) at pH 9. Substituting these values into Equation (12), we find $\log_{10} \overset{v}{k} = 5.54$ g m^{-2} d^{-1}. This estimate for $\overset{v}{k}$ must be considered tentative until sufficient data are available to accurately compute it, as was done for LD6-412 glass shown in Figure 29.

The kinetic rate law formulation in the STORM code uses the above forward rate constant and equilibrium constant for the reaction of the form

$$W_j = A_{m(j)} k_j \left[\prod_{\nu_{ij}<0} (\gamma_i c_i)^{\frac{|\nu_{ij}|}{f_j}} - \prod_{\nu_{ij}>0} (\gamma_i c_i)^{\frac{\nu_{ij}}{f_j}} \Big/ \left(K_j^{eq}\right)^{1/f_j} \right]. \quad (13)$$

SPFT experiments are a relatively new approach for estimating the effective equilibrium constant for waste glasses [11]. In Section 2.3.2.2, preliminary results for LAWABP1 glass were used to estimate a K_g for this glass at 90 and 40°C. These data are plotted in Figure 36. Lacking additional data or a literature precedent for an activation energy associated with K_g, we are forced to rely on only two data points at this time to extrapolate the K_g to 15°C giving $K_g(15°C) = 3.6 \times 10^{-10}$. The apparent activation energy from the plot is approximately 60 kJ/mol, which places it between the E_a for SiO_2(am) of 18 kJ/mol and kaolinite of 100 kJ/mol. We will of course refine the estimated K_g for LAWABP1 glass as additional data become available.

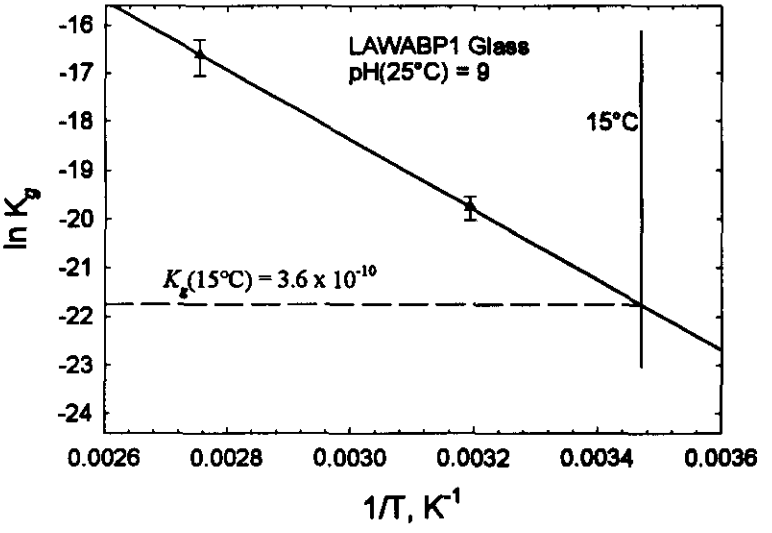

Figure 36. Temperature Dependence of Pseudoequilibrium Constant K_g for LAWABP1 Glass

3.2.9 Initial and Boundary Conditions

For each specified gas species concentration, the following data are needed:

- Partial pressure of gaseous species,

For each specified aqueous species, the following data are needed:

- Specified total concentration
- Stoichiometric coefficient of each aqueous species.

Initial partial pressures of gas species will be specified at typical atmospheric values. Aqueous species concentrations at the upper boundary, and for initial conditions, will be specified as a part of the near-field geochemistry data package [27].

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4.0 CONCLUSION

In this data package, a large body of data is presented on the corrosion behavior of a wide range of prototypic glass forms for low-activity waste. Four test methods, SPFT, PCT, VHT, and PUF were used in combination to examine the corrosion behavior of these glasses over a wide range of conditions. For one of the glasses, LAWABP1, which performed well in each of the tests, more detailed experiments were conducted to derive the parameters necessary to conduct long-term PA calculations with the STORM reactive transport computer code. A summary of the parameters derived from the laboratory testing is provided in Table 19. Because of the limited data available for LAWABP1 glass, extrapolations in temperature were required in many cases using only a few data points. Consequently, the parameters in Table 19 should be viewed as tentative until significantly more experimental data are available. A large number of experiments with LAWABP1 (and four other glass compositions) are underway. As these data become available, revisions to the parameters in Table 19 will be evaluated along with quantitative estimates of uncertainty.

Table 19. Summary of Best Estimate Parameters for LAWABP1 Glass

Parameter	Meaning	Value	Test Method	Evaluation Method
Kinetic Rate Law Parameters				
k^{v}	intrinsic rate constant	3.5×10^{5} g m^{-2} d^{-1}	SPFT	Substitution of regressed coefficients in Eq. (12)
K_g	apparent equilibrium constant for glass based on activity product $a[AlO_2^-] \cdot a[SiO_2(aq)]$	3.6×10^{-10}	SPFT	Linear regression
η	pH power law coefficent	0.5	SPFT	Linear regression
E_a	activation energy of glass dissolution reaction	75 kJ/mol	SPFT	Nonlinear regression [13]
r_x	Na ion-exchange rate	3.5×10^{-6} mol/(m^2·d)	SPFT	Linear regression
Secondary Mineral Phases				
$\log_{10} K_1$	$Al(OH)_3$(am)	-13.10	PCT[a]	log K adjusted to fit PCT data

Table 19. Summary of Best Estimate Parameters for LAWABP1 Glass

Parameter	Meaning	Value	Test Method	Evaluation Method
$\log_{10} K_2$	Analcime	-9.86	PUF[b],VHT[b]	EQ3/6 database
$\log_{10} K_3$	Anatase	-6.64	PCT	log K adjusted to fit PCT data
$\log_{10} K_4$	Baddeleyite	-9.29	PCT	EQ3/6 database
$\log_{10} K_5$	Goethite	-11.09	PCT	EQ3/6 database
$\log_{10} K_6$	Herschelite	-40.94	PUF	Polymer model [34]
$\log_{10} K_7$	$La(OH)_3(am)$	22.55	PCT	log K adjusted to fit PCT data
$\log_{10} K_8$	Nontronite-K	-43.70	PUF	EQ3/6 database
$\log_{10} K_9$	Nontronite-Mg	-43.36	PUF	EQ3/6 database
$\log_{10} K_{10}$	Nontronite-Na	-43.33	PUF	EQ3/6 database
$\log_{10} K_{11}$	PuO_2	-5.18		EQ3/6 database
$\log_{10} K_{12}$	Sepiolite	31.29	PCT	EQ3/6 database
$\log_{10} K_{13}$	$SiO_2(am)$	-2.85	PUF,PCT	EQ3/6 database
$\log_{10} K_{14}$	Soddyite	-20.24		EQ3/6 database
$\log_{10} K_{15}$	$Zn(OH)_2(am)$	14.44	PCT	log K adjusted to fit PCT data
$\log_{10} K_{16}$	Na-Zn-Ti-silicate (TBD)	Unknown	PUF	Not evaluated

[a]Solid phases inferred from modeling - not directly observed.

[b]Solid phases identified from direct observation of reacted solids.

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APPENDIX L

Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment

P. D. Meyer
R. J. Serne

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Pacific Northwest National Laboratory
Richland, Washington

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Summary

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method for disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in near-surface, shallow land burial facilities. The LMHC project to assess the performance of these disposal facilities is the Hanford ILAW Performance Assessment (PA) Activity. The goal of this project is to provide a reasonable expectation that the disposal of the waste is protective of the general public, groundwater resources, air resources, surface water resources, and inadvertent intruders. Achieving this goal will require prediction of contaminant migration from the facilities. This migration is expected to occur primarily via the movement of water through the facilities and the consequent transport of dissolved contaminants in the pore water of the vadose zone.

Pacific Northwest National Laboratory (PNNL) assists LMHC in its performance assessment activities. One of PNNL's tasks is to provide estimates of the physical, hydraulic, and transport properties of the materials comprising the disposal facilities and the disturbed region around them. These materials are referred to as the near-field materials. Their properties are expressed as parameters of constitutive models used in simulations of subsurface flow and transport. In addition to the best-estimate parameter values, information on uncertainty in the parameter values and estimates of the changes in parameter values over time are required to complete the PA. These parameter estimates and information are contained in this report, the Near-Field Hydrology Data Package.

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1.0 Introduction

The Hanford Site was established in 1944 as a U.S. Government nuclear materials production facility. During its history, site missions included nuclear reactor operation, storage and reprocessing of spent nuclear fuel, and management of radioactive and hazardous wastes. Today, activities on the site involve environmental restoration, energy-related research, and technology development. Fifty-five years of operations have resulted in the accumulation of significant quantities of radioactive and hazardous wastes as well as their intentional and unintentional release to the environment. Figure 1.1 shows the location of the Hanford Site within Washington State and the proximity of major population centers. Figure 1.2 shows the boundaries of the Hanford Site and the location of the major facilities. The 100 Areas are the sites of reactor facilities. The major processing facilities, waste storage facilities, and waste disposal areas are located in the 200 Areas.

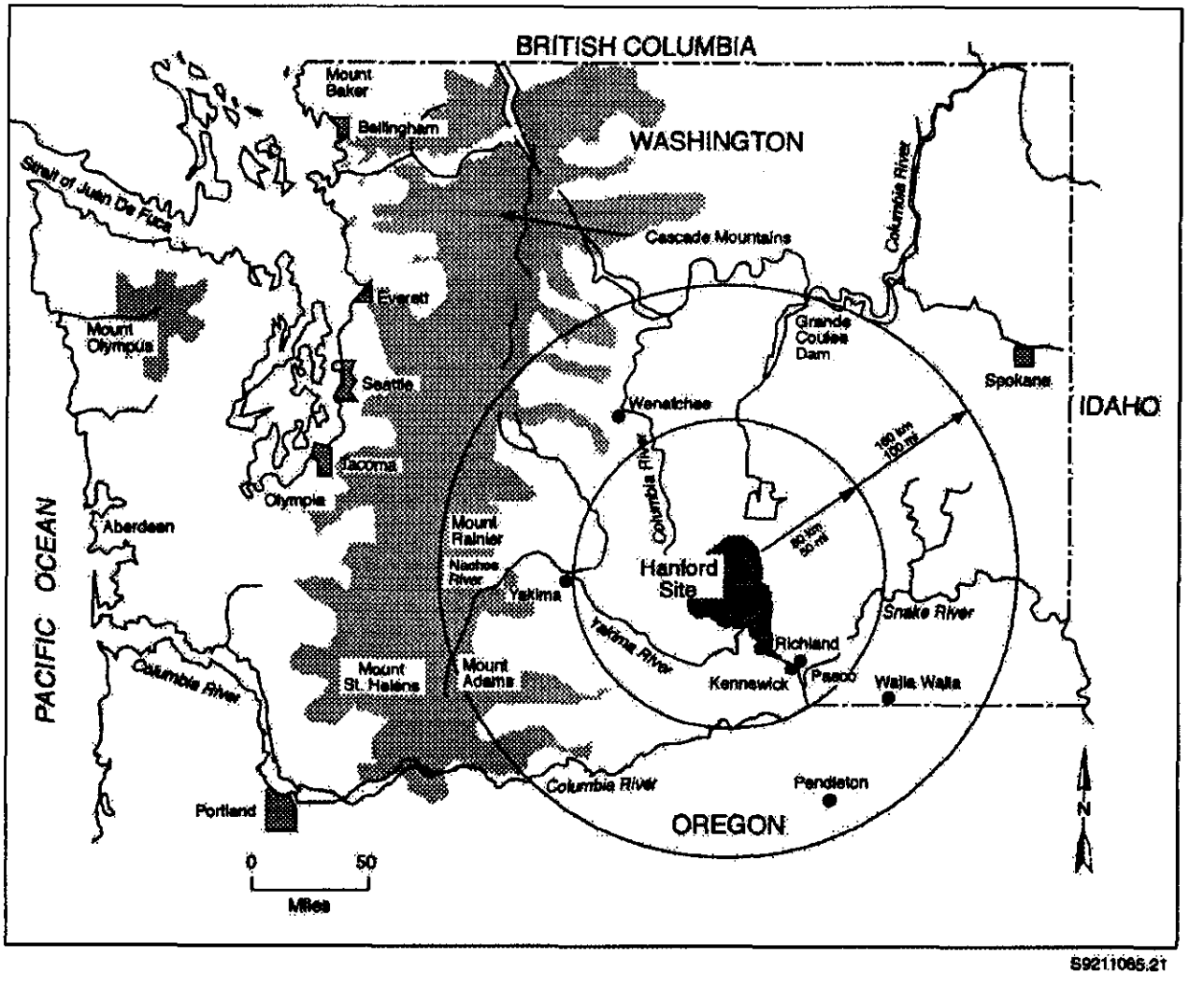

Figure 1.1. Location of the Hanford Site in Washington State

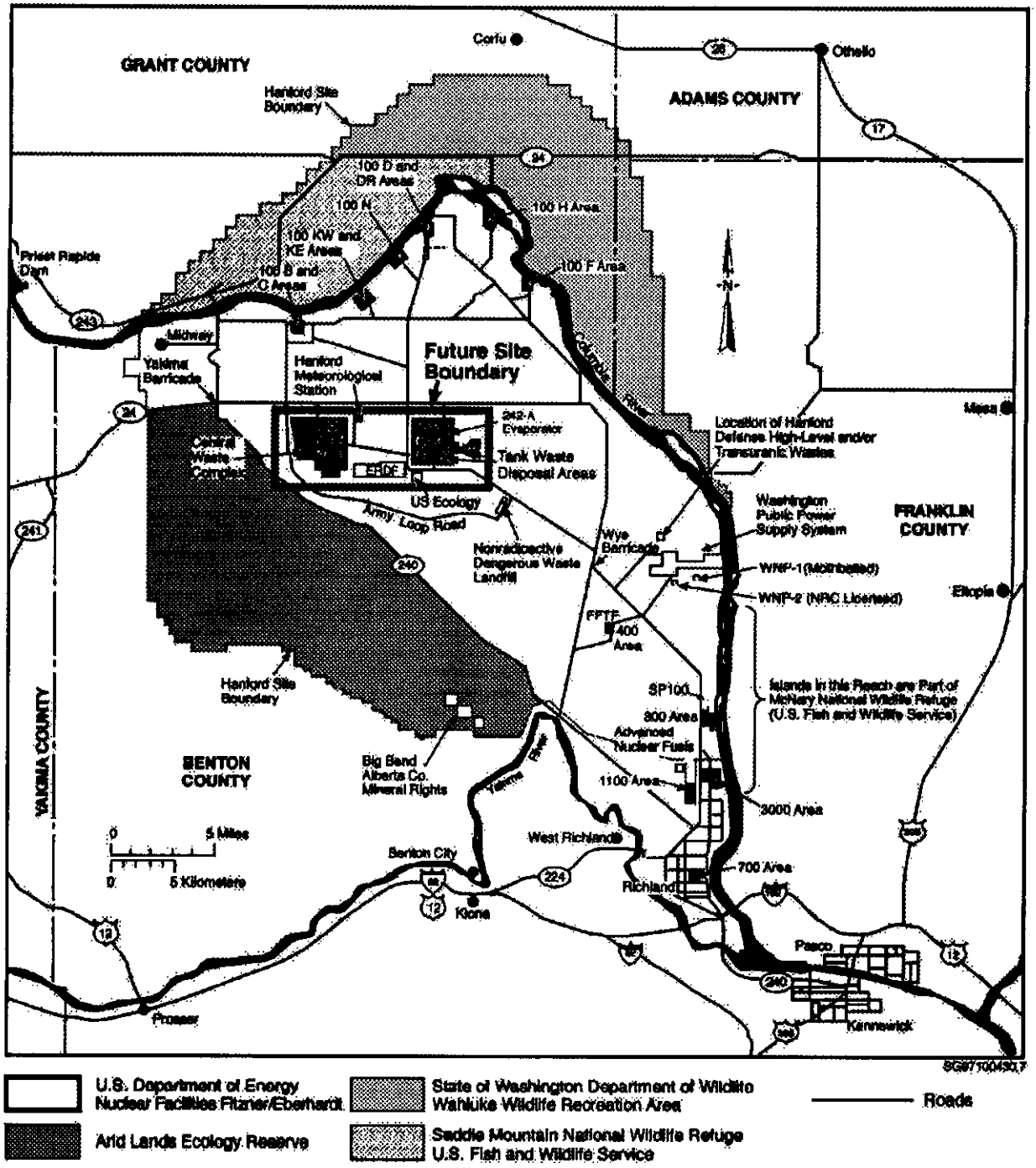

Figure 1.2. Hanford Site Map Illustrating the Locations of Major Facility Areas, Public Roads, Rivers, and the Future Site Boundary

1.1 Source and Destination of ILAW

The legacy of the earlier Hanford missions consists of approximately 204,000 m^3 of radioactive and mixed waste stored in 177 buried single- and double-shell tanks in the Hanford Site 200 Areas. Some of the more important radionuclides in these wastes are ^{3}H, ^{79}Se, ^{90}Sr, ^{99}Tc, ^{129}I, ^{126}Sn, and ^{137}Cs, as well as isotopes and progeny of uranium, plutonium, neptunium, and americium. The current plan for disposal of this waste calls for retrieval of the waste from the tanks, separation of the waste into high-level and low-activity waste streams, and vitrification (incorporation in glass) of each waste stream. Vitrification is intended to immobilize the waste components within the glass matrix. The high-level waste stream will be relatively low in volume, but will contain most of the radionuclides. Vitrified high-level waste will be stored on the Hanford Site until shipped to a federally approved repository. The immobilized low-activity waste (ILAW) will contain the bulk of the material from the tanks, including most of the non-radioactive chemical constituents, but relatively few radionuclides. (This paragraph references information found in Mann, 1999b.)

Current plans for disposal of the ILAW call for the molten glass waste to be placed in steel containers. These containers will be stacked in underground vaults located in the 200 East Area. Existing vaults, constructed for the grouted tank waste disposal program, will be used for the initial production of ILAW. The location of these existing disposal facility vaults is shown in Figure 1.3. The bulk of the waste (approximately 96%) will be placed in newly constructed vaults located to the southwest of the existing vaults, within the area marked ILAW on Figure 1.3 (Mann, 1999b; Burbank and Hohl, 1999). Protective surface covers will be constructed over the vaults prior to closure. Additional details on disposal facility design are given in Section 2.2.

1.2 ILAW Performance Assessments

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of the disposal facilities to receive the ILAW. The LMHC project to assess the performance of these disposal facilities is called the Hanford ILAW Performance Assessment (PA) Activity, referred to as the ILAW PA within this report. An interim PA (Mann et al., 1997) and the 1998 ILAW PA (Mann et al., 1998) were the initial efforts to demonstrate the feasibility of safely disposing of ILAW at the Hanford Site. Because the ILAW PA project was in its early stages during the preparation of these PAs, the analyses were conducted using conceptual designs of the facilities and reasonable estimates of material properties without having site-specific and waste-form-specific information. The project has since collected a variety of information including geologic, geochemical, and hydraulic data from a borehole adjacent to the new ILAW disposal site, site-specific recharge data, and geochemical information on contaminant transport through the site sediments. In addition, hydraulic and geochemical information for the expected materials of the disposal facilities and data regarding the behavior of the expected waste form have been and continue to be collected. In addition, various facility design alternatives have been considered and a definitive conceptual design has been proposed for the new ILAW disposal facility. In preparation for a revision of the ILAW PA

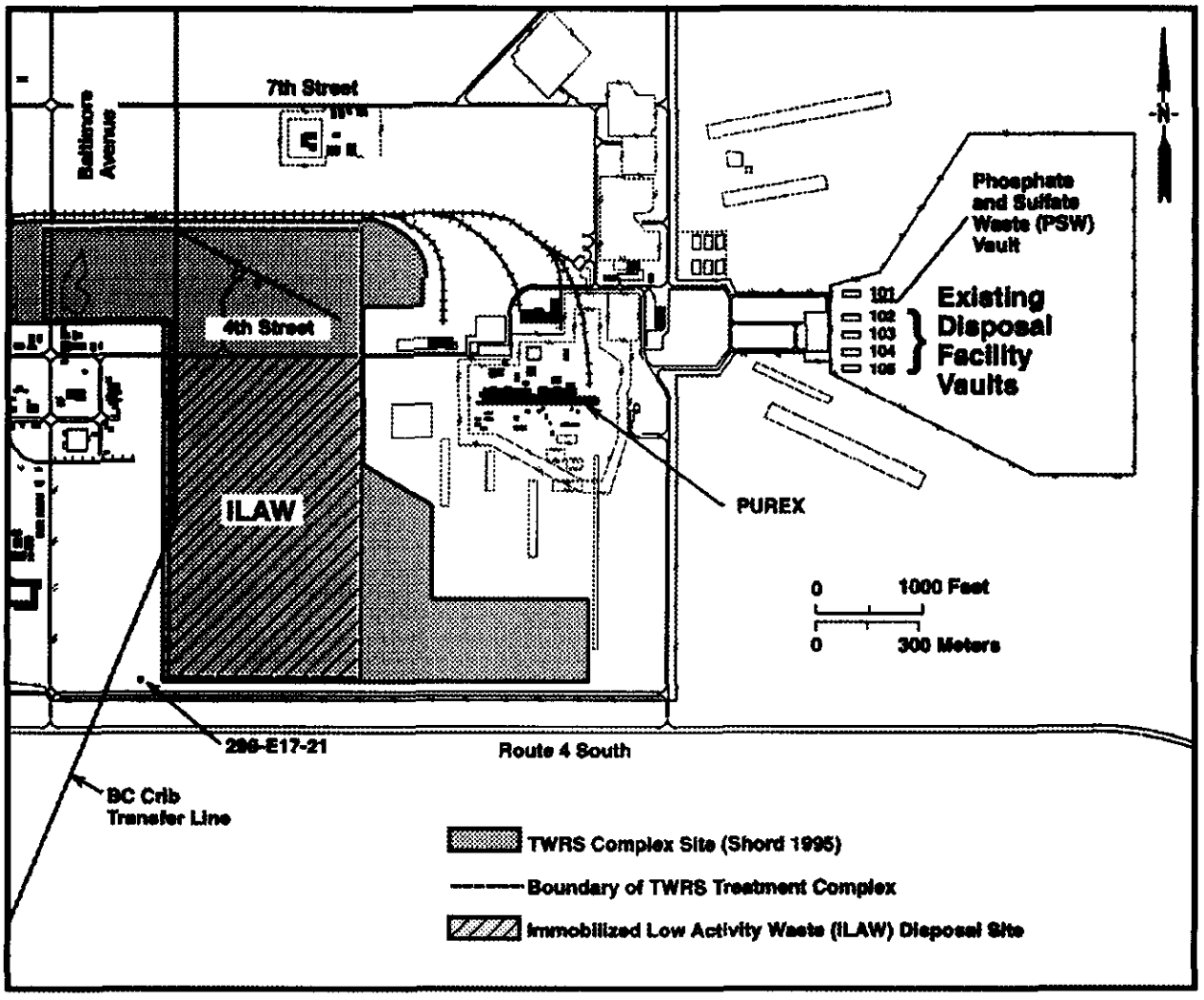

Figure 1.3. Location of the ILAW Disposal Facilities within the Hanford Site 200 East Area: Existing Disposal Facility and New ILAW Disposal Facility (labeled ILAW)

(the 2001 ILAW PA), a number of data packages are being prepared (LMHC, 1998). These data packages will bring together recently collected site-specific ILAW data as well as relevant data collected by other projects. This additional information will be used in the 2001 ILAW PA. These additional data packages include information on geology (Reidel and Horton, 1999), recharge (Fayer et al., 1999), flow and transport in the natural sediments (Khaleel, 1999), geochemistry (Kaplan and Serne, 1999), waste form release (McGrail et al., 1999), and facility design (Puigh, 1999). All data package reports will be included as appendices in the 2001 ILAW PA.

The goal of the PAs is to provide a reasonable expectation that the disposal of the waste is protective of the general public, groundwater resource, air resources, surface water resources, and inadvertent intrud-

ers. Radiological performance objectives and dangerous material (hazardous chemical) performance goals to be used in the 2001 ILAW PA are described in Mann (1999a). The radiological performance objectives include dose limits for an all-pathways scenario and an inadvertent intruder scenario as well as concentration and dose limits in groundwater, surface water, and air. Performance objectives are evaluated for 1,000 and 10,000 years, but are calculated to the time of peak or 10,000 years, whichever is longer. Results from the 1998 ILAW PA (Mann et al., 1998) showed that long-lived radionuclides (e.g., uranium and its daughter products) may produce peak impacts at times significantly greater than 10,000 years after closure.

The specific scenarios to be considered in the 2001 ILAW PA are discussed in Mann (1999b). It is assumed that the main pathway by which exposure will occur involves water movement into and through the disposal facilities, dissolution of the waste, transport of contaminants through the vadose zone to the unconfined aquifer, transport in the aquifer to an extraction well, and human exposure via domestic use of the pumped water. Prediction of subsurface flow and contaminant transport via numerical simulation will be required to complete the 2001 PA. In addition to a base case simulation, sensitivity calculations will be performed to demonstrate that the design for the ILAW disposal achieves impacts that are as low as reasonably achievable (ALARA).

Pacific Northwest National Laboratory (PNNL) assists LMHC in its performance assessment activities. One of PNNL's tasks is to provide estimates of the physical, hydraulic, and transport properties of the materials comprising the disposal facilities and the disturbed region around them. These materials are referred to as the near-field materials. Their properties are expressed as parameters of constitutive models used in simulations of subsurface flow and transport. In addition to the best-estimate parameter values (to be used in the base case simulation), information on uncertainty in the parameter values and estimates of the changes in parameter values over time are required to satisfy the ALARA requirement of the PA. These parameter estimates and information are contained in this report, the Near-Field Hydrology Data Package.

1.3 Quality Assurance and Safety

All laboratory and field experiments are conducted under PNNL quality assurance (QA) requirements as described in the guidance provided in PNNL's Standards Based Management System (SBMS) and as specified in the Project QA Plan. Significant modifications to the QA plan are made in accordance with the guidance in the SBMS.

Project staff members are qualified and receive any training needed to carry out their assigned responsibilities. Staff use equipment of known accuracy for data collection. For measurements necessary to substantiate test results, staff ensure that standards used for calibration are traceable to nationally recognized standards. Measuring and Test Equipment (M&TE) lists are generated by each task and maintained in the project files applicable to the specific task. M&TE used is identified in the laboratory record books or other data recording location to provide traceability to instrument calibrations.

Test procedures and methods are documented and deviations noted. New methods developed during the course of this work are documented and reviewed. All test procedures, data processing software, and supporting documentation undergo independent technical review by qualified PNNL staff. Staff maintain records necessary to substantiate results and processes of research activities. After activities are completed, records are filed and maintained per the project Records Inventory and Disposition Schedule (RIDS).

All precautionary measures are taken in accordance with standard PNNL safety procedures to ensure that field work is conducted in a safe manner. No hazardous wastes have been generated during the conduct of work described in this report.

2.0 Facility Design and Description of Near-Field Materials

A brief summary of the hydrologic and geologic setting of the ILAW disposal facilities is presented in this section. This is followed by a detailed discussion of the current conceptual design of the disposal facilities and the near-field materials to be used in their construction.

2.1 Hydrologic and Geologic Setting

The Hanford Site is located in the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State, within the rain shadow of the Cascade Mountain Range. The Hanford Meteorological Station, located between the 200 East and 200 West Areas on the Hanford Site, has been collecting climatological data representative of the ILAW disposal sites since 1945 (Hoitink et al., 1999). Precipitation at the Hanford Meteorological Station has averaged 17.4 cm/yr. since 1946, with more than half of the annual precipitation occurring from November through February. Days with more than 1.3 cm of precipitation occur on average less than once each year. Rainfall intensities of 1.3 cm/hr. with a duration of one hour are expected to occur once every 10 years. Rainfall intensities of 2.5 cm/hr. with a one-hour duration are expected to occur once every 500 years. Monthly average snowfall ranges from 0.8 cm in March to 13.7 cm in December. The maximum recorded monthly snowfall is 60 cm; the maximum recorded seasonal snowfall is 142 cm. On average, snowfall accounts for about 38% of precipitation from December through February.

Average daily maximum temperature varies from 2°C in late December and early January to 35°C in late July. On average, there are 52 days during the summer months with a maximum temperature greater than or equal to 32°C and 12 days with a maximum temperature greater than 38°C. From mid-November through early March, minimum temperatures average less than or equal to 0°C. The recorded maximum temperature is 45°C; the recorded minimum is -31°C.

The Hanford Site is characterized as a shrub-steppe ecosystem that is adapted to the region's mid-latitude, semiarid climate (Neitzel, 1998). Such ecosystems are typically dominated by a shrub overstory with a grass understory. Livestock grazing and agricultural production prior to government control of the Hanford Site contributed to colonization by non-native vegetation species that currently dominate portions of the landscape. In addition, summer range fires have tended to eliminate fire-intolerant species and have allowed more opportunistic and fire-resistant species a chance to become established. The dominant non-native species on the site is cheatgrass.

Three soil types occur in the vicinity of the ILAW disposal sites. As described by Hajek (1966), these soils are: Burbank Loamy Sand, a coarse-textured soil usually about 40 cm thick, underlain by a subsoil with a gravel content ranging from 20 to 80 volume percent; Ephrata Sandy Loam, a medium-textured soil underlain by gravelly material; and Rupert Sand, generally characterized as a coarse sand developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits.

The semiarid climate results in fairly low rates of groundwater recharge. Natural recharge rates across the Hanford Site are estimated to range from 0 to more than 10 cm/yr depending on surface soils, vegetation, and topography (Fayer and Walters, 1995). Minimal recharge rates occur in fine-textured soils where deep-rooted plants prevail. Larger recharge rates are likely to occur in areas with coarse, gravelly surface sediments and little or no vegetation. Fayer et al. (1999) provides estimates of the recharge rates expected to occur on the ILAW disposal sites.

The ILAW disposal sites are located on the Cold Creek bar (commonly referred to as the 200 Areas Plateau), a geomorphic remnant of the cataclysmic floods of the Pleistocene epoch (the Missoula Floods). The stratigraphy in the area consists of basalt flows overlain by the Ringold Formation sediments, Hanford Formation sediments, and surficial deposits. The Ringold Formation consists of clay, silt, compacted mud, fine- to coarse-grained sand and granular to cobble gravel. The Hanford Formation, deposited by the Missoula Floods, consists of pebble-to-boulder sized gravel, fine- to coarse-grained sand, and silt. The fine-grained sediments were deposited under slackwater and backflooded conditions. The surficial sediments consist of alluvial and eolian silt, sand, and gravel deposits that are generally less than 5 m thick. The southernmost 200 m of the new ILAW disposal site (see Figure 1.3) is covered with a stabilized sand dune that is as much as 8 m high (Fayer et al., 1999). Reidel and Horton (1999) provides detailed information on the available geologic information for the ILAW disposal sites (see also Reidel and Reynolds, 1998).

The ILAW disposal vaults will be constructed in excavations within the surficial and upper Hanford Formation sediments. Excavations are likely to be no more than 10 to 15 m deep. Three boreholes drilled near the southwest corner of the new ILAW disposal site in 1998 provide information on the nature of the sediments within the depth of the facility excavations (Reidel et al., 1998). Figure 2.1 contains the detailed geologic logs from the three boreholes for the upper 15 m (50 ft.). Note the generally coarse nature of the sediments and the presence of gravelly layers.

2.2 Facility Design

The existing disposal facility consists of concrete vaults constructed for the grouted waste disposal program (Kincaid et al., 1995). Use of these existing vaults for ILAW disposal will involve removal of the roofs from the vaults and subsequent placement of ILAW waste packages and filler material into the vaults. The vaults will then be sealed with new concrete roofs, and a modified RCRA C cover will be constructed to the original grade. The existing disposal facility vaults will hold about 4% of the anticipated volume of ILAW.

The new ILAW disposal facility will be constructed as described in PHMC (1998) (see also Puigh, 1999). The facility consists of a series of concrete vaults within which the waste packages will be placed. Each vault will be approximately 208 m long, 23 m wide, and 9 m deep and will be constructed within its own excavated trench. Construction of a new vault will take place as each vault is filled. A schematic cross-section of one of the new ILAW disposal facility vaults is shown in Figure 2.2

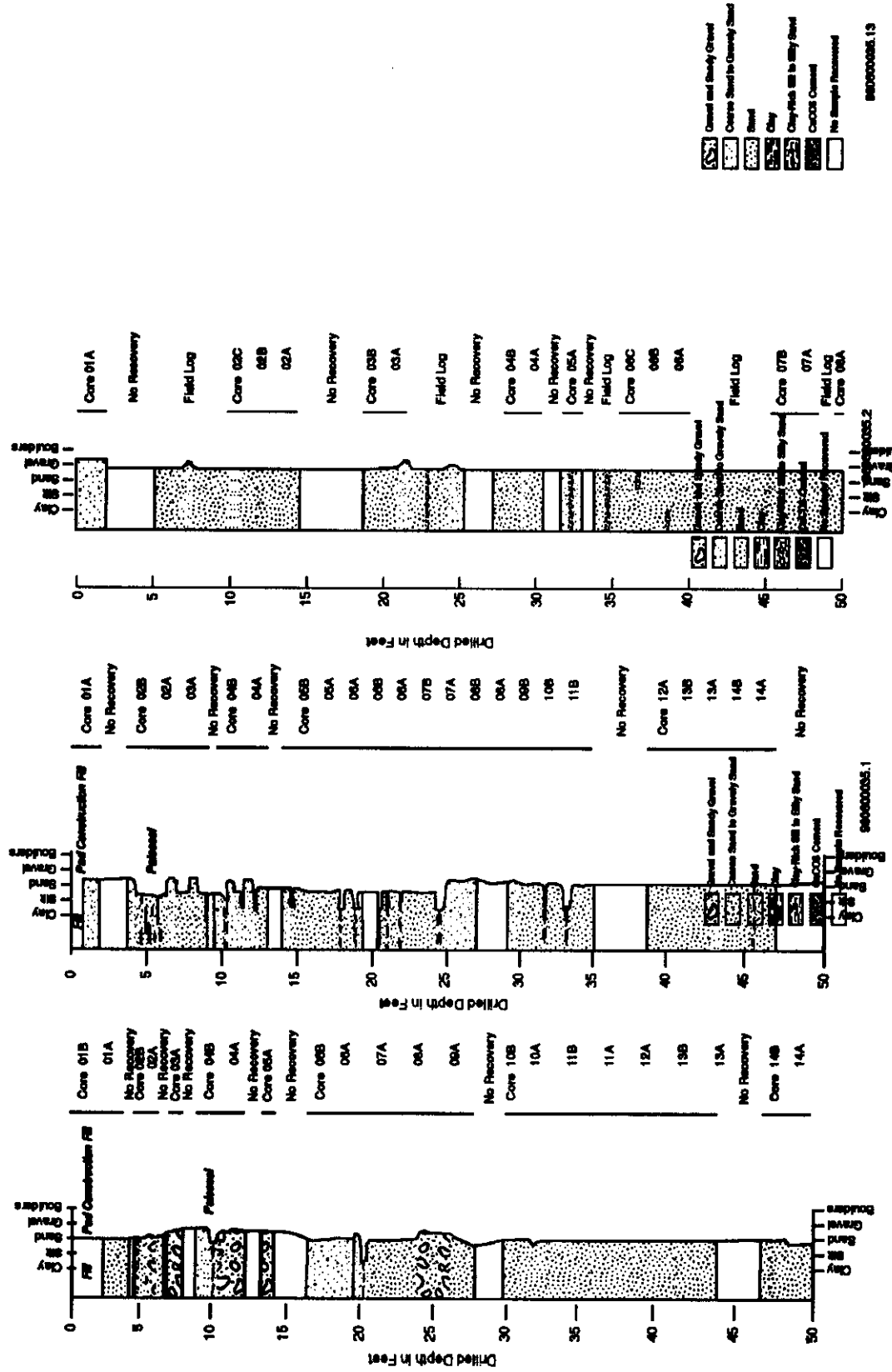

Figure 2.1. Detailed Geologic Logs for Boreholes B8501, B8502, and 299-E17-21 from the Southwest Corner of the New ILAW Disposal Site (after Reidel et al., 1998)

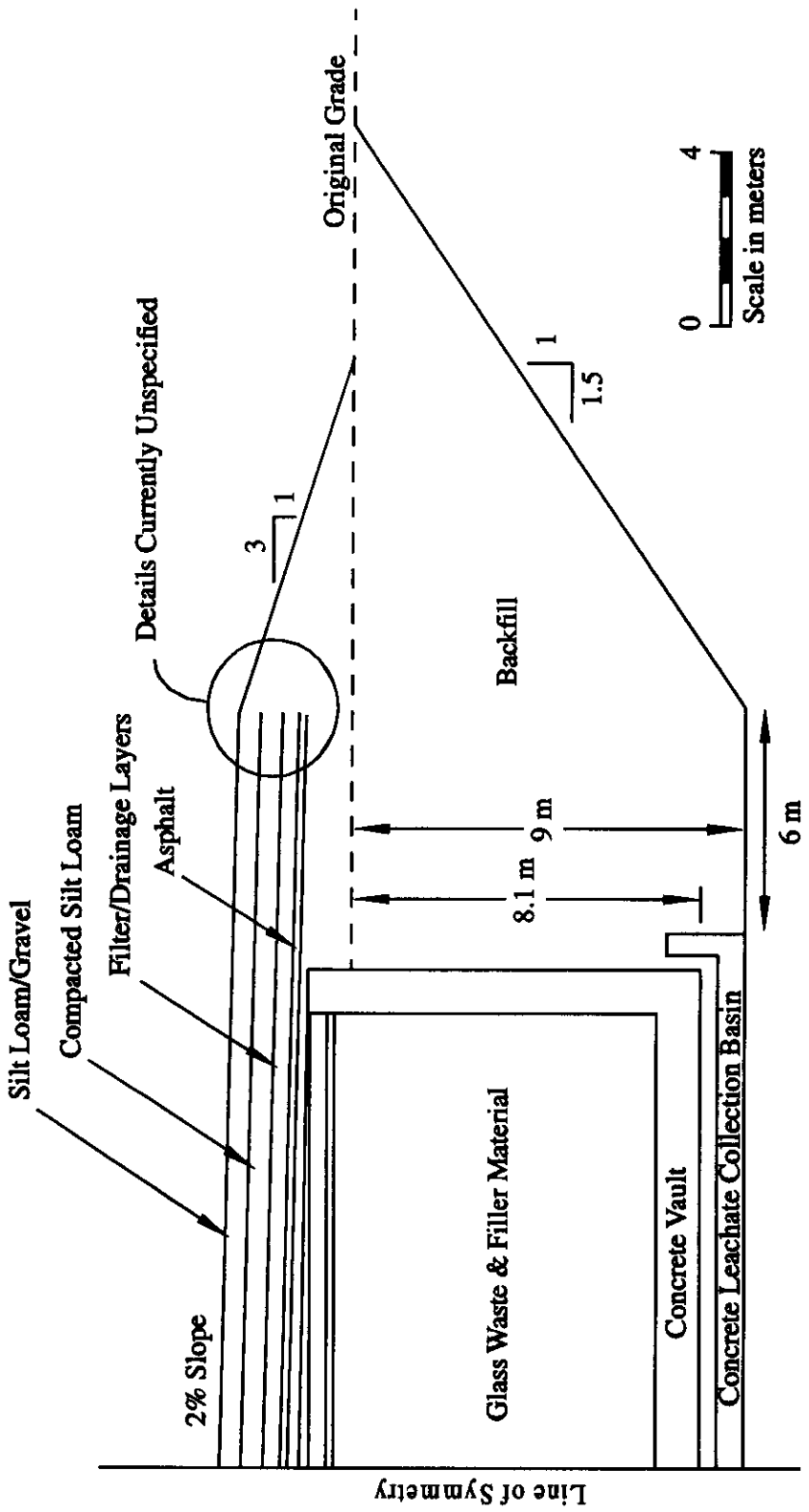

Figure 2.2. Schematic Cross-Section of an Excavation Trench and Vault at the New ILAW Disposal Facility

For both ILAW facilities the waste packages consist of steel containers filled with the glass waste. The space in the vaults between waste packages will be filled with a porous material such as sand. The vaults will be covered with a controlled density fill (defined below) and a layer of concrete to produce a 2% slope. Backfill material will be used to fill in to the original grade. Prior to closure, a protective surface cover will be constructed over the vaults to provide a barrier to water. (Components of the cover will also serve as an inadvertent intruder barrier.) The current conceptual design for the new ILAW disposal facility calls for individual surface barriers to be constructed over each vault. Other design features such as a water conditioning layer and a water diversion layer are not currently specified, but may be included in the final facility design.

For the purposes of hydrologic modeling, the primary differences between the two facilities are as follows.

1. The geometry of the vaults differs.
2. The top of the existing disposal facility vaults are well below grade, whereas the top of the new disposal facility vaults will be approximately at the original grade.
3. High-strength concrete with an asphalt shell was used in the existing disposal facility vault. The type of concrete to be used in the new facility has not yet been specified, but it is anticipated to be a more conventional concrete, with no asphalt shell or coating.

Other than the type of concrete used and the asphalt shell, the near-field materials to be used at the existing disposal site and at the new ILAW disposal site are similar. Because no measurements have been made of the hydraulic properties for the concrete at the existing site, the discussion below of the near-field materials and the parameter values to be presented later in this report should be applied at both sites.

Each material currently specified or that may potentially be used in the ILAW disposal facility is discussed below.

2.2.1 Surface Cover

A Modified RCRA Subtitle C Barrier Design (DOE-RL, 1993) will be used as a surface cover for both the existing and the new disposal facilities. The components of this cover and their minimum thicknesses are shown in Figure 2.3. The combined minimum thickness of the cover is 1.7 m. The thickness of individual components of the cover could be increased if needed to meet regulatory requirements. A description of each component in the cover is given below, taken primarily from DOE-RL (1993). The ILAW facility cover is similar in design to the Hanford Prototype Barrier (DOE-RL, 1999; DOE-RL, 1993) and is expected to perform in a similar manner.

2.2.1.1 Layer 1: Silt Loam Soil with Gravel

This layer consists of 50 cm of sandy silt to silt loam soil from the McGee Ranch area on the Hanford Site with 15% pea gravel by weight. The design bulk density of this layer is about 1.46 g/cm^3. The

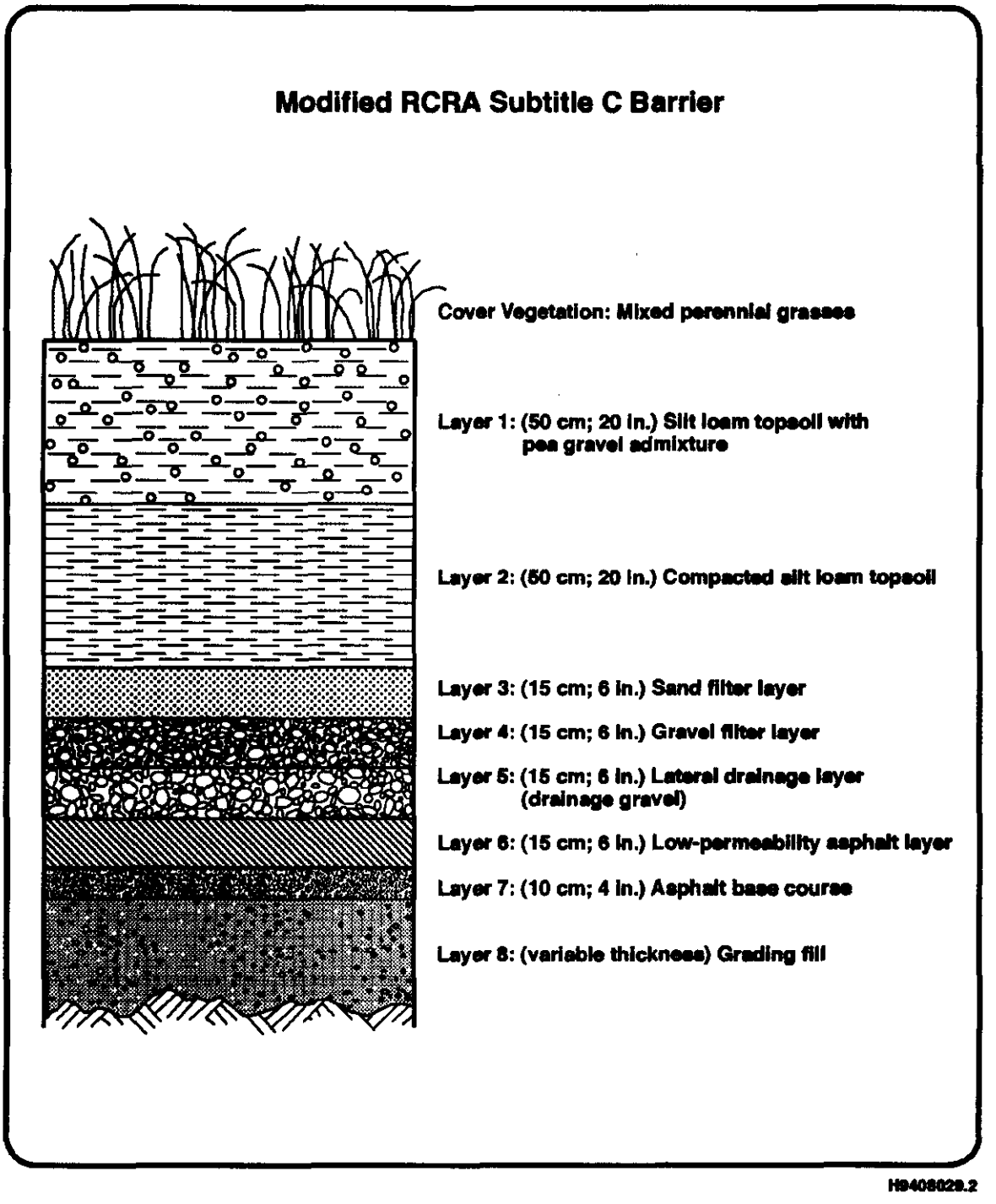

Figure 2.3. Schematic Profile of the Modified RCRA Subtitle C Barrier Currently Intended for Use on the ILAW Disposal Facilities. Note, minimum total barrier thickness is 1.7 m.

surface slope is limited to a maximum of 2% (after allowances for settlement and subsidence). The purpose of Layer 1 is to support vegetation and provide maximum storage capacity for precipitation and snowmelt. A large storage capacity in conjunction with evapotranspiration from vegetation will tend to minimize percolation from the cover (recharge). The pea gravel provides resistance to erosion of the silt loam.

2.2.1.2 Layer 2: Compacted Silt Loam Soil

This layer consists of an additional 50 cm of soil from the McGee Ranch area, but without the addition of pea gravel. This layer will be compacted during construction to a design bulk density of about 1.76 g/cm^3. The purpose of Layer 2 is to provide water storage capacity for precipitation and snowmelt and support for vegetation. The purpose of the compaction is to reduce the hydraulic conductivity of the layer.

2.2.1.3 Layer 3: Sand Filter

This layer consists of 15 cm of graded sand that is intended to serve, in conjunction with Layer 4, as a filter, preventing the fine particles of Layer 2 from moving into the lateral drainage layer (Layer 6). Particle size requirements for the sand filter were taken from Cedergren (1989) [also cited in Ecology (1987) and EPA (1989)] and are as follows.

Retention Criteria:	D_{15} (Filter)/ D_{85} (Filtrate) < 4 to 5
	D_{50} (Filter)/ D_{50} (Filtrate) < 25
Permeability Criterion:	D_{15} (Filter)/ D_{15} (Filtrate) > 4 to 5

The D values refer to the particle diameters on a particle size distribution curve (e.g., D_{15} is the particle diameter at which 15% of the particles are smaller). The filter material in this case is the sand; the filtrate material is the compacted silt loam. These filtration criteria were developed for applications in earth dams under saturated conditions. They are expected to be conservative for the unsaturated conditions of the ILAW surface cover.

The presence of the relatively coarse textured sand layer immediately beneath the fine textured silt loam will produce a capillary barrier effect at the interface. This effect arises because the unsaturated hydraulic conductivity of the sand will be significantly less than that of the silt loam for a large range of matric potential. Significant flow into the sand layer will not occur until the matric potential at the silt loam-sand interface becomes sufficiently large (close to zero) that water can move into the relatively large pores of the sand (Hillel, 1980). The capillary barrier will, in effect, increase the water storage capacity of the silt loam layers. Its ability to do so will depend on the hydraulic properties of the silt loam and sand materials.

2.2.1.4 Layer 4: Gravel Filter

This layer consists of 15 cm of a graded gravel that functions, with Layer 3, as a filter, preventing the fine particles of Layer 2 from moving into the lateral drainage layer (Layer 6). Particle size requirements for this layer are identical to those of the sand filter (Layer 3), with the exception that the filter material in this case is the gravel and the filtrate material is the sand. No slope is specified for the sand and gravel filter layers. It is assumed that they will be constructed at a 2% slope (as drawn in Figure 2.2) to minimize required thickness of the surface cover.

2.2.1.5 Layer 5: Gravel Lateral Drainage Layer

This layer consists of 15 cm of screened gravel with a required saturated hydraulic conductivity of no less than 1.0 cm/s. This layer will be constructed at a 2% slope. Its purpose is to divert (to the edge of the cover) water that passes through the filter layers and reaches the asphalt layer (Layer 6).

2.2.1.6 Layer 6: Asphaltic Concrete

This layer consists of 15 cm of a durable asphaltic concrete mixture consisting of double-tar asphalt with added sand as binder material, conforming to WSDOT M41-10, Section 9-02.1(4), Grade AR-4000W (WDOT, 1991). The asphaltic concrete will potentially be coated with a spray-applied asphaltic material. This layer will be constructed at a 2% slope. The asphalt layer is intended to function as a low permeability layer and as an inadvertent intruder barrier. As a low permeability layer, analogous to the compacted soil component of a standard RCRA Subtitle C barrier, the asphalt layer should be expected to have a maximum saturated hydraulic conductivity of 10^{-7} cm/s.

2.2.1.7 Layer 7: Asphalt Base Course

This layer serves as a stable base for placement of the asphalt and consists of 10 cm of screened, crushed surfacing material, with 100% passing the 32 mm sieve. The material must conform to WSDOT M 41-10, Section 9-03.9(3) (WDOT, 1991).

2.2.1.8 Layer 8: Grading Fill

This material consists of a well-graded, granular soil mixture, which may include as much as 20% by volume of cobbles measuring no more than 75 mm in the greatest dimension. This material will be used as needed to establish the base for construction of the other cover layers. Backfill material from excavation of the sites may serve as the grading fill.

2.2.2 Vault Materials

These materials include the vault itself as well as the materials of the waste packages and the filler material.

2.2.2.1 Concrete

The vaults will be constructed of steel-reinforced concrete approximately 1.0 m thick on the bottom and sides. After placing the waste packages and the filler material in the vault, 0.45 m of controlled density fill will be used to fill the vault to the level of the side walls. (Controlled density fill is a mixture of Portland cement, fly ash, aggregate, water, and admixtures proportioned to provide a non-segregating, self-consolidating, free-flowing, and excavatable material that will result in a hardened, dense, non-settling fill.) A steel-reinforced concrete layer 5 to 21 cm thick will be constructed on top of the controlled density fill to create a 2% sloped vault roof. No specifications have currently been given for the concrete or the controlled density fill.

2.2.2.2 Glass Waste and Container

The current design calls for molten glass waste to be poured into stainless steel containers. Although significant fracturing of the glass is anticipated, there have been no studies to determine the extent of the fracturing and the effect this will have on hydraulic properties of the glass.

2.2.2.3 Filler Material

Filler material may be used to fill the void space in the steel waste containers and will be used to fill the space in the vault between the waste containers. The inter-container filler is specified to be an inert material, such as graded sand. Crushed glass is also a possible filler material. Since the inter-container filler material will be poured into the vault from an overhead hopper, it must have a consistency that allows it to flow into the void spaces in the vault with little potential for bridging.

2.2.2.4 Leachate Collection System

A steel-reinforced concrete catch basin will be located beneath the vault to catch leachate. The catch basin will be sloped at 2% toward a trench in the center. The trench will be sloped toward each end of the basin. The interior of the catch basin walls must be no less than 25 cm outside of the exterior of the vault walls. Two 60-mil, high-density polyethylene liners will be used within the catch basin, with a polypropylene geonet placed between the liners and a 60 mil geotextile above the upper liner. Gravel will be placed above the liners and beneath the vault to facilitate movement of water to the leachate detection riser pipes.

2.2.3 Backfill

It is anticipated that backfill around the vault will consist of excavation spoils, potentially screened to remove large cobbles (for use as grading fill immediately beneath the surface cover, for instance). As a result of the excavation, re-emplacement, and compaction, the backfill hydraulic properties are expected to differ from the properties of the naturally occurring sediments. The backfill is likely to be more homogeneous and isotropic.

2.2.4 Water Conditioning Layer

A water conditioning layer consisting of quartz sand or crushed glass is being considered as a component of the facility. The intent of this layer is to increase the silica content of water that contacts the waste, thus reducing the dissolution of silica in the glass waste and decreasing the contaminant flux from the facility. The water conditioning layer would likely be located immediately above the concrete vault, or may even be used as the filler material within the vault. No specifications have been given for the material itself.

2.2.5 Diversion Layer

A diversion layer consisting of a sand and gravel capillary barrier may potentially be used in the final design of the facility covers. This diversion layer would be used as an alternative to, or in addition to, the asphalt low permeability layer. This layer would consist of a well-graded sand overlying a well-graded gravel. The diversion layer would likely be constructed at a 2% slope, corresponding to the other surface cover components.

The required hydraulic properties of the sand and gravel components of the diversion layer depend on the length of the layer and on the expected water flux reaching the layer. Appropriate hydraulic parameters could be determined using numerical modeling and matched to available materials.

3.0 Required Properties and Parameters of Near-Field Materials

This section provides a brief description of the properties and parameters required to model unsaturated flow and nonreactive contaminant transport in the near-field environment of the ILAW disposal facilities. Additional parameters required to model reactive transport are discussed in Kaplan and Serne (1999) and McGrail et al. (1999).

3.1 Particle Size Distribution

The particle size distribution (PSD) is typically presented as the cumulative fraction by weight of particles whose mean diameter is less than a specific value. This physical property is useful for classifying soils (e.g., sand, silt loam), but is not typically used directly in modeling. Those particles greater than 2 mm in diameter are often removed from the sample before measuring the particle size distribution using standard methods (ASTM D422-63; Gee and Bauder, 1986). For ILAW PA purposes, however, the fraction greater than 2 mm should be included in the particle size distribution or recorded as a gravel percentage.

In the absence of a direct measurement of water retention (see Section 3.5), the particle size distribution can be used to estimate water retention by assuming the particle size distribution reflects the pore size distribution (Arya and Paris, 1981).

3.2 Particle Density

Particle density (ρ_p) is the mass of solids in a sample divided by the volume of the solids. It is typically used to calculate porosity. The fraction less than 2 mm may be used in the measurement of particle density (Blake and Hartge, 1986b).

3.3 Bulk Density

The dry bulk density (ρ_b) is the mass of solids in a sample divided by the total (bulk) volume of the sample. The total volume includes the volume occupied by the solids, water (or other liquid), and air. Due to the potential for compaction during sampling, bulk density measured in the laboratory may vary from that measured *in situ* (Blake and Hartge, 1986a). Bulk density is used to calculate porosity and retardation coefficients. Some techniques for estimating water retention and hydraulic conductivity may also use the bulk density.

3.4 Porosity

Porosity (ϕ) is the volume of voids in a sample (the air- and liquid-filled volume) divided by the total volume of the sample. It is typically calculated using measured values of particle and dry bulk densities.

$$\phi = 1 - \rho_b/\rho_p \quad (3.1)$$

The porosity can also be measured directly (Danielson and Sutherland, 1986).

3.5 Water Retention

Water retention [$\theta = f(\psi)$]in a porous medium refers to the relationship between water content and matric potential. Volumetric water content (θ) is the volume of water in a sample divided by the total volume of the sample. The matric potential represents the capillary and adsorptive forces that attract and bind water to the soil matrix. (Matric potential is also referred to as soil water pressure or negative soil water tension.) A variety of methods are available to obtain water retention data (Klute, 1986; Rawlins and Campbell, 1986; Wierenga, et al., 1993). In some cases, laboratory measurements of water retention have been conducted on samples for which the gravel fraction (particle diameter > 2 mm) has been removed. The water contents obtained on such samples should be corrected for the gravel content (Bouwer and Rice, 1983; Gardner, 1986) before estimating the parameters of a water retention model.

Water retention is typically represented in simulation codes using one of a number of water retention models that have been presented in the literature. In this report, the model proposed by van Genuchten (1980) is used:

$$S_e(\psi) = [1 + (\alpha\psi)^n]^{-m} \quad (3.2)$$

where

ψ = matric potential

S_e = effective saturation = $\frac{\theta - \theta_r}{\theta_s - \theta_r}$, $0 \le S_e \le 1$

α = curve fitting parameter related to air entry pressure

n, m = curve fitting parameters related to pore size distribution; the relationship, m=1-1/n, is often assumed

θ_r = residual (or irreducible) water content

θ_s = saturated water content.

The saturated water content is often assumed to be equal to porosity. It has been observed in laboratory and field measurements, however, that soils often cannot be saturated to the full porosity. This effect is more pronounced in the field, presumably because of the greater variation in soil structure and the inability to carefully control wetting. For this reason, θ_s is sometimes a fitted parameter, in which case it represents a field-saturated water content. Klute (1986) states that field-saturated water content is typically 80 to 90% of the porosity.

The residual water content is interpreted here as an empirical parameter and thus is generally a fitted parameter. This interpretation is a subject of debate (Nimmo, 1991; Luckner et al., 1991). At very low matric potentials (large negative values), the van Genuchten model may provide a poor representation of water

retention. Alternative models have been proposed that improve the fit at low water contents (Rossi and Nimmo, 1994; Fayer and Simmons, 1995). Because water contents in the ILAW disposal facilities and the surrounding soils are expected to be low, accurate representation by the water retention model may be important. This is especially true if diffusion dominates the transport of contaminants and a water-content-dependent diffusion coefficient is used.

The remainder of the parameters in the van Genuchten water retention model are fitting parameters, estimated using measured or inferred water retention data.

There are many water retention models that could be used. Although the parameters in the van Genuchten model are related to the parameters used in other models, the transformation from one to the other is not always straightforward. Caution should be exercised in using the results presented in this report with water retention models other than the van Genuchten model.

Water retention in soils and sediment exhibits hysteresis: the observed water content at a given matric potential depends on whether the soil is being wetted or is drying. Models have been developed for describing this hysteresis, but the data on which the parameters of hysteresis can be estimated are often not available. Hysteresis is likely to be most important near the ground surface where water content changes with time will be the largest. In the deeper materials (below the cover), water content changes will be less significant and hysteresis effects are not anticipated to be significant.

3.6 Saturated Hydraulic Conductivity

Darcy's Law is used in models of subsurface flow to relate water flux to the potential gradient. Under saturated conditions, the proportionality constant in this relationship is the saturated hydraulic conductivity (K_s). Measurements can be made using a variety of methods (Klute and Dirksen, 1986). Saturated hydraulic conductivity may exhibit anisotropy: a value that depends on the direction in which it is measured. Data on anisotropy are typically not available. Hydraulic conductivity anisotropy is not anticipated to be significant in any single near-field material. At a scale that encompasses multiple near-field materials that have contrasting properties, anisotropy should be considered.

Saturated hydraulic conductivity measurements are often made on small-scale laboratory samples. Because of the variability in natural materials, these small-scale measurements should not be interpreted as field-measured hydraulic conductivity values, which are typically larger. Values used in numerical models should represent the scale of the numerical grid size. The appropriate scaling methods for deriving model values of saturated hydraulic conductivity from laboratory measurements is currently a matter of scientific debate. Because the near-field materials will be relatively homogeneous, this scale issue is anticipated to be less important than for the naturally occurring sediments.

3.7 Unsaturated Hydraulic Conductivity

Under unsaturated conditions, the water flux occurring through a porous material in response to a specified potential gradient is strongly dependent on the water content of the material. The unsaturated hydraulic conductivity [$K = f(\theta, \psi)$] describes this dependence. Direct measurement of the unsaturated hydraulic conductivity as a function of water content is possible using a steady-state method (Klute and Dirksen, 1986) and centrifugal methods (Nimmo et al., 1987; Nimmo, 1990; Conca and Wright, 1992; Wright et al., 1994), but such data is often not available. More typically, the unsaturated hydraulic conductivity relationship is estimated using water retention and saturated hydraulic conductivity measurements and adopting a particular model (Mualem, 1986). Eching and Hopmans (1993) and Eching et al. (1994) present an alternative method of estimating unsaturated hydraulic conductivity using outflow measurements, but this method also requires adopting a specific model.

The unsaturated hydraulic conductivity model used in this report is the model derived by van Genuchten (1980) using the relationship of Mualem (1976). This model can be written either in terms of the water content or the matric potential.

$$K(S_e) = K_s\sqrt{S_e}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2 \tag{3.3}$$

$$K(\psi) = K_s\frac{\left\{1-(\alpha\psi)^{n-1}\left[1+(\alpha\psi)^n\right]^{-m}\right\}^2}{\left[1+(\alpha\psi)^n\right]^{0.5m}} \tag{3.4}$$

Parameters in these equations are as defined for the water retention model and can be estimated using both water retention and unsaturated hydraulic conductivity data when available. The factor of 0.5 in the exponent of the denominator of Equation 3.4 represents the pore interaction term. A value of 0.5 is typical.

Khaleel et al. (1995) found that the van Genuchten-Mualem model did not provide accurate estimates of unsaturated hydraulic conductivity for Hanford sediments at low water contents when these estimates were based solely on water retention data and a saturated hydraulic conductivity measurement. This condition may be explained by observing that the saturated hydraulic conductivity for these relatively coarse materials is dominated by large pores, whereas the unsaturated hydraulic conductivity appears to be dominated by small pores. Khaleel et al. (1995) recommended the use of at least one direct measurement of hydraulic conductivity at a low water content as a match point.

3.8 Dispersivity

Dispersivity (λ), when multiplied by the pore water velocity, yields the mechanical dispersion coefficient, which relates the dispersive solute flux to the solute concentration gradient. Dispersivity is generally larger in the direction of flow than in transverse directions and it is also scale dependent. Khaleel

(1999) provides a discussion of the issues related to scale-dependent dispersion. Because of the smaller scale and the relative homogeneity, this issue is likely to be less important for the near-field materials.

Field measurements of dispersivity are extremely rare and small-scale laboratory measurements have only marginal utility in estimating field values. In the absence of data, dispersivity values are often based on simple guidelines related to the size of the computation elements in numerical simulation codes.

3.9 Diffusion Coefficient

The diffusion coefficient is the proportionality factor in Fick's law that relates the diffusive transport flux to the gradient in solute concentration. Diffusion results in mass transport from regions of high solute concentration to regions of lower concentration and occurs as a result of the random thermal motion (Brownian motion) of molecules and atoms. Diffusive transport in a dilute water solution is quantified by the free-water diffusion coefficient, D_f. Several models have been proposed for calculating the diffusion coefficient of a dilute solute in water (Grathwohl, 1998). The viscosity of the solution, which depends strongly on temperature, affects D_f most directly. For most simple aqueous species D_f is about 10^{-5} cm^2/s (10^{-9} m^2/s). Kemper (1986) provides a table of diffusion coefficients of common ions in water; values range from approximately 4.8×10^{-6} to 1.6×10^{-5} cm^2/s at 15 °C.

In the constrained geometry of a porous medium, the diffusion coefficient is reduced compared to the diffusion coefficient in free aqueous solution. The intrinsic diffusion coefficient for a species within a saturated porous medium, D_i, can be expressed as

$$D_i = D_f \phi \delta/\tau \tag{3.5}$$

where δ = a constrictivity factor

$1/\tau$ = a tortuosity factor.

The intrinsic diffusion coefficient has also been referred to as the effective diffusion coefficient.

The constrictivity factor in Equation 3.5 represents a reduction in diffusion due to the constricted flow path caused by small pores and pore throats in the porous medium. The effect of constrictions on diffusion has been attributed to an increased viscocity in the vicinity of the pore walls (Grathwohl, 1998) and electrical interactions (Kemper, 1986). The tortuosity factor represents a reduction in diffusion due to the increased path length taken by solute molecules in traveling through the porous medium. The tortuosity factor is given by $1/\tau = (L/L_e)^2$, where L_e is the length of the tortuous path and L is the straight-line path length (Porter et al. 1960).

In a saturated porous medium, the cross-sectional area available for diffusion in the aqueous phase is reduced by the volume fraction of the void space. This fraction will be the total porosity, ϕ, if all porosity in the porous medium is interconnected and can thus contribute to contaminant diffusion. If there are pores that do not contribute to diffusion (such as dead end pores), the porosity appearing in Equation 3.5 will be less than the total porosity.

In practice, it is difficult to directly measure or reliably estimate the constrictivity and tortuosity factors. As a result, the intrinsic diffusion coefficient is frequently modeled as a function of the porosity alone.

$$D_i = D_f \phi^{\beta} \tag{3.6}$$

In this equation, β is an empirical parameter incorporating the tortuosity and constrictivity effects. The empirical form of this equation is attributed to Buckingham (1904) (although it was then proposed to describe the equivalent concept of effective diffusion of a vapor-phase species through the air-filled pore space of a porous medium). Millington (1959) derived a value of $\beta = 4/3$. Grathwohl (1998) states that the expected range of β for most natural porous media is 1.5 to 2.5.

In unsaturated porous media, Equation 3.5 or 3.6 must be modified to account for the additional reduction in cross-sectional area available for diffusion as a result of the reduced volumetric water content. Millington (1959) derived a model for gas-phase diffusion in unsaturated porous media that has also been applied to aqueous-phase diffusion. [See also Millington and Quirk (1959; 1961).] The Millington expression for the intrinsic diffusion coefficient in unsaturated porous media is

$$D_i = D_f \theta^{10/3}/\phi^2 \tag{3.7}$$

This model assumes $\delta = 1$ in Equation 3.5, replaces the porosity with the volumetric water content, and results in a tortuosity factor defined by $1/\tau = \theta^{7/3}/\phi^2$. In the saturated case with $\theta = \phi$, Equation 3.7 reduces to Equation 3.6 with $\beta = 4/3$.

Papendick and Campbell (1980), citing Brooks and Corey (1966), assumed a tortuosity factor in Equation 3.5 of $1/\tau = c\theta^2$. With $\delta = 1$ and the volumetric water content replacing the porosity, Equation 3.5 becomes

$$D_i = cD_f \theta^3 \tag{3.8}$$

Campbell (1985) suggested that the empirical parameter 'c' in this relationship could be taken as a constant with a value of $c = 2.8$.

Kemper and Van Schaik (1966), Olsen et al. (1965), Olsen and Kemper (1968) and Porter et al. (1960) developed a model for diffusive transport in agricultural systems.

$$D_i = a\, D_f \exp(b\theta) \tag{3.9}$$

where a = an empirical constant based on particle size (0.003 is a representative value for sand)

b = an empirical constant based on particle size (10 is a representative value for sand).

The value of the diffusion coefficient can vary significantly depending on which of the empirical relationships (Equations 3.7 to 3.9) is used, particularly at low water contents. For example, $\log(D_i)$ is linear in θ using Equation 3.9, but is nonlinear for the other two models. Furthermore, Equations 3.7 and 3.8 are similar for porosities of 0.4 to 0.6, but can be significantly different for porosities outside this range, particularly porosities that are smaller than 0.3. Fayer and Kincaid (1998)[1] demonstrate the potential impact of using different diffusion relationships for a waste-form-alone simulation (no vault) of the new

ILAW disposal facility. Predictions of dose were reduced by more than 80% when using Equation 3.7 as compared with using Equation 3.9. A discussion in Section 5.3 of available diffusion data suggests that the model of Kemper and Van Schaik (Equation 3.9) is inappropriate for use in the ILAW PA.

The chemical contributions to diffusion can potentially be quite varied (ion-exchange, specific adsorption, precipitation, and lattice substitution) as well as quite significant. If we assume a very simple chemical process, i.e., reversible surface adsorption having fast kinetics and a linear isotherm (adsorption is proportional to the concentration in solution via a fixed constant, K_d), then diffusion of a reactive contaminant can be characterized by an apparent diffusion coefficient, D_a:

$$D_a = D_i/\alpha' = D_f \delta \phi/(\tau \alpha') \tag{3.10}$$

using Equation 3.5 for the intrinsic diffusion coefficient. In this equation, α' is the capacity factor or ratio of the moles of contaminant per unit volume of water-saturated solid, C_s, to the moles of contaminant per unit volume of liquid, C_l. The capacity factor is related to the distribution coefficient, K_d, by the equation

$$\alpha' = \phi + \rho_b K_d \tag{3.11}$$

where ρ_b is the dry bulk density of the porous media and K_d is the amount of contaminant adsorbed per unit mass of porous solid divided by the amount of contaminant per unit volume of liquid. Also note that α'/ϕ is the familiar retardation factor used in transport modeling in water-saturated porous media:

$$\alpha'/\phi = R = 1 + \rho_b K_d/\phi. \tag{3.12}$$

For unsaturated porous media, it is appropriate to replace the porosity in Equations 3.10 to 3.12 with the volumetric water content.

Remember that these simple relationships are strictly valid only for reversible, linear adsorption reactions with fast kinetics. These conditions may not be met for many actual porous media-contaminant-solution interactions. Nevertheless such simplifying assumptions allow for some useful analysis such as performed in the ILAW PAs. In Equation 3.10 one can see that the term D_i contains all the physical aspects of diffusional transport and the term α' contains all the chemical aspects of diffusional transport. Because the distribution coefficient for different contaminants in various porous media can be substantially greater than 1 cm^3/g, the apparent diffusion coefficient may be significantly less than the value of the intrinsic diffusion coefficient.

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[1] Fayer, M.J. and C.T. Kincaid. 1998. *Simulations to Guide Measurements of Near-Field Hydraulic Parameters.* Letter Report to Fluor Daniel Hanford, Inc., September 30, 1998, Pacific Northwest National Laboratory, Richland, Washington.

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4.0 Best-Estimate Values for Hydraulic Parameters of Near-Field Materials

This section contains best-estimate values for the hydraulic parameters of the near-field materials to be used in performance assessment analyses of the ILAW disposal facilities. A description of the source of these values is included. In determining the best-estimate parameter values it has been assumed in most cases that the saturated volumetric water content is equal to the porosity. This assumption was made to avoid the application of an arbitrary factor to account for field saturation in such disparate materials as gravel and concrete. In those cases where a model was fit to water retention data the saturated water content was a fitted parameter and may be less than the porosity. Best-estimate values for transport parameters are discussed in Chapter 5. Information on parameter uncertainty and changes in parameter values over time is discussed in Chapter 6.

4.1 Cover Materials

4.1.1 Silt Loam-Gravel Admix

The silt loam component of this material is specified to come from the McGee Ranch area on the Hanford Site. Gee et al. (1989) obtained sixteen samples of this soil from the top meter of a site in the McGee Ranch area. Particle size analysis of the samples yield textures from loam to silt loam with the percentage of sand ranging from 32 to 44%, silt from 42 to 59%, and clay from 7 to 16%. The average particle density of the samples was 2.72 g/cm^3. Samples were packed to a bulk density of 1.37 g/cm^3 and the saturated hydraulic conductivity and water retention (drying curve) were measured.

Gee et al. (1989) estimated hydraulic parameters of the van Genuchten-Mualem model for each McGee Ranch soil sample. In addition, they determined average parameters by simultaneously fitting data from all sixteen samples. Gee et al. (1989) reported that complete saturation was not achieved in the samples during the hydraulic conductivity measurements. Thus the saturated hydraulic conductivity was a fitted parameter in their study with the measured values used as match points. The average parameter values reported by Gee et al. (1989) for the McGee Ranch soil samples were as follows:

$\theta_s = 0.496$, $\theta_r = 0.0049$, $\alpha = 0.0163$ cm^{-1}, $n = 1.372$, and $K_s = 9.9 \times 10^{-4}$ cm/s.

To adjust the silt loam parameters for a 15% by weight addition of pea gravel, the relationships of Bouwer and Rice (1983) were used. These relationships have been used previously for Hanford soils (e.g., Khaleel and Freeman, 1995). The water content was updated using the relationship

$$\theta^{Mix} = (1 - F_g)\,\theta^{SiL} \tag{4.1}$$

where θ^{Mix} is the volumetric water content of the silt loam-gravel admix, θ^{SiL} is the volumetric water content of the silt loam, and F_g is the volume fraction of gravel (the volume of gravel divided by the total volume of the silt loam-gravel admix).

F_g can be calculated by assuming that the addition of gravel to the silt loam soil does not increase the volume of voids in the sample (i.e., there is no porosity associated with the gravel). With a 1000 g sample of silt loam-gravel admix, for example, the volume of silt loam is the ratio of silt loam mass (850 g) to silt loam bulk density (1.37 g/cm^3), or 620.4 cm^3. The volume of gravel is the ratio of gravel mass (150 g) to gravel particle density (2.72 g/cm^3), or 55.1 cm^3. The gravel particle density used is the average density reported by Rockhold et al. (1993) for samples from a borehole adjacent to the existing disposal facility, and is comparable to the values measured for cores taken from a borehole adjacent to the new ILAW disposal site.[1] Using the values above, the volume fraction of gravel in the silt loam-gravel admixture is $F_g = 55.1/(55.1 + 620.4) = 0.0816$. The bulk density of the admixture is 1.48 g/cm^3.

The saturated hydraulic conductivity of the silt loam-gravel admixture is estimated using a relationship from Bouwer and Rice (1983).

$$K_s^{Mix} = (e^{Mix}/e^{SiL})\, K_s^{SiL} \tag{4.2}$$

where K_s^{Mix} is the saturated hydraulic conductivity of the silt loam-gravel admixture, K_s^{SiL} is the saturated hydraulic conductivity of the silt loam, and e^{Mix} and e^{SiL} are the void ratios of the admixture and silt loam soils, respectively. The void ratio is a function of the porosity, with $e = \phi/(1 - \phi)$. Using the bulk and particle densities listed above and Equation 3.1 to calculate the porosities, the scaling factor for the saturated hydraulic conductivity is $e^{Mix}/e^{SiL} = 0.850$.

Applying the scaling factors for the water content and hydraulic conductivity to the silt loam parameters listed above results in the best-estimate physical and hydraulic parameters for the silt loam-gravel admixture given in Table 4.1.

Table 4.1. Best-Estimate Parameter Values for Silt Loam-Gravel Admixture

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.72	1.48	0.456	0.0045	0.0163	1.37	8.4×10^{-4}

4.1.2 Compacted Silt Loam

This material is also specified to come from the McGee Ranch area on the Hanford Site. The silt loam parameters obtained by Gee et al. (1989) were adjusted to account for an increase in bulk density from 1.37 g/cm^3 used by Gee et al. (1989) in their measurements to a value of 1.76 g/cm^3 as specified in DOE-RL (1993). The effect of the compaction was estimated using the relationships of Arya and Paris (1981). Since the compaction will not affect the particle size distribution, the equations presented in Arya

[1] Fayer, M.J., A.L. Ward, J.S. Ritter, and R.E. Clayton. 1998. "Physical and Hydraulic Measurements of FY 1998 Borehole Cores." Letter Report to Fluor Daniel Northwest, Inc., September 10, 1998, Pacific Northwest National Laboratory, Richland, Washington.

and Paris (1981) can be used with the compacted bulk density to estimate the expected change in water content and soil matric potential as a result of the compaction. Water contents are expected to be reduced by a factor of $(\rho_p - \rho_{bc})/(\rho_p - \rho_{bu})$ where the c and u subscripts indicate the compacted and uncompacted bulk densities. Soil matric potentials will be increased by a factor of $\sqrt{e_u/e_c}$ where e indicates the void ratio of the uncompacted and compacted soils and is calculated as $e = (\rho_p - \rho_b)/\rho_b$.

Preliminary water content-matric potential pairs were generated using the silt loam parameters determined by Gee et al. (1989). The generated values were then adjusted for the effect of compaction using the factors given above, and the van Genuchten water retention function was fit to the adjusted water content-matric potential pairs. The resulting parameters for the compacted silt loam soil are given in Table 4.2. The saturated hydraulic conductivity in this table is the geometric mean of two measurements made by Wing (1993) on compacted silt loam soil from the McGee Ranch area. These samples were compacted to 1.70 and 1.75 g/cm^3. This hydraulic conductivity value is similar to the value of 1.4×10^{-6} cm/s reported by Skelly (1994) for measurements on compacted silt loam samples from the McGee Ranch area.

Table 4.2. Best-Estimate Parameter Values for Compacted Silt Loam

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.72	1.76	0.353	0.0035	0.0121	1.37	1.8×10^{-6}

4.1.3 Sand Filter

Wing (1993) measured the physical properties and saturated hydraulic conductivity of a variety of materials used in the construction of a prototype Hanford Barrier on the Hanford Site. The design of this barrier is similar to the barrier design to be used in the ILAW disposal facilities. Wing (1993) report on the properties of two sand samples prepared from sediments gathered from the excavation spoil pile of the existing disposal facility. The sediments were sieved to provide two samples that bracketed a specified range in particle size distribution. Measurements were made on both the fine and coarse samples at two bulk densities, representing uncompacted and compacted conditions.

It is assumed here that the sand filter will be compacted during construction. The best-estimate parameter values for the sand filter are listed in Table 4.3. The particle density and bulk density are the average values of the compacted samples from Wing (1993). The porosity (and saturated water content) calculated from these two values is 0.318. The best-estimate saturated hydraulic conductivity is the geometric average of the compacted sand values reported by Wing (1993). Water retention parameters were estimated from the particle size distribution using the midpoint of the ranges specified in Wing (1993). The particle size distribution range specified in Wing (1993) and the distribution assumed here are shown in Table 4.4. The method of Arya and Paris (1981) was used to calculate water retention points from the particle size distribution. An average soil temperature of 20°C (PNL, 1973) and a contact angle of zero were

assumed in these calculations. The van Genuchten water retention function was fit to the calculated points to provide the parameter values for θ_r, α, and n shown in Table 4.3.

Table 4.3. Best-Estimate Parameter Values for Sand Filter

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.755	1.88	0.318	0.030	0.538	1.68	8.58×10^{-5}

Table 4.4. Particle Size Distribution for Sand Filter: Specified Range from Wing (1993) and Midpoint Values Used to Estimate Water Retention Parameters

U.S. Sieve Size/No.	Particle Diameter (mm)	Percent Passing	
		Range (Wing, 1993)	Midpoint
No. 4	4.75	100	100
No. 10	2.00	85 - 100	92.5
No. 20	0.85	30 - 90	60
No. 40	0.425	15 - 55	35
No. 100	0.15	5 - 35	20
No. 200	0.075	1 - 25	12

4.1.4 Gravel Filter

Best-estimate parameter values for the gravel filter material were calculated in a manner similar to the sand filter. Wing (1993) obtained 5/8 in. crushed basalt road top course and prepared two samples corresponding to the fine and coarse extremes of a specified particle size distribution. This material was also used in the prototype Hanford Barrier (Buckmaster, 1993). The average particle and bulk densities of compacted samples of the crushed basalt are given in Table 4.5. Porosity (and saturated water content) was calculated from these two values. The best-estimate saturated hydraulic conductivity is the geometric mean of the two sample values measured by Wing (1993). Water retention parameters were calculated using the method of Arya and Paris (1981) with the particle size distribution assumed to be the midpoint of the values specified in Wing (1993). Particle size distributions are shown in Table 4.6.

Table 4.5. Best-Estimate Parameter Values for Gravel Filter

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.725	1.935	0.290	0.026	8.10	1.78	1.39×10^{-2}

Table 4.6. Particle Size Distribution for Gravel Filter: Specified Range from Wing (1993) and Midpoint Values Used to Estimate Water Retention Parameters

U.S. Sieve Size/No.	Particle Diameter (mm)	Percent Passing	
		Range (Wing, 1993)	Midpoint
5/8 in.	15.9	100	100
1/4 in.	6.35	55 - 75	65
No. 40	0.425	8 - 24	16
No. 200	0.075	0 - 10	5

4.1.5 Gravel Lateral Drainage Layer

No measurements are available for the gravel drainage layer material. It was assumed that this layer would be composed of crushed basalt and could be compacted to the same bulk density as the gravel filter layer. The particle density, bulk density, and porosity (saturated water content) were thus assumed to be the same as those of the gravel filter. Water retention parameter values for the gravel drainage layer were based on particle size distribution requirements for the gravel drainage component of the prototype Hanford Barrier as given in Buckmaster (1993). As with the sand and gravel filters, the midpoint particle size distribution was assumed and the Arya and Paris (1981) method was used to calculate the parameters, which are given in Table 4.7. The particle size distribution range and midpoint are given in Table 4.8. Saturated hydraulic conductivity is an estimated value based on the minimum required conductivity (1.0 cm/s) and the measurement (via the constant head method) of a gravel sample in Rockhold et al. (1993). This sample had a saturated hydraulic conductivity of 1.85 cm/s.

Table 4.7. Best-Estimate Parameter Values for Gravel Drainage Layer

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.725	1.935	0.290	0.006	17.8	4.84	2.0

Table 4.8. Particle Size Distribution for Gravel Drainage Layer: Specified Range from Buckmaster (1993) and Midpoint Values Used to Estimate Water Retention Parameters

U.S. Sieve Size/No.	Particle Diameter (mm)	Percent Passing	
		Range (Buckmaster, 1993)	Midpoint
1 in.	25.4	100	100
3/4 in.	19.0	80 - 100	90

Table 4.8. Particle Size Distribution for Gravel Drainage Layer: Specified Range from Buckmaster (1993) and Midpoint Values Used to Estimate Water Retention Parameters (Continued)

U.S. Sieve Size/No.	Particle Diameter (mm)	Percent Passing	
		Range (Buckmaster, 1993)	Midpoint
3/8 in.	9.5	10 - 40	25
No. 4	4.75	0 - 4	2
No. 200	0.075	0.5	0.5

4.1.6 Asphaltic Concrete

No water retention measurements on asphaltic concrete have been found in the literature. In estimating parameters for use in the Grouted Tank Waste Disposal PA (Kincaid et al., 1995), Rockhold et al. (1993) assumed that the asphalt layer was impermeable to liquid water and assigned a low conductivity (10^{-20} cm/s) to achieve this. Clemmer et al. (1992) analyzed several asphalt samples and estimated a porosity of 3% to 4% and a hydraulic conductivity of 2×10^{-13} cm/s based on measured N_2 permeability. Hydraulic conductivity values reported in DOE-RL (1993) for asphaltic concrete are 10^{-10} cm/s based on falling head measurements in the laboratory and 10^{-7} to 10^{-9} cm/s for in-field values measured with a falling head permeameter (DOE-RL, 1994). These tests were carried out on materials used in the prototype Hanford Barrier. The spray-applied asphalt coating is expected to reduce the permeability of the asphaltic concrete layer. A polymer-modified asphalt coating from the Hanford Barrier prototype had measured hydraulic conductivity values of approximately 10^{-11} cm/s (Freeman et al., 1994).

Best estimate parameter values for the asphaltic concrete are given in Table 4.9. The average particle density was assumed to be the same as that of the concrete (see Section 4.2.1). The bulk density was calculated from this assumed particle density and the saturated water content. Water retention parameters θ_r, α and n are those assumed by Rockhold et al. (1993) and are not based on data. The saturated hydraulic conductivity assumes that a low permeability coating is applied to the asphaltic concrete.

Table 4.9. Best-Estimate Parameter Values for Asphaltic Concrete

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.63	2.52	0.04	0.000	1.0×10^{-7}	2.0	1.0×10^{-11}

4.1.7 Asphalt Base Course and Grading Fill

The asphalt base course and grading fill components fulfill structural requirements of the disposal facility, but are unlikely to have a significant impact on water flow or contaminant transport. For this rea-

son, they are assigned the hydraulic parameters of materials discussed in other sections. The best-estimate parameter values for the asphalt base course are the same as those of the gravel lateral drainage layer material (Section 4.1.5), which meets the maximum particle size requirement of the base course. These parameter values are repeated here in Table 4.10. The backfill material (Section 4.4.1) is likely to be suitable for use as grading fill. The parameter values of the backfill are thus assigned to the grading fill and given here in Table 4.11.

Table 4.10. Best-Estimate Parameter Values for Asphalt Base Course

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.725	1.935	0.290	0.006	17.8	4.84	2.0

Table 4.11. Best-Estimate Parameter Values for Grading Fill

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
1.89	2.76	0.316	0.049	0.035	1.72	1.91×10^{-3}

4.2 Vault Materials

4.2.1 Concrete

The concrete for the new ILAW disposal facility has not yet been specified and the hydraulic properties of the concrete in existing disposal vaults have not been measured. To provide representative parameter values for the concrete components of the disposal facilities (i.e., the vault itself and the leachate collection system), a number of cores were obtained from the wall of a concrete munitions bunker near Gable Butte on the Hanford Site. This bunker, designated 213J, was built in the late 1940s. This vault was chosen for coring because of the available access to the interior of the vault and because the outer wall has been buried in Hanford sediments for 50 years under natural conditions similar to those expected in the ILAW disposal vaults. Seven cores were drilled from the interior of the vault, five of which were cored all the way to the soil interface on the exterior side of the vault wall (approximately 30.5 cm, or 12 inches). Two of the cores were intact, one had a single clean fracture, and the others fractured when steel reinforcing bars were contacted. The cores were about 4.5 cm in diameter, a dimension chosen to allow collection of intact cores that could be used with minimal modification as samples in a centrifuge machine.

Two of the cores were selected for hydraulic property measurements. After removing a thin layer on the interior and exterior ends of the cores, three sections about 5.5 cm long were cut for samples. Two sections were from each end of the cores, and one section was from the middle. The samples were initially saturated with CO_2 and then vacuum saturated for at least 72 hours with a synthetic Hanford vadose zone

water. Bulk density was calculated from the dry weight and known bulk volume of each sample. Saturated water content was calculated from the difference between the dry and saturated sample weights and the known bulk volume of each sample. Particle density was calculated from the saturated water content and the bulk density.

Water retention and hydraulic conductivity were measured using centrifuge techniques.[1, 2] The parameters of the van Genuchten function, α and n, were fit to the water retention data. Residual water content was assumed to be zero in the fitting procedure, which resulted in superior fits to the data. Hydraulic conductivity was sufficiently low that no unsaturated values could be obtained. Average values for the six concrete samples are given in Table 4.12 and should be used as the best-estimate values until further information about the concrete specifications of the ILAW vaults is known. Arithmetic averages are given except for α and K_s, which are the geometric averages.[3]

Table 4.12. Best-Estimate Parameter Values for Concrete

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.63	2.46	0.067	0.00	3.87×10^{-5}	1.29	1.33×10^{-9}

4.2.2 Filler Material

The filler material to be used in the vault has not been specified. It is assumed here that a quartz sand will be used. This material provides the desired texture to fill the voids and will provide the additional benefit of serving as a water conditioning medium. The parameters given in this section should be used for both the filler material within the steel waste containers and for the filler material between the waste containers until additional specifications for these materials are available.

Kaplan et al. (1998) report measurements made on a coarse quartz sand sample that may be suitable as the filler material. [Kaplan et al. (1998) identify this sand as #2095 Industrial Quartz, Unimin Corp., Emmett, Idaho. It has also been referred to as No. 8 sand.] In this material, particle size was greater than 2 mm for 3.4%, between 1 and 2 mm for 87.5%, and between 0.5 and 1 mm for 8.2%. The particle density of this material was about 2.56 g/cm^3. It was packed to a bulk density of 1.56 g/cm^3 resulting in a porosity of

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1. UFA Ventures, Inc. 1997. *Procedure for Using the UFA to Measure the Matric Potential of a Core Sample.* Technical Procedure: MPP1, Rev. 001.

2. *Test Method for Determining Unsaturated and Saturated Hydraulic conductivity in Porous Media by Open-Flow Centrifugation.* Currently under review by American Society for Testing and Materials D18.21 Subcommittee on Ground Water.

3. Meyer, P.D. 1999. *Hydraulic Parameters of Aged Near-Field Materials of the Immobilized Low-Activity Waste Disposal Facility,* Letter Report to Fluor Daniel Northwest, Inc., August 30, 1999, Pacific Northwest National Laboratory, Richland, Washington.

0.39. Saturated hydraulic conductivity and water retention measurements were made. The van Genuchten function was fit to the water retention data reported by Kaplan et al. (1998). The resulting parameters for the quartz sand are:

$\theta_s = 0.39$, $\theta_r = 0.005$, $\alpha = 0.014$ cm^{-1}, n = 2.82, and $K_s = 0.0712$ cm/s.

Because the matric potential values used by Kaplan et al. (1998) in their water retention measurements do not adequately delineate the water retention curve, the resulting parameters are not reliable.

The same quartz sand material analyzed by Kaplan et al. (1998) was also evaluated more recently using the multistep outflow method of Eching et al. (1994). A sample of the sand was packed to a bulk density of 1.586 g/cm^3; average particle density was measured at 2.63 g/cm^3. This resulted in a porosity of 0.397. Estimated water retention and hydraulic conductivity parameter values from the multistep outflow experiment are given in Table 4.13. These values are the best-estimate parameter values for the filler material.

Table 4.13. Best-Estimate Parameter Values for Filler Material

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}

4.2.3 Glass Waste

According to current plans, the glass waste will be poured into steel packages and allowed to cool. Significant fracturing is anticipated. It is assumed here that the fracturing will be sufficient to allow the glass waste to be treated as an effective porous medium, instead of a fractured medium, and thus the parameters are the same as for the other materials. All porosity in the glass will reside in the fractures (i.e., the glass matrix has no porosity). Total porosity is anticipated to be small – on the order of a few percent[1]. A porosity of 2% was assumed for the best estimate, given in Table 4.14. Bulk density was calculated from the porosity and the measured particle density of ILAW glass (BP1 glass)[1].

McGrail et al. (1998) report hydraulic measurements on crushed and sieved glass waste samples. Glass samples were crushed by hand and sieved to obtain particles between 0.15 and 0.212 mm (the size of fine sand). The sieved material was washed to remove fines smaller than 0.15 mm. Although the process of crushing the glass will result in a porosity much higher than expected to occur in the disposal containers, these are the only known measurements of the hydraulic properties of the glass waste.

The glass samples prepared by McGrail et al. (1998) were packed to a porosity of approximately 0.55. Water retention and unsaturated hydraulic conductivity were measured using centrifuge methods.

1. B.P. McGrail, July 1999, personal communication.

Although the results reported in McGrail et al. (1998) were limited, they indicate that the material behaved similarly to a fairly well-graded loam or sandy loam soil with an air-entry matric potential less than 50 cm. It is difficult, however, to draw conclusions about the best-estimate hydraulic parameters from these experimental results because of the dissimilarity between the expected glass waste form and these sample materials. Measurements on more representative materials are planned for FY 2000.

Assuming that the glass block will be sufficiently fractured to behave as an equivalent porous medium and with the additional assumption that the fracture apertures in the glass waste will have a relatively narrow distribution, it can be expected that the glass waste will behave like a well-sorted material. This suggests a value of n greater than 2 or 3. The value of α and K_s will depend on the actual fracture apertures, which are unknown. If significant fracturing occurs, and yet the porosity remains small, this suggests that the fracture aperture will be small. For the best-estimate hydraulic parameters of the fractured glass waste it has been assumed that the glass waste will behave similarly to a coarse sand. Parameter values, given in Table 4.14, are based on these assumed characteristics of the glass and on representative parameters for a coarse sand.

Note that Fayer et al. (1997) and Fayer and Kincaid (1998)[1] used properties of a clean gravel to represent the glass fractures in a dual porosity model of the new ILAW disposal facility. These properties were measured by Rockhold et al. (1993), with saturated and residual water contents reduced to reflect the low porosity of the fractured glass waste. Particle size in the sample measured by Rockhold et al. (1993) varied from 3.7 to 8 mm. The parameters given in Table 4.14 reflect a small anticipated fracture aperture and thus smaller α and K_s values. The best-estimate α and n values are comparable to the estimates obtained by Reitsma and Kueper (1994) from measurements made on a single fracture in a limestone rock sample.

Table 4.14. Best-Estimate Parameter Values for Glass Waste

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.68	2.63	0.02	0.00	0.2	3	0.01

4.3 Diversion Layer Materials

A diversion layer consisting of a sand drainage layer over a gravel capillary barrier is not a component of the current conceptual design of the new ILAW disposal facility as described in PHMC (1998). It is under active consideration, however, and may be included in the final design as a replacement for, or in addition to, the asphaltic concrete layer. Specifications for the hydraulic properties of the sand and gravel

[1] Fayer, M.J. and C.T. Kincaid. 1998. *Simulations to Guide Measurements of Near-Field Hydraulic Parameters.* Letter Report to Fluor Daniel Hanford, Inc., September 30, 1998, Pacific Northwest National Laboratory, Richland, Washington.

materials will depend on the required performance of the diversion layer and on the particular design of the layer in terms of its dimensions and slope. The materials will need to be chosen to achieve satisfactory hydraulic performance and long-term stability. Nichols and Meyer (1996) performed detailed, two- and three-dimensional simulations of capillary barrier performance for three sand/gravel combinations and three values of slope. Until further analysis is carried out to define the diversion layer materials for the ILAW facilities, hydraulic properties for the materials of the diversion layer are assumed equal to those of materials used in the simulations of Nichols and Meyer (1996) that resulted in the best performance.

4.3.1 Sand Drainage Layer

The best-estimate parameters of the sand drainage layer are those estimated by Rockhold et al. (1993) for a backfill sample. This sample was obtained from the excavation spoil pile of the existing disposal facility. The material was sieved to remove particles greater than 2 mm. The resulting material was 91% sand, 3% silt, and 6% clay. These parameter values were also used by Nichols and Meyer (1996) for the sand component of the best-performing capillary barrier they simulated. The parameter values are given in Table 4.15.

Table 4.15. Best-Estimate Parameter Values for Sand Drainage Layer

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.8	1.65	0.371	0.045	0.0683	2.08	3.00×10^{-2}

4.3.2 Gravel Capillary Barrier Layer

The best-estimate parameter values of the gravel capillary barrier layer are those estimated by Rockhold et al. (1993) for a gravel sample. This sample had particle sizes in the range of 4 to 8 mm. These parameters were also used by Nichols and Meyer (1996) for the gravel component of the best-performing capillary barrier they simulated. The parameter values are given in Table 4.16.

Table 4.16. Best-Estimate Parameter Values for Gravel Capillary Barrier Layer

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.8	1.38	0.518	0.014	3.54	2.66	1.85

4.4 Other Materials

4.4.1 Backfill Material

Kaplan et al. (1998) report measurements made on a backfill sample composited from archived samples collected from 200 East Area boreholes (85 individual samples obtained at depths of 3 to 17 m were composited). This material was 92.5% sand, 2.5% silt, and 5% clay. The sand component had particle size fractions of 11.8% between 1 and 2 mm, 33.8% between 0.5 and 1 mm, 30% between 0.25 and 0.5 mm, 13.5% between 0.1 and 0.25 mm, and 3.3% between 0.075 and 0.1 mm. Reported bulk density and porosity were 1.79 g/cm^3 and 0.29, respectively. Saturated hydraulic conductivity and water retention measurements were made. The van Genuchten function was fit to the water retention data reported by Kaplan et al. (1998) resulting in the following parameters for the composite backfill material:

$\theta_s = 0.34$, $\theta_r = 0.025$, $\alpha = 0.04$ cm^{-1}, $n = 1.49$, and $K_s = 0.0022$ cm/s.

Note that the fitted saturated water content is greater than the reported porosity. As with the quartz sand measurements discussed in Section 4.2.2, the matric potentials used by Kaplan et al. (1998) in their water retention measurements do not adequately delineate the water retention curve. As a result, the fitted parameters are not reliable.

The same composite backfill material was also evaluated more recently using the multistep outflow method of Eching et al. (1994). A sample of the material was packed to a bulk density of 1.889 g/cm^3; average particle density was measured at 2.762 g/cm^3. This resulted in a porosity of 0.316. Estimated water retention and hydraulic conductivity parameter values from the multistep outflow experiment are given in Table 4.17. These values are the best-estimate parameter values for the backfill material.

Table 4.17. Best-Estimate Parameter Values for Backfill

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.76	1.89	0.316	0.049	0.035	1.72	1.91×10^{-3}

4.4.2 Water Conditioning Layer

Quartz sand and crushed glass are being considered for the material of the water conditioning layer. The best-estimate values for the water conditioning layer are the parameter values obtained for the quartz sand sample discussed in Section 4.2.2. These parameter values are repeated here in Table 4.18.

Table 4.18. Best-Estimate Parameter Values for Water Conditioning Layer

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}

4.5 Summary

The best-estimate water retention and hydraulic conductivity functions for the near-field materials of the ILAW disposal facilities are displayed in Figure 4.1. These functions use the best-estimate parameters given in this chapter. The best-estimate parameter values are also collected together in Table 4.19.

Table 4.19. Summary of Best-Estimate Parameter Values for Near-Field Materials

Material	ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
Silt Loam-Gravel Admix	2.72	1.48	0.456	0.0045	0.0163	1.37	8.4×10^{-5}
Compacted Silt Loam	2.72	1.76	0.353	0.0035	0.0121	1.37	1.8×10^{-6}
Sand Filter	2.755	1.88	0.318	0.030	0.538	1.68	8.58×10^{-5}
Gravel Filter	2.725	1.935	0.290	0.026	8.10	1.78	1.39×10^{-2}
Gravel Drainage	2.725	1.935	0.290	0.006	17.8	4.84	2.0
Asphaltic Concrete	2.63	2.52	0.04	0.000	1.0×10^{-7}	2.0	1.0×10^{-11}
Vault Concrete	2.63	2.46	0.067	0.00	3.87×10^{-5}	1.29	1.33×10^{-9}
Vault Filler	2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}
Glass Waste	2.68	2.63	0.02	0.00	0.2	3	0.01
Diversion Layer Sand	2.8	1.65	0.371	0.045	0.0683	2.08	3.00×10^{-2}
Diversion Layer Gravel	2.8	1.38	0.518	0.014	3.54	2.66	1.85
Backfill	2.76	1.89	0.316	0.049	0.035	1.72	1.91×10^{-3}
Conditioning Layer	2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}

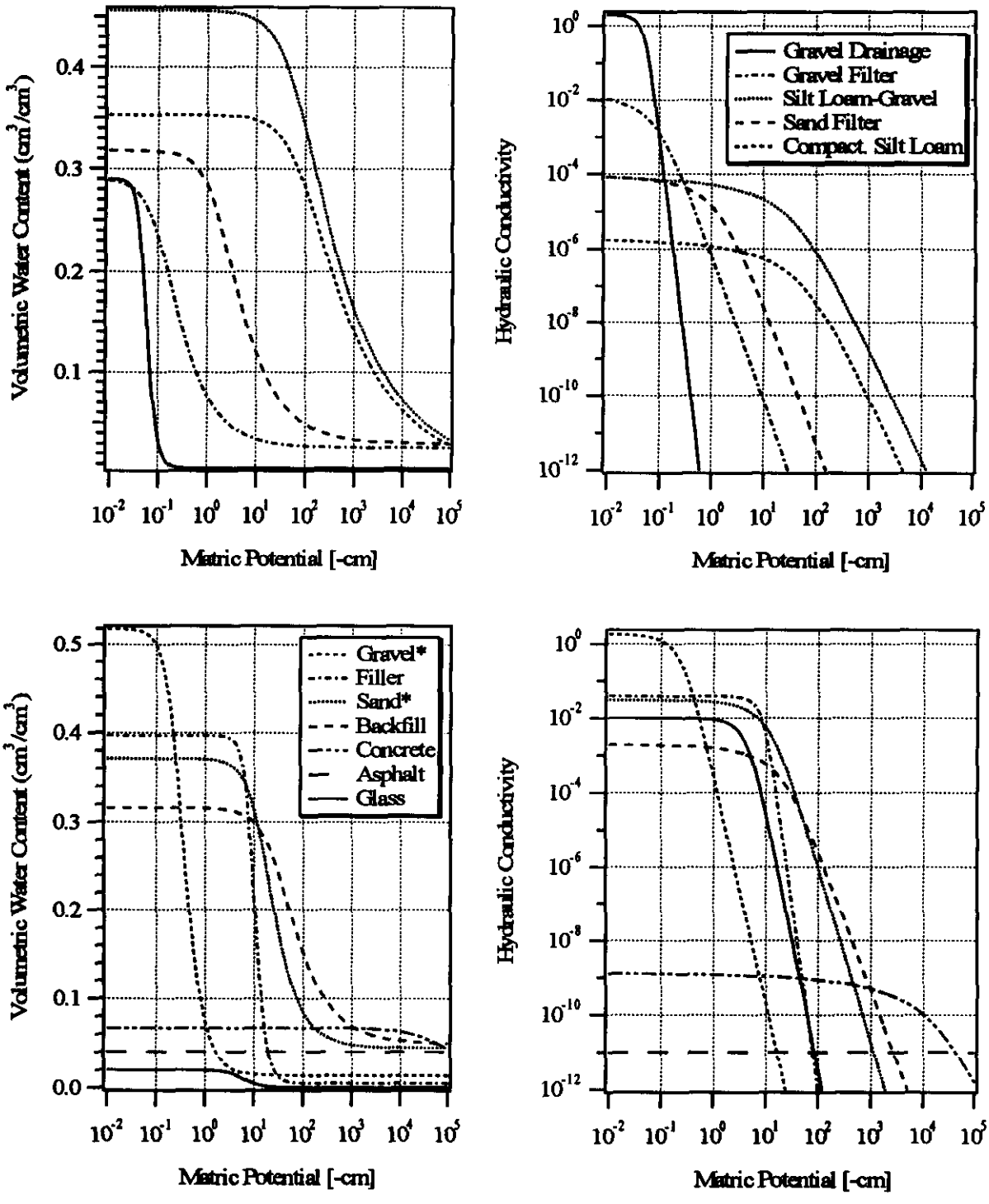

Figure 4.1. Water Retention and Hydraulic Conductivity Functions for Near-Field Materials Using the Best-Estimate Parameters (*component of diversion layer). Note, best-estimate conditioning layer parameters are identical to those of the filler material.

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5.0 Best-Estimate Values for Transport Parameters of Near-Field Materials

This chapter presents the best-estimate values for the transport parameters of the near-field materials. Transport parameter values for the materials of the surface cover are not discussed, however, because contaminants are expected to travel primarily out and down from the concrete vaults. Although diffusion has been shown to be the primary means of transport in simulations of the ILAW disposal facilities, the small flux of water through the surface cover has been sufficient to prevent upward transport from the vaults.[1] If the simulations carried out for the 2001 ILAW PA behave differently, the effect of transport parameters in the surface cover materials may become more important.

Consideration of transport parameters here is also limited to dispersivity and diffusion coefficients. Parameters governing the chemistry of the near-field materials (e.g., adsorption distribution coefficients and solid phase solubility controls) can be found in other data packages (McGrail et al., 1999; Kaplan and Serne, 1999).

5.1 Dispersivity

Transport in the near-field is expected to take place within the materials of the vault and within the backfill. Thus, the discussion will be limited to those materials. Khaleel (1999) provides a discussion of dispersion in the naturally occurring sediments beneath the excavated areas of the ILAW facilities.

Mechanical dispersion is not expected to be a significant factor in transport at the ILAW disposal facilities. Fayer et al. (1997) performed a cursory sensitivity analysis of dispersivity using a waste-form-alone simulation of the ILAW disposal (i.e., no vault) and found that the value of the dispersivity had little effect on the contaminant transport results. Although these results applied to transport from the waste-form to the groundwater, they are expected to hold for near-field simulations as well. The transport flux in the near-field materials due to mechanical dispersion is expected to be small for a number of reasons.

- The scale of transport is limited to the extent of the near field. This limited scale tends to result in small values of dispersivity (Gelhar et al., 1992).
- The near-field materials are relatively homogeneous – the vault materials because they are constructed to be homogeneous and the backfill material because of mixing by construction equipment. This homogeneity will tend to reduce dispersivity (Gelhar, 1986).
- Pore water velocities in the near field are expected to be small due to the low water flux through the surface barrier. Such low pore water velocities decrease the magnitude of the dispersive flux relative to the diffusive flux.

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[1] Fayer, M.J. and C.T. Kincaid. 1998. *Simulations to Guide Measurements of Near-Field Hydraulic Parameters.* Letter Report to Fluor Daniel Hanford, September 30, 1998, Pacific Northwest National Laboratory, Richland, Washington.

Measurements of dispersion in unsaturated field soils are rare. Indirect evidence suggests that the dispersivities in the backfill soil at the ILAW facilities will be on the order of a few centimeters. Rockhold et al. (1996) modeled a detailed tracer-infiltration experiment in heterogeneous sandy soils in New Mexico. The scale of the model was 7 m deep, comparable to the scale of the near-field depth at the ILAW disposal facilities. Excellent predictive results were obtained by Rockhold et al. (1996) using a dispersivity value of 3 cm.

Recently, Ward et al. (1998)[1] conducted a pair of tracer-infiltration tests in the 200 East Area of the Hanford Site, on the new ILAW disposal site. The first test measured field-scale flow and transport properties in the naturally occurring surface soils. After excavating to a depth of 1.5 m, the experiment was repeated. The scale of each experiment was approximately 1 m by 6 m in plan and 1.5 m deep (thus the second experiment sampled sediments 3 m below the surface). Dispersivities estimated from the experimental results of the second test increased with scale, but appeared to approach an asymptotic value of about 7 cm at a scale of about 1 m.

Many numerical methods for simulating contaminant transport in the subsurface have difficulty when dispersivity is significantly less than the dimension of the numerical grid. As a result, dispersivity values have often been selected to satisfy numerical restrictions. In the simulation of Rockhold et al. (1996) this problem was avoided by using a numerical grid size of 10 cm, sufficiently small to avoid numerical difficulties with the dispersivity of 3 cm they used. (This dispersivity value was based on tracer measurements.) The observations of Ward et al. (1998) and the expected conditions at the site suggest that, for the ILAW PA, longitudinal dispersivity in the near-field materials should be small. A value of 10 cm is recommended. If numerical requirements dictate that a larger dispersivity be used in the near-field, the effect of this choice should be investigated and estimated.

5.2 Apparent Diffusion Coefficients through Concrete

5.2.1 Conceptual Model of Diffusion through Cement

Atkinson (1983), Atkinson et al. (1986), and Atkinson and Nickerson (1988) present a useful conceptual model for describing the transport of contaminants through cement. The authors consider that the transport is a combination of both physical processes such as diffusion and chemical processes such as precipitation/dissolution and adsorption/desorption. The first two articles discuss diffusion-controlled release (leaching) of a contaminant out of cement while the latter article discusses how to evaluate the diffusion of

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[1] Ward, A.L., R.E. Clayton and J.S. Ritter. 1998. *Hanford Low-Activity Tank Waste Performance Assessment Activity: Determination of In Situ Hydraulic Parameters of the Upper Hanford Formation.* Letter Report to Fluor Daniel Hanford, Inc., December 31, 1998, Pacific Northwest National Laboratory, Richland, Washington.

a contaminant through a slab of cement or into a thick slab of cement. All three articles are limited to water-saturated cement.

The model used by Atkinson and colleagues for the apparent diffusion coefficient was presented previously as Equation 3.5.

$$D_a = D_i/\alpha' = D_f \delta \phi/(\tau \alpha') \quad (5.1)$$

Recall that in this equation the term D_i contains all the physical aspects of diffusional transport and the term α' contains all the chemical aspects. Several experimental approaches can be used to measure these two parameters and, by observation, Atkinson et al. (1986) and Atkinson and Nickerson (1988) have determined which experimental techniques give the best results for various contaminants under various geochemical conditions.

5.2.2 Measurement of Diffusion Coefficients

Atkinson et al. (1986) suggest that classical leach tests of spiked cement solids (saturated with aqueous solution) that use the intermittent solution exchange method such as the ISO and ANSI/ANS-16.1 tests (see ISO, 1979; Mendel, 1982; and ANS, 1986), and the purely static leach test, can be used in concert to calculate D_a and α', respectively. Using the combination of two leach test methods, one can get fairly accurate values for the physical and chemical parameters of interest.

At long time periods, the static leach test provides a good estimate of the ultimate amount of contaminant that can leave the solid waste and go into solution for scenarios with limited water flux, such as is expected in the ILAW disposal facilities. From knowledge of the starting inventory in the waste, $A_s(t = 0)$, one can determine the final inventory left in the solid, $A_s(t = \infty)$, which represents equilibrium between the solid and solution phases. From knowledge of the volumes of solution and the volume of the solid present in the static test, one can calculate α' from Equation 5.2:

$$\alpha' = A_s(\infty)\, V_L/(A_L(\infty)\, V_s) \quad (5.2)$$

where A_s = amount of contaminant in solid, per volume, at end of test

A_L = amount of contaminant in solution, per volume, at end of test

V_L = volume of liquid used in static test

V_s = volume of solid used in static test.

After α' has been calculated, Equation 3.11 and known solid characteristics of porosity and dry bulk density can be used to estimate the K_d value. The intermittent solution exchange leach tests previously mentioned give a direct measurement of D_a. (Note that D_a is also referred to as the effective diffusion coefficient, D_{eff}, in the leaching literature.) Given that the apparent diffusion coefficient is related to the intrinsic diffusion coefficient of the porous media, D_i, by Equation 5.1, one can calculate D_i for each contaminant from its value of D_a (obtained from the intermittent leach test) and its value of α' (obtained from the static leach test).

Alternatively, one can make some other contaminant measurements and estimate D_i and α' for a given cement type and particular contaminant solely from the intermittent leach tests as follows. If one believes that there is a constituent that does not interact with the cement chemically, then it can be used to measure the intrinsic diffusion coefficient directly because α' will be equal to the porosity (because the K_d for a non-reacting constituent is zero, see Equation 3.11). Some researchers have assumed that nitrate, tritium, chloride, sodium, or potassium are non-reactive constituents in concrete or cement leach tests. If so, then the measured D_e can be used to estimate the intrinsic diffusion coefficient for the particular cement by multiplying it by the cement porosity (see Equations 3.10 and 3.11). In this instance, D_i is assumed to be a property solely of the cement and not the contaminants within the cement. Once D_i is established, then the other leach data for reactive constituents within the cement give a measure of their unique D_e, from which the individual values of α' can be calculated. In addition, from knowledge of the porosity and dry bulk density, the value of K_d for an individual contaminant can be estimated. Atkinson et al. (1986) suggest that such an approach should provide an estimate of α' that is within one order of magnitude for a contaminant with a large K_d and should provide a much better estimate for a contaminant with a small K_d. Measurements used as the basis for the best-estimate diffusion coefficients reported in later in this chapter have used nitrate as the noninteracting chemical.

5.2.2.1 Through-Diffusion Test

There are numerous through-diffusion and diffusion penetration profile experiments that have been performed by the nuclear waste community to evaluate contaminant fate. These data can also be used to estimate the two basic parameters in Atkinson and Nickerson's conceptual model, D_i and α', from which the K_d value can be obtained. We have found by analysis of many experiments that D_i is most accurately measured using the through-diffusion type of test where a thin slab of porous media is mounted between two reservoirs of liquid. In one reservoir the solution is devoid of the contaminant of interest, and in the other, the solution chemical composition is the same except that the contaminant is present. The "hot" reservoir is connected to a large recirculating reservoir such that there is no drop in the contaminant concentration throughout the test. The build-up of the contaminant in the initially "cold" reservoir is monitored until it reaches a steady state. Steady state is reached when a plot of C/C_0 on the Y-axis and time on the X-axis (the breakthrough curve) culminates in a straight line. D_i is related to the slope of such a plot by the constant factor ($\phi VL/A$)

where V = volume of solution in the initially "cold" reservoir (no contaminant present)

L = thickness of the porous slab or disk

A = geometric surface area of the porous slab or disk

C = concentration of the contaminant in the "cold" reservoir at time t

C_0 = concentration in the "hot" reservoir at all times (must be kept constant).

If the experiment is performed correctly the chemical term α' can also be estimated from the equation

$$\alpha' = 6\, D_i\, t_0 / L^2 \tag{5.3}$$

where t_0 = the intercept of the slope of the above mentioned plot with zero breakthrough (the amount of time delay before contaminant starts to appear in the cold reservoir under steady state conditions).

Atkinson and Nickerson (1988) suggested that through-diffusion tests give an accurate measure of D_i but they felt that the estimate of α' was not as accurate because there appear to be two types of porosity in cement. Dual porosity causes the estimates of α' to be smaller than they really are.

One type of porosity makes up a small percentage of the total porosity and is conceptualized as well-connected pores allowing fast transport and relatively lower chemical capacity (adsorption). The second type of porosity makes up the bulk of the total porosity and allows slow transport because of constrictions/tortuosity in the pore "connectiveness." Because this second type of porosity makes up most of the total porosity it also can adsorb (chemically react) more than the first type of porosity and thus it exhibits a higher chemical capacity factor, α'.

One drawback to the through-diffusion testing is that highly adsorbing contaminants take long time periods to show up in the cold reservoir. Also, for concretes with large aggregate, one must make the slabs or disks thicker to prevent short circuits around the individual grain boundaries of the large aggregates.

5.2.2.2 Penetration Profile Test

A second experimental approach generally referred to as the penetration profile test utilizes a slab of porous medium that has all but one side blocked off to solution penetration (e.g., by being cast in an epoxy mold or embedded in hydrophobic plastic or wax). If the slab is assumed to be semi-infinitely thick, then at any given time the penetration profile of a contaminant that is in contact with the surface ($x = 0$) of the slab is related to the physical aspects of diffusion, D_i, and the chemical capacity factor, α', through the complementary error function.

$$\frac{C_s(x)}{C_L} = \alpha' \mathrm{erfc}\left\{\sqrt{\frac{\alpha' x^2}{4 D_i t}}\right\} \tag{5.4}$$

where C_s = concentration of contaminant on solid at depth x and time t

C_L = concentration in liquid at time t

Brown et al. (1964; 1969), Phillips and Brown (1964), and Relyea et al. (1986) describe a convenient data reduction scheme that transforms the contaminant penetration profile into the cement or other porous medium as a probit probability distribution. One takes the breakthrough profile, determined as the concentration of the contaminant in cement at depth x and time t divided by the concentration of the contaminant in the face of the cement at $x = 0$ and $t = 0$, and after calculating this ratio (as a percentage) one looks up the equivalent probit value for all the data points between 5% and 95% using the probit table in Finney (1971) or equivalent tables of mathematical functions. The probit data are then plotted on the Y-

axis and the depth of penetration is plotted on the X-axis. Such plots should generate a straight line as opposed to the sigmoidal curve that is the outcome of Equation 5.4. Thus the probit transformation curve is easier to interpret. The apparent diffusion coefficient, D_a, is related to the slope, Δ, of the line formed by the data through the following equation.

$$D_a = (2\,\Delta^2\,t)^{-1} \tag{5.5}$$

Again by using several tracers or contaminants and having one that is considered a non-reactive constituent (perhaps nitrate, tritium or chloride), one can estimate K_d values for the other reactive constituents using Equations 3.10 and 3.11. This goes back to the original conceptual model that breaks transport into a purely physical term, D_i, and a purely chemical term α'. Because D_i is a property of the porous medium, it is the same for all the tracers or contaminants moving through a given cement. When one knows that a particular contaminant is non-reactive then its measured apparent diffusion coefficient, D_a, is equivalent to D_i/ϕ because the K_d of the non-reactive contaminant is zero. Once D_i is known, α' for each reactive contaminant can be calculated from its measured apparent diffusion coefficient, D_a, and the measured value of the cement's intrinsic diffusion coefficient, D_i, can be determined from the non-reactive contaminant. When α' has been determined for each reactive contaminant, then K_d can be estimated from Equation 3.10 and the known porosity and dry bulk density of the cement.

Application of these conceptual models and mathematical techniques to diffusion and leach data in the literature could increase the available estimates of K_d values for important contaminants, given that there are many more waste-form leach tests and diffusion tests for cement in the literature than there are well implemented adsorption tests. We have not pursued this approach for this data package, however. Instead, we have tabulated the apparent diffusion coefficients, D_a, directly without trying to separate the physical and chemical reaction components. For the next data package we will try to see if the leach and diffusion data in the literature are, in fact, readily converted and whether the calculated α' values seem plausible in comparison to direct K_d measurements on concrete/cement.

5.2.3 Best-Estimate Diffusion Coefficients

Tests using both the through-diffusion concrete slab test and the penetration profile test are currently underway as part of the ILAW PA project. In both cases we are studying the diffusion of I^- and TcO_4^- through concrete. The first results should be available in January 2000, but the through-diffusion test will likely require another year to reach steady state.

In the through-diffusion test, a 2-cm-thick slab of concrete with the composition shown in Table 5.1 is mounted between two reservoirs of liquid. In one reservoir the solution is devoid of the contaminant of interest and in the other (much larger reservoir) the chemical composition is the same except the contaminants are present. It was hoped that the reservoir was large enough that there would be no significant drop in the contaminant concentration throughout the test. Preliminary results suggest that the concentration of contaminants in the "hot" reservoir is decreasing with time. A more sophisticated mathematical algorithm

to analyze diffusion data has recently been published (Moridis, 1999). This algorithm can analyze data for which the concentration of contaminant in the hot reservoir decreases over time.

Table 5.1. The Composition of ILAW Concrete Used in Diffusion Testing

Material	Design Mix	Material Details
Cement	0.27	Portland Type I & II
Fly Ash	0.04	Class F fly ash; 20% of cement volume
Coarse Aggregate	0.04	Particle size 2.83 mm to 2 mm (ASTM sieve -7 to +10)
Fine Aggregate	0.48	Sand particle size < 2 mm (ASTM sieve -10)
Water	0.13	Water-to-cement ratio: 0.5
Steel Fiber	0.04	Deformed, nominal length 8 mm (0.32 in.)
Polyheed 997	3.75e-3	
Air Content	4.5%	

In the penetration profile test, two cells, one containing Hanford sediment and one consisting of a plug of concrete, are butted up to each other in a cylindrical half-cell arrangement. The soil cell is a typical Hanford sand soil (4 cm diameter and 25 cm long) while the concrete monolith (4 cm in diameter and 4 cm long) is spiked with 0.5 mCi/l of ^{125}I, 0.05 mCi/l of ^{99}Tc and 20 mg/l of U. Preliminary results of the penetration of the isotopes into the Hanford soil are expected in January 2000. Identical half-cells with spiked and unspiked Hanford sediment are used to differentiate the diffusion of contaminants out of the concrete and into the sediment.

Apparent diffusion coefficients for constituents migrating through cement are shown in Table 5.2. Sources for the diffusion coefficient data presented in Table 5.2 are Serne (1990), Serne et al. (1987), Serne et al. (1989a), Serne et al. (1989b), Serne et al. (1992), Serne et al. (1995), and Krupka and Serne (1996) and are predominantly from grouts and solidified cementitious waste forms without any aggregate present. We have found one recent article on the diffusion of Cl^-, considered a non-reactive species, through various concretes. The median value obtained was 8×10^{-8} cm^2/s (Bretton et al., 1992). This value can be compared to the apparent diffusion coefficients of several nonreactive constituents in grouts and cement (no aggregate present) from Table 5.2. The grout/cement diffusion values for nonreactive tracers are consistently ~5×10^{-8} cm^2/s. The slightly higher apparent diffusion coefficient in concrete may be attributable to the presence of aggregate and the relatively higher porosity around the aggregate/cement paste interfaces.

Table 5.2. Best-Estimate Apparent Diffusion Coefficients for Constituents Migrating through Cement

Contaminant	Apparent Diffusion Coefficients (cm^2/s)	Comment
Ac	5×10^{-11}	
Am	5×10^{-13}	
Sb	2×10^{-10}	
As	5×10^{-10}	
Ba	5×10^{-11}	
Bi	5×10^{-8}	
C-14 as carbonate	1×10^{-12}	
Cd	5×10^{-10}	
Ce	5×10^{-11}	
Cr(III)	5×10^{-10}	
Cr(VI)	1×10^{-10}	
Cm	5×10^{-11}	
Co	5×10^{-11}	
Cs	5×10^{-10}	
CN^-	5×10^{-8}	
Eu	5×10^{-11}	
Fe	5×10^{-11}	
H^3 (tritium)	5×10^{-8}	
I^- (iodide)	5×10^{-8}	
Pb	1×10^{-11}	
Hg	5×10^{-11}	
Mn	5×10^{-11}	
Nb	5×10^{-11}	
Ni	5×10^{-10}	
NO_3^-	5×10^{-8}	
Np(V)	5×10^{-10}	
Pa	5×10^{-8}	conservative guess
Pd	5×10^{-11}	
Pm	5×10^{-10}	
Po	5×10^{-11}	

Table 5.2. Best-Estimate Apparent Diffusion Coefficients for Constituents Migrating through Cement (Continued)

Contaminant	Apparent Diffusion Coefficients (cm^2/s)	Comment
Pu	5×10^{-11}	
Ra	5×10^{-11}	
Rn	5×10^{-8}	guess
Ru	5×10^{-10}	
Se	2×10^{-10}	
Ag	5×10^{-11}	
Sm	5×10^{-11}	
Sn	1×10^{-11}	
Sr	5×10^{-11}	
Tc	1×10^{-8}	
Th	1×10^{-12}	
Tl	5×10^{-10}	
U	1×10^{-12}	
Y	5×10^{-11}	guess
Zn	5×10^{-10}	

For the ILAW PA simulations, the values in Table 5.2 should be used directly if possible. In the event that the simulation codes cannot directly use the apparent diffusion coefficients, the free-water diffusion coefficients and capacity factors for the potential ILAW contaminants are given in Table 5.3. The free-water diffusion values were taken from Robinson and Stokes (1959). The values presented are for 25° C and should be adjusted for other temperatures by multiplying by the ratio of the viscosity of water at 25° C to the viscosity at the desired temperature. For example, at 15° C the D_f values in Table 5.3 should be multiplied by 0.782 to correct for the lower temperature. The capacity factors in Table 5.3 were calculated by taking the measured (or estimated) values of the apparent diffusion coefficients from Table 5.2 and assuming that nitrate has no interaction with the cements/grouts and thus has a capacity factor of one. The intrinsic diffusion coefficient, which represents the physical aspects of the grout/cement/concrete, therefore becomes 5×10^{-8} cm^2/s for all constituents. The estimated capacity factors are thus the intrinsic diffusion coefficient (5×10^{-8}) divided by each reactive constituent's apparent diffusion coefficient (see Equation 5.1).

Table 5.3. Best-Estimate Free-Water Diffusion Coefficients and Capacity Factors for Constituents Migrating through Concrete

Contaminant	Free-Water Diffusion Coefficient [cm^2/s]	Capacity Factor [unitless][3]	Comment
Ac	6×10^{-6}	1,000	D_f assumed to be La
Am	6×10^{-6}	100,000	D_f assumed to be La
Sb	1×10^{-5}	250	D_f conservative estimate
As	1×10^{-5}	100	D_f conservative estimate
Ba	8.5×10^{-6}	1000	Both measured
Bi	1×10^{-5}	1	D_f and α' conservative estimates
C-14 [bicarbonate]	1.1×10^{-5}	50,000	Both measured
Cd	7×10^{-6}	100	D_f assumed to be Zn
Ce	6×10^{-6}	1000	D_f assumed to be La
Cr(III)	7×10^{-6}	1000	D_f assumed to be Zn
Cr(VI)	1×10^{-5}	500	D_f conservative estimate
Cm	6×10^{-6}	1000	D_f assumed to be La
Co	7×10^{-6}	1000	D_f assumed to be Zn
Cs	2.1×10^{-5}	100	Both measured
CN^-	2×10^{-5}	1	D_f and α' conservative estimates
Eu	6×10^{-6}	1000	D_f assumed to be La
Fe	6×10^{-6}	1000	D_f assumed to be Zn
H^3 (as OH^-)	6×10^{-5}	1	Both measured
I^-	2×10^{-5}	1	Both measured
Pb	9×10^{-6}	5000	Both measured
Hg	8×10^{-6}	1000	D_f conservative estimate
Mn	7×10^{-6}	1000	D_f assumed to be Zn
Nb	2×10^{-5}	1000	D_f conservative estimate
Ni	7×10^{-6}	100	D_f assumed to be Zn
NO_3^-	1.8×10^{-5}	1	Both measured
Np(V)	2×10^{-5}	100	D_f conservative estimate
Pa	2×10^{-5}	1	D_f and α' conservative estimates
Pd	2×10^{-5}	1000	D_f conservative estimate
Pm	6×10^{-6}	100	D_f assumed to be La
Po	2×10^{-5}	1000	D_f conservative estimate
Pu(V,VI)	2×10^{-5}	100	D_f conservative estimate

Table 5.3. Best-Estimate Free-Water Diffusion Coefficients and Capacity Factors for Constituents Migrating through Concrete (Continued)

Pu(III,IV)	6×10^{-6}	1000	D_f assumed to be La
Ra	8×10^{-6}	1000	D_f assumed to be Ba
Rn	1×10^{-4}	1	D_f and α' conservative estimates
Ru	2×10^{-5}	100	D_f conservative estimate
Se	2×10^{-5}	250	D_f conservative estimate
Ag	2×10^{-5}	1000	Both measured
Sm	6×10^{-6}	1000	D_f assumed to be La
Sn	2×10^{-5}	5000	D_f conservative estimate
Sr	8×10^{-6}	1000	Both measured
Tc	2×10^{-5}	1	D_f conservative estimate
Th	6×10^{-6}	50,000	D_f assumed to be La
Tl	2×10^{-5}	100	D_f conservative estimate
U(VI)	2×10^{-5}	100	D_f conservative estimate
U(IV)	6×10^{-6}	50,000	D_f assumed to be La
Y	2×10^{-5}	1000	D_f conservative estimate
Zn	7×10^{-6}	100	Both measured

5.3 Apparent Diffusion Coefficients in Backfill and Glass Waste

For nonreactive solutes diffusing through unsaturated sediments, one of the empirical relationships discussed in Section 3.9 can be used. Measurements of intrinsic diffusion coefficients were reported in Conca and Wright (1990 and 1991) for a variety of materials, including sediments from the Hanford Site. The results obtained by Conca and Wright suggest that the model of Kemper and Van Schaik (1966) (Equation 3.9) is inappropriate and may significantly overestimate the intrinsic diffusion coefficients at low water contents. The models of Millington (1959) and Campbell (1985) (Equations 3.7 and 3.8) are more representative of the relationship between the intrinsic diffusion coefficient and volumetric water content observed by Conca and Wright. It was also observed that the $D_i(\theta)$ relationship (for a chemically nonreactive solute) was remarkably similar for the variety of materials reported in Conca and Wright (1991), which included porous and nonporous tuff gravels, bentonite clays, Hanford sandy soils and gravels, and whole rock cores of non-welded tuff. This result suggests that the aqueous intrinsic diffusion coefficient may not depend strongly on the porosity of the material and that the model of Millington (Equation 3.7) may not be the most appropriate model for the ILAW PA. An informal comparison of the results presented in Conca and Wright (1991) and the diffusion models represented by Equations 3.7 and 3.8 suggest that a slightly modified version of the model of Campbell (1985) appears to fit the data of Conca and Wright (1991) reasonably well. This model has the form

$$D_i = 2.8 D_f \theta^{2.3} \quad (5.6)$$

which is Equation 3.8, with a slightly smaller exponent. Equation 5.6 can be used in the ILAW PA simulations to model diffusion of nonreactive constituents in the non-cementitious materials of the near field. The free-water diffusion coefficients, D_f, for individual contaminants can be selected from Table 5.3 or calculated using one of the available equations (see Grathwohl, 1998).

To estimate the effect of chemical interactions on the diffusion coefficients, the retardation factor can be used. Combining Equations 3.10 and 3.12, the apparent diffusion coefficient (which includes the chemical effects) can be obtained from the intrinsic diffusion coefficient (which includes only physical effects of the porous medium).

$$D_a = D_i / R\theta \quad (5.7)$$

The porosity in Equation 3.12 is replaced by the water content for unsaturated media. Estimated values for the K_d of a given constituent and sediment (required to calculate the retardation coefficient) can be obtained from the geochemistry data package (Kaplan and Serne, 1999).

6.0 Uncertainty and Other Issues Affecting Parameter Values

The best-estimate parameter values discussed in Chapters 4 and 5 are not the only values required for the 2001 ILAW PA. The PA must consider uncertainty in its predictions of facility performance and this uncertainty is due, in part, to uncertainty in the hydraulic and transport parameters of the near-field materials. In addition, the long time-frame of the PA analysis requires that potential changes over time in the near-field materials and their properties be considered. This chapter discusses the currently available information regarding near-field hydraulic and transport parameter uncertainty and changes in near-field material parameter values over time.

The issue of effective parameter values is also briefly discussed here. Effective parameter values are required when the scale of material heterogeneity represented in simulations is larger than the scale of that heterogeneity in the actual system being modeled. This issue is particularly important for the naturally occurring sediments beneath the excavated areas of the ILAW disposal facilities (and is discussed in Khaleel [1999]), but it is also relevant in the near-field simulations where the materials of the vault (concrete, glass waste, filler material, and steel corrosion products) are not likely to be represented in detail.

The materials of the surface barrier, except for the asphaltic concrete, are not discussed here. Fayer (1999) discusses the uncertainty in the recharge rate allowed through the surface barrier and the manner in which the recharge rate is expected to change over time as a result of changes in the surface barrier.

6.1 Uncertainty in Parameter Values

The best-estimate parameter values discussed in Chapter 4 are uncertain because they are based on limited data, they use indirect methods to estimate parameters (such as the Arya and Paris [1981] method), or they use data from existing materials that are not expected to be identical to the materials used in the ILAW facilities (such as the concrete). In addition, material properties are expected to vary spatially and the small-scale measurements obtained in the laboratory may not represent the large-scale behavior in the field. Improving the available data on critical materials and planning for construction of a test pad to make field-scale measurements are anticipated to be subjects of further investigation by the ILAW PA project in FY 2000. Available information concerning the uncertainty of the near-field material properties is discussed in this section.

This discussion of uncertainty is framed in terms of reasonable bounding cases that should be considered in the 2001 ILAW PA. As a result, the bounding parameter values provided in this section represent reasonable bounds on the average properties of each material. It is not unreasonable to expect that spatial heterogeneity in material properties may result in point measurements that are outside these bounding values.

In an uncertainty analysis, it is generally not necessary to consider all the parameters used in the simulation models. The input parameters that are most important to the uncertainty in the output of the

models (e.g., predictions of dose or contaminant concentrations) are those parameters that simultaneously possess two characteristics.

1. The uncertainty (or variability) of the parameter is significant. The parameter uncertainty can be represented by its coefficient of variation, which is the standard deviation of the parameter divided by its mean value. This can be estimated from measured data and/or from expert judgement and experience.
2. The sensitivity of the simulation model results to the value of the parameter is significant. The relative sensitivity of a model to its parameter values is measured by systematically or randomly varying parameter values and calculating the resulting changes in model output. It should be noted that the typical procedure of varying parameters individually ignores parameter correlation and the potential dependence of sensitivity on the values of other parameters.

It is worthwhile to note that significant parameter variability does not always mean large parameter variability. If simulation model results are very sensitive to a particular parameter, the variability of that parameter value may not need to be very large in order to be significant.

In evaluating parameters with respect to the two characteristics above for application to the ILAW PA, the authors have relied primarily on expert judgement and experience because there is currently no comprehensive sensitivity analysis of the ILAW disposal facilities and there is insufficient data to calculate parameter uncertainty in most cases.

6.1.1 Asphaltic Concrete

Although the water retention parameters of the asphaltic concrete layer are highly uncertain (because there are no known measurements of water retention on this material), these parameters are not anticipated to greatly affect the performance of this low permeability layer. This is because the asphaltic concrete is expected to remain saturated over a very wide range of matric potentials (see Figure 4.1). The hydraulic parameter expected to most significantly impact the performance of the asphaltic concrete is the saturated hydraulic conductivity. In addition, the porosity may be of secondary importance.

Several studies of the hydraulic conductivity of asphalt or asphaltic concrete conducted as part of the development of the Hanford Barrier were discussed in Section 4.1.6. Lacking other information, these studies form the basis of the reasonable bounds on the saturated hydraulic conductivity of the asphaltic concrete layer of the ILAW disposal facilities. The asphalt measurements of Clemmer et al. (1992) represent the lower bound on hydraulic conductivity (10^{-13} cm/s) and porosity (0.03). The in-field measurements of asphaltic concrete hydraulic conductivity reported in DOE-RL (1993) represent the upper bound (10^{-7} cm/s). This upper bound represents the potential for the in-field value to be significantly larger than the small-scale laboratory measurements and assumes that the asphalt coating fails to perform as designed or is not used. The upper bound porosity is taken from the largest porosities measured in the concrete cores obtained from the 213J bunker on the Hanford Site (0.08). Reasonable bounding values are given in Table 6.1.

Table 6.1. Reasonable Bounding Values for Critical Asphaltic Concrete Parameters. Best-Estimate Values Shown for Comparison

Parameter	Lower Bound	Best Estimate	Upper Bound
K_s (cm/s)	1.0×10^{-13}	1.0×10^{-11}	1.0×10^{-7}
ϕ (= θ_s)	0.03	0.04	0.08

6.1.2 Concrete

Because the concrete functions hydraulically as a low permeability layer, like the asphaltic concrete, the hydraulic parameter expected to most significantly impact concrete behavior is the saturated hydraulic conductivity. Water retention measurements on concrete are rare. However, the measurements on the cores obtained from the 213J vault on the Hanford Site are available to estimate potential variability in these parameters. These measurements and literature values are available to estimate potential variability in concrete saturated hydraulic conductivity.

The saturated hydraulic conductivity of concrete is known to vary significantly with the water/cement ratio, additives such as slag or fly ash, and the curing conditions (Whiting and Walitt, 1988). In addition, the hydraulic conductivity of concrete is typically greater than the hydraulic conductivity of the cement paste alone. Because of the difficulty in directly measuring hydraulic conductivity, gas permeability and electrical conductivity measurements are often used as indirect methods to estimate concrete hydraulic conductivity. Gas permeability measurements have been an unreliable estimator of water permeability and the electrical conductivity measurements appear to result in hydraulic conductivity estimates that are two orders of magnitude smaller than obtained with direct measurement (Tumidajski and Lin, 1998).

The concrete to be used in the new ILAW disposal facility has currently not been specified, but it is assumed here that it will be a standard concrete with no additives. The best-estimate value of saturated hydraulic conductivity is representative of the direct measurements on concrete that have appeared in the literature. This best estimate was based on measurements of a 50-year-old concrete with large aggregate. (The observed diameter of the aggregate was typically 2 cm, but exceeding 4.5 cm in one of the cores.) For the six concrete samples from the 213J vault, the measured hydraulic conductivity varied from 4.4×10^{-10} to 5.9×10^{-9} cm/s. Based on a survey of literature values, a reasonable lower bound for the saturated hydraulic conductivity of concrete is 5×10^{-11} cm/s. Currently available data are based on measurements made on small samples. It is possible that large-scale field measurements of concrete hydraulic conductivity will be significantly larger, as reported in DOE-RL (1993) for the asphaltic concrete of the Hanford Barrier. Assuming this is the case, a reasonable upper bound on the saturated hydraulic conductivity of concrete is 1×10^{-7} cm/s.

Reasonable bounds on the variability of the water retention parameters for concrete were based on the measurements from the six core samples obtained from the 213J vault on the Hanford Site. The lower and upper bounds were taken as the approximate 0.01 and 0.99 quantiles of the parameter distributions. A normal distribution was assumed for the saturated water content (porosity) and for the van Genuchten parameter, n. A lognormal distribution was assumed for the van Genuchten parameter, α. The mean and variance of each distribution was assumed to be the sample mean and variance obtained from the six concrete samples. The resulting lower and upper bounds are given in Table 6.2 for the water retention parameters and the saturated hydraulic conductivity.

Table 6.2. Reasonable Bounding Values for Concrete Parameters. Best-Estimate Values Shown for Comparison

Parameter	Lower Bound	Best Estimate	Upper Bound
K_s (cm/s)	5.0×10^{-11}	1.33×10^{-9}	1.0×10^{-7}
ϕ (= θ_s)	0.039	0.067	0.095
θ_r	0	0.00	0
α (cm^{-1})	8.67×10^{-6}	3.87×10^{-5}	1.73×10^{-4}
n	1.17	1.29	1.41

6.1.3 Glass Waste

The best-estimate parameter values for the glass waste were based on qualitative information about the expected final form of the glass waste. Because there were no direct measurements on this expected material and there are no measurements in the literature on analogous materials, the best-estimate parameter values are very uncertain. Because of the lack of data, the reasonable lower and upper bounds for the glass waste are based on a judgement about what the nature of the fractures might be. The lower bound parameter values represent a case in which there are fewer fractures and the fracture apertures are very small. The glass waste behaves more like a fine sand in this case, albeit one with a very low porosity. The upper bound parameters represent a case in which the fracture apertures are much larger. The glass waste behaves more like a gravel in this case. The values given in Table 6.3 reflect these assumptions.

The bounding values for the glass waste assume that the waste is sufficiently fractured that it can be represented as a porous medium. If the actual glass waste violates this assumption, the hydraulic behavior of the glass waste may be quite different than the best-estimate and bounding values presented. The resultant uncertainty in contaminant fate and transport is a key issue, anticipated to be a subject of further investigation by the ILAW PA project in FY 2000.

Table 6.3. Reasonable Bounding Values for Glass Waste Parameters. Best-Estimate Values Shown for Comparison

Parameter	Lower Bound	Best Estimate	Upper Bound
K_s (cm/s)	1.0×10^{-4}	0.01	1.0
ϕ (= θ_s)	0.01	0.02	0.05
θ_r	0	0.00	0
α (cm^{-1})	0.01	0.2	4
n	1.5	3	5

6.1.4 Filler Material

The best-estimate filler material parameters are based on a single measurement of a quartz sand. The actual material to be used, however, has not yet been specified, although it is likely to be a sediment with a sandy texture. Using regression techniques, Carsel and Parrish (1988) derived probability distributions for soil hydraulic parameters, classified by soil texture. Schaap and Leij (1998) calculated means and variances for hydraulic parameters obtained from fitting the van Genuchten water retention function to three large databases of water retention measurements. These results were also classified according to soil texture. These references, combined with the authors' judgement, form the basis of the reasonable upper and lower bounds for the hydraulic parameters of the filler material.

The lower and upper bounds for the saturated water content are the 0.10 and 0.90 quantiles of an assumed normal distribution for this parameter, with the mean and variance of the distribution taken from the sample statistics for sand soils presented by Schaap and Leij (1998) using all their data. The upper bound of the residual water content is calculated in the same manner. The lower bound for the residual water content is the best-estimate value, because this value is very low for a sand [lower than the 0.10 quantile from the statistics of Schaap and Leij (1998)]. The reasonable bounds for the van Genuchten parameters, α and n, and for the saturated hydraulic conductivity were calculated in a similar manner, with the assumption that these parameters were lognormally distributed. Schaap and Leij (1998) presented statistics for log(α), log(n), and log(K_s), implying that their data exhibited skewed distributions. The upper bound for α is the mean sand value from Carsel and Parrish (1988). The best-estimate value was greater than the 0.90 quantile using the statistics of Schaap and Leij (1998).

The reasonable bounding values for the filler material parameters are given in Table 6.4. These values were based on an assumption that the material would have a sand texture. If the ultimate material used as the filler violates this assumption, these bounding values (and the best estimate) should be reevaluated.

Table 6.4. Reasonable Bounding Values for Filler Material Parameters. Best-Estimate Values Shown for Comparison

Parameter	Lower Bound	Best Estimate	Upper Bound
K_s (cm/s)	1.3×10^{-3}	3.79×10^{-2}	4.3×10^{-2}
ϕ (= θ_s)	0.30	0.397	0.45
θ_r	0.005	0.005	0.09
α (cm^{-1})	0.017	0.106	0.15
n	1.9	4.26	5.4

6.1.5 Backfill

Reasonable bounding values for the backfill were based on the statistics presented in Khaleel and Freeman (1995) for the sediment samples they classified as gravelly sand. The sediment samples analyzed by Khaleel and Freeman (1995) were all obtained from boreholes located in the 200 Areas of the Hanford Site. Ten of the 183 samples included in the analysis were classified as gravelly sand. The gravelly sand classification was used for the backfill bounding values because the boreholes drilled at the new ILAW disposal facility indicated the presence of gravel in the near-surface sediments (see Figure 2.1) and the best-estimate parameter values for the backfill appeared to most closely match the mean parameters values for the gravelly sand class of Khaleel and Freeman (1995), with the exception of the saturated water content.

The reasonable bounding values for the backfill material were taken as the minimum and maximum values reported by Khaleel and Freeman (1995) for their 10 gravelly sand samples. These values bound the best-estimate values and are given in Table 6.5.

Table 6.5. Reasonable Bounding Values for Backfill Parameters. Best-Estimate Values Shown for Comparison

Parameter	Lower Bound	Best Estimate	Upper Bound
K_s (cm/s)	5.4×10^{-5}	1.91×10^{-3}	8.0×10^{-3}
ϕ (= θ_s)	0.20	0.316	0.33
θ_r	0.01	0.049	0.07
α (cm^{-1})	0.004	0.035	0.074
n	1.5	1.72	2.5

6.1.6 Diversion Layer Materials

As discussed in Section 4.3, the performance of the diversion layer will depend critically on the hydraulic parameters of the sand drainage and gravel capillary barrier layer. Because the required performance of the diversion layer and the specification of the materials are unknown, it is difficult to set reasonable bounds on the hydraulic properties. In addition, it is the combination of the two materials and their hydraulic interaction under the particular conditions of the ILAW facilities that can result in poor performance. It is suggested here that the approach of Nichols and Meyer (1996) be used in the 2001 ILAW PA to examine uncertainty in the diversion layer performance. They identified three combinations of sand and gravel hydraulic properties that resulted in progressively better performance under the conditions they simulated. The best performing properties were assigned as the best-estimate parameter values for the diversion layer materials (see Tables 4.15 and 4.16). The poorest performing materials used by Nichols and Meyer (1996) and those that performed moderately well are listed in Table 6.6. These parameter values could serve as a starting point for the ILAW PA sensitivity simulations of the diversion layer.

Table 6.6. Diversion Layer Parameters Used by Nichols and Meyer (1996) for their Poorest and Moderate Performing Cases. Best-Estimate Values Shown for Comparison

	Poorest Performance		Moderate Performance		Best Estimate	
Parameter	**Sand**	**Gravel**	**Sand**	**Gravel**	**Sand**	**Gravel**
K_s (cm/s)	1.0×10^{-4}	1.0×10^{-2}	3.0×10^{-2}	1.0	3.00×10^{-2}	1.85
θ_s	0.35	0.34	0.35	0.34	0.371	0.518
θ_r	0.01	0.02	0.01	0.02	0.045	0.014
α (cm^{-1})	0.044	0.101	0.044	0.4	0.0683	3.54
n	1.52	2.92	1.52	2.92	2.08	2.66

6.1.7 Diffusion Coefficient Uncertainty

Regarding the uncertainty in apparent diffusion coefficients for solute transport through concrete we suggest that the values given in Table 5.2 be considered realistic estimates or best-estimate values. Based solely on expert judgement, we recommend that reasonable bounding values for the apparent diffusion coefficients in concrete be taken as as a factor of ten larger and smaller than the values from Table 5.2. For the diffusion coefficients in other materials calculated using Equation 5.7, the contribution to uncertainty should be considered to come primarily from the retardation coefficient and from any uncertainty in the water content.

6.2 Changes in Parameter Values over Time

A number of the materials discussed in Section 2.2 may undergo significant changes over time, potentially affecting the performance of the disposal facilities. These changes will be caused by natural processes and in response to chemical changes in the near-field environment resulting from degradation of the glass waste. The materials for which hydraulic property changes over time are expected to most significantly impact the transport of contaminants are the asphaltic concrete of the surface barrier, the concrete vault, and the glass waste; corrosion of the steel waste containers is also expected to have a significant effect on contaminant transport. In addition, changes in backfill material, the filler material within the vaults, and the gravel capillary barrier material (if used as a component of the surface barrier) are potentially important. Potential changes in the hydraulic parameters of each of these materials as a function of time (material aging) is discussed below.

Changes in recharge through the surface cover either as a result of subsidence or in response to expansion of the waste containers due to steel corrosion are not discussed here. While these processes will not produce changes in the small-scale hydraulic properties of the surface cover materials (with the exception of the low-permeability asphaltic concrete layer), they may significantly affect the overall performance of the cover. Potential variations in the recharge rate over time as a result of changes in the volume of the waste are discussed in the recharge data package (Fayer et al., 1999).

6.2.1 Asphaltic Concrete

Changes to the hydraulic properties of the asphaltic concrete component of the surface barrier may increase the recharge rate reaching the concrete vaults. Because the upper layers of the surface barrier will protect the asphalt component from ultraviolet radiation and from extremes in temperature, the asphaltic concrete is expected to change little over the initial 500-year period from the time of construction. U.S. Nuclear Regulatory Commission (U.S. NRC) guidance for low-level waste disposal performance assessments recommends that the man-made components of the facility should be credited with a maximum of 500 years of as-built performance (NRC, 1997). Studies of naturally occurring asphalts, undertaken as part of the Hanford Barrier development (Waugh et al., 1994; Freeman and Romine, 1994), indicate that asphalt lifetimes under conditions expected in the ILAW disposal facilities are in excess of 500 years. One issue that has not been addressed, however, is the effect on asphalt of changes in pore water chemistry due to glass dissolution. Preliminary simulation studies of the near-field chemistry indicate that a high pH front may travel up towards the surface from the glass waste[1]. This issue will be given additional consideration before the disposal facility designs are finalized.

Given the current information, it is recommended that the best-estimate asphaltic concrete parameter values be assumed constant for a period of 500 years. The hydraulic properties of this barrier layer can

[1] B.P. McGrail. June, 1999. Personal communication.

be given the properties of the aggregate material of the concrete after the 500-year period of performance. This is consistent with the assumptions of the recharge rate discussed in the recharge data package (Fayer et al., 1999) and with the approach used in the initial ILAW PA (Mann et al., 1998).

6.2.2 Concrete

The concrete vaults provide a low-permeability barrier to water intrusion and also influence the chemistry of the water reaching the glass waste. For the purpose of low-level waste disposal, NRC guidance recommends assuming a 500-year service life for man-made components unless justification for a longer service life can be made. The degradation of concrete in response to the chemical conditions to which it is exposed has been studied extensively (Clifton, 1993). Service life predictions can be based on a comparison of performance to existing concretes; accelerated testing using elevated temperature, pressure, and chemical conditions; and mathematical modeling.

Simulations by Fayer and Kincaid (1998)[1] indicate that the presence of intact concrete may have either a relatively small effect on the peak dose from the ILAW facility or a fairly large effect, depending on the parameters assumed for the glass waste. In these simulations, various concrete hydraulic properties were assumed for intact, fractured, and degraded concrete. The peak dose over a 100,000-year period from a single vault was compared to the case where no concrete was used. Peak dose increased by 14% to 259% when no concrete was used as compared to the use of intact concrete. The wide range in the effect of the concrete was due to the particular model assumed for the glass waste. It must be pointed out that the hydraulic properties for the intact concrete and the glass waste were not the best-estimate values presented in Sections 4.2.1 and 4.2.3.

Sensitivity simulations for the 2001 ILAW PA should be carried out using (1) the intact properties of concrete given in Section 4.2.1 and (2) the backfill properties given in Section 4.4.1 in place of the concrete. This latter case represents an assumption that no concrete is used in the ILAW disposal facility. The two cases together serve to bound the importance of the concrete properties to the facility performance and consequently provide some guidance on the importance of modeling the degradation of concrete over time. If concrete degradation is to be modeled, the specific chemical conditions of the ILAW facilities should be included in the analysis. Available models such as described in Snyder and Clifton (1995), Berner (1992), Walton (1990), and Clifton and Knab (1989) may be useful in the estimation of concrete service life. An empirical approach, used in the Grouted Waste Disposal PA (Winkel, 1994), may also prove practical.

The volume occupied by the corrosion products of the steel waste containers is expected to be greater than the volume of the intact steel. Corrosion of the steel will thus result in additional stress on the

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1. Fayer, M.J. and C.T. Kincaid. 1998. *Simulations to Guide Measurements of Near-Field Hydraulic Parameters.* Letter report to Fluor Daniel Hanford, Inc., Sept. 30, 1998, Pacific Northwest National Laboratory, Richland, Washington.

concrete vault, potentially producing cracks in the concrete[1]. Stress fractures will increase the effective hydraulic conductivity of the concrete. Wang et al. (1997) provide laboratory measurements of the relationship between hydraulic conductivity and crack width for concrete that has undergone stress fracturing. Depending on final design decisions for the disposal facilities, the interaction between corrosion of the steel waste containers, geotechnical stability of the disposal facility, and the near-field hydrology may be a subject of further investigation by the ILAW PA project in the future.

If the degradation of the concrete vault is not modeled explicitly, there is no technical basis for assuming a transition in concrete properties between the best-estimate values and the fully degraded properties. In addition, the simulations conducted by Fayer and Kincaid (1998)[2] resulted in minor differences between the peak dose when using fractured concrete properties and that obtained when using their fully degraded concrete properties. We recommend that the best-estimate parameter values for concrete be used for the first 500 years of facility operation and that the fully degraded concrete parameter values be used for the remainder of the time. The fully degraded concrete parameter values should be assigned based on the expected composition of the concrete aggregate, which has not been specified for the new ILAW disposal facility. It is assumed here that the fully degraded concrete can be represented as a mixture of 60% of the backfill material (see Section 4.4.1) and 40% of a gravel with particle diameters distributed relatively uniformly between 2 and 10 mm. The assumed particle size distribution for this material is given in Table 6.7.

Table 6.7. Assumed Particle Size Distribution for Fully Degraded Concrete

Particle Size (mm)	10	7	5	3	2	1	0.5	0.25	0.1	0.05	0.002
Percent Finer	100	95	88	75	60	52.9	32.6	14.6	6.5	4.5	3

The particle size distribution of Table 6.7 was used in the method of Arya and Paris (1981) to generate a set of sample water retention points for the fully degraded concrete. The bulk and particle densities were assumed to be the same as the best-estimate backfill values. Using the sample water retention points and the RETC code (van Genuchten et al., 1991), water retention parameters were estimated for the fully degraded concrete. Saturated hydraulic conductivity was estimated using the Kozeny-Carmen equation (Bear, 1972).

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1. Nozaki, A., B.P. McGrail, M.J. Fayer, and K.M. Krupka. 1999. "Mechanical stability analysis for the immobilized low-activity waste (ILAW) disposal facility at the Hanford Site." *Computers and Structures,* in review.

2. Fayer, M.J. and C.T. Kincaid. 1998. *Simulations to Guide Measurements of Near-Field Hydraulic Parameters.* Letter report to Fluor Daniel Hanford, Inc., Sept. 30, 1998, Pacific Northwest National Laboratory, Richland, Washington.

$$K_s = \frac{\rho g}{\mu} \cdot \frac{\phi^3}{(1-\phi)^2} \cdot \frac{d_m^2}{180} \quad (6.1)$$

where ρ and μ are the density and viscosity of water, respectively, g is the acceleration due to gravity, and d_m is a mean particle diameter. Density and viscosity were specified at 15° C. Porosity was assumed to be equal to the saturated water content. The mean particle diameter of 2.1 mm was calculated as the average of the particle size fractions defined in Table 6.7 weighted by the percent in each fraction. Parameter values for the fully degraded concrete are given in Table 6.8.

Table 6.8. Parameter Values for Fully Degraded Concrete

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
2.76	1.89	0.313	0.0	2.43	1.41	1.34×10^{-3}

6.2.3 Glass Waste

The hydraulic properties of the fractured glass waste are expected to undergo changes over time in response to chemical reactions between the glass waste and the water moving through the waste. Corrosion testing of potential low-activity waste glasses is discussed in McGrail et al. (1998). As discussed in Section 4.2.3, this testing was performed on crushed glass samples, whereas the actual glass waste form is expected to be a highly fractured material. As discussed in McGrail et al. (1998), corrosion of their crushed glass sample resulted in pronounced changes in the sample's water retention characteristic. The changes appeared to be related to the onset of precipitation of zeolitic alteration phases. Scanning electron microscope pictures revealed that the originally pristine fracture surfaces of the grains had a relatively thick coating of alteration phases.

The effect of the alteration phases coating the glass particle surfaces was to increase the water content of the sample at a given matric potential. Although a water retention model was not fit to the data observed by McGrail et al. (1998), the alteration phase coating apparently resulted in a sizeable decrease in the values of the α and n parameters in the van Genuchten water retention function. That is, the crushed glass sample behaved less like a coarse sand and more like a loamy-textured soil. Little change in the porosity or the saturated hydraulic conductivity was observed during the test conducted by McGrail et al. (1998), although this was attributed to the relatively short duration of the test.

The changes in the surfaces of the glass grains observed by McGrail et al. (1998) are expected to occur on the fracture surfaces of the ILAW glass waste and should produce similar changes in the hydraulic parameters of the glass waste, that is, a decrease in the α and n parameters in the van Genuchten water retention function. The magnitude of these changes are currently unknown and are anticipated to be a subject of further investigation by the ILAW PA project in FY 2000.

6.2.4 Steel Container Corrosion

The steel containers holding the glass waste are expected to be impermeable to water when initially put into the concrete vaults, but they are expected to corrode over time. The nature of the corrosion process and the consequent changes in the permeability of the steel and the ability of contaminants to be transported out of the steel containers has not been a subject of investigation. It is assumed here that the steel will eventually be converted completely to products of its corrosion. The hydraulic properties of these corrosion products is the subject of this section.

The specific products of steel or stainless steel corrosion depend on the unique environmental conditions within which corrosion takes place. Studies of steel exposed to the atmosphere, in non-polluted sea water, and in concrete have shown the iron oxides goethite (α-FeOOH) and lepidocrocite (γ-FeOOH) to be the dominant corrosion products. Schwertmann and Cornell (1991) describe the formation and transformation pathways of iron corrosion products. Under oxidizing conditions and with pH in the range of 5-7, the transformations lead from Fe^{2+} to goethite and lepidocrocite. Transformation of these phases to hematite depends on the environmental conditions (Cornell and Schwertmann, 1996). With pH > 8, Fe^{2+} will oxidize directly to magnetite, maghemite, and hematite (Schwertmann and Cornell, 1991).

Based on studies for disposal of high-level radioactive waste at Yucca Mountain and on modeling studies for the ILAW PA project[1], the dominant steel corrosion products in the ILAW disposal facilities are expected to be goethite and hematite. Although goethite is expected to transform to hematite, the reaction rate is expected to be slow enough that significant goethite will be present for a long period. (Actual corrosion transformation rates are unknown.)

Naturally occurring rock samples of hematite, goethite, and lepidocrocite were obtained to serve as surrogate materials for the steel corrosion products. The rocks were crushed in the laboratory to prepare samples for hydraulic property measurements. The crushed samples were hand-sieved using 2-mm (No. 10), 0.125-mm (No. 120), and 0.075-mm (No. 200) sieves to provide a general separation of particle sizes, but not a complete separation. Coarse-textured and fine-textured samples of crushed hematite and goethite were analyzed for physical and hydraulic properties (four samples total). A centrifuge method was used to measure water retention and unsaturated hydraulic conductivity[2].

Average particle densities of the goethite and hematite samples were 3.82 and 4.50 g/cm^3, respectively. Average bulk densities were 2.05 and 2.78 g/cm^3, respectively, for the goethite and hematite samples. Hydraulic parameters were fit to each sample using RETC (van Genuchten et al., 1991). A simultaneous fit to the water retention and hydraulic conductivity data was performed with all parameters

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1. B.P. McGrail, April, 1999, Personal communication.

2. Meyer, P.D. 1999. *Hydraulic Parameters of Aged Near-Field Materials of the Immobilized Low-Activity Waste Disposal Facility*, Letter Report to Fluor Daniel Northwest, Inc., August 30, 1999, Pacific Northwest National Laboratory, Richland, Washington.

being fit[1]. Note that compaction of the fine-textured hematite sample during the centrifuge measurements and the relative difficulty of fitting unsaturated hydraulic conductivity data resulted in a variable quality of fit for each sample. Other than the particle and bulk densities, the texture of the samples (coarse or fine) seemed to have a greater influence on the parameter values than the mineral type. The average parameters of the fine goethite and hematite samples are given in Table 6.9. Arithmetic averages were used except for α and K_s, for which geometric averages are given. These parameters may be representative of the fully corroded steel containers. Average grain size measurements for the fine samples were 96% finer than 0.125 mm, 50% finer than 0.063 mm, and 36% finer than 0.045 mm.

Table 6.9. Representative Parameter Values for the Fully Corroded Steel Containers

ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
4.16	2.30	0.39	0.04	0.0008	1.77	2.2×10^{-6}

6.2.5 Backfill and Filler Material between Waste Packages

The backfill and filler material within the vault may undergo changes in their hydraulic properties due to the high pH conditions expected within and around the vault. Kaplan et al. (1998) report on a series of experiments in which the quartz sand and backfill materials discussed in Sections 4.2.2 and 4.4.1 were exposed to NaOH solutions. NaOH was chosen as the experimental solution because its ions in solution are expected to be prevalent in the near-field pore water resulting from dissolution of the glass waste. Kaplan et al. (1998) performed batch and column experiments using 0.5, 1.0, 2.0, and 3.0 M solutions of NaOH with contact time of up to 10 months. No systematic changes in hydraulic properties were observed for either material. Results remained inconclusive, however, because biological growth was observed to occur in all samples. These experiments are currently being repeated on sediments that have been irradiated to sterilize them and minimize biological growth. Results will be available in FY 2000.

6.2.6 Gravel Capillary Barrier Layer

One of the changes suggested to occur from the degradation of the glass waste is the migration of a high pH front upward from the vault. If the diversion layer is used as a component of the surface barrier, the migration of a high pH front into the gravel capillary layer may produce mineral precipitation that could change the gravel hydraulic properties and potentially affect the performance of the diversion layer. Precipitation on the gravel grains would cause the hydraulic behavior of the gravel to become more like a sand; that is, the α and n parameters of the van Genuchten water retention function, and potentially the sat-

[1] Meyer, P.D. 1999. *Hydraulic Parameters of Aged Near-Field Materials of the Immobilized Low-Activity Waste Disposal Facility.* Letter Report to Fluor Daniel Northwest, Inc., August 30, 1999, Pacific Northwest National Laboratory, Richland, Washington.

urated hydraulic conductivity as well, would be reduced. Potential rates of mineral precipitation and resulting changes in hydraulic properties have not been quantified, but are anticipated to be a subject of further investigation by the ILAW PA project in FY 2000-2001.

6.3 Comments on Effective Parameter Values

Physical heterogeneity is widespread in natural porous media, and can be manifest on a hierarchy of scales from the sub-pore (microns) to the field (meters or more) (e.g., Cushman 1997; Whitaker 1999). A number of approaches have been proposed for deriving effective parameters when the scale of the heterogeneity is not explicitly represented in simulation models (Renard and de Marsily, 1997; Dagan, 1997). Although the near-field materials are not naturally occurring, there is nonetheless potentially significant physical heterogeneity due to the use of different materials over a fairly small scale, particularly within the vaults where concrete, glass waste, filler material, and steel corrosion products are all present. Nonuniform changes in material properties over time may also result in increasing heterogeneity of near-field materials. The methods developed for deriving the effective properties of naturally heterogeneous materials should also apply in simulations of the near-field materials.

Volume averaging is one approach that has been successfully used to formally account for the effects of subsurface heterogeneity on flow and transport. In volume averaging approaches, one seeks to describe the behavior of a system averaged over a volume of a porous medium. The approach can be applied in two distinct modes.

In the first mode, volume averaging is used to upscale random heterogeneous structures. Often, the problem that heterogeneity poses is that there exist structures in the porous medium that cannot be fully characterized deterministically because such a characterization is either impractical or impossible. For such cases, methods have been developed that use statistical information for developing the upscaled conservation equations and for determination of the effective parameters that appear in the conservation equation.

In the second mode, the method is used to upscale deterministic structure. Such upscaling may be necessary, for example, when one has available a high-resolution model (such as a geologic process model) of the heterogeneous porous media (Ahmadi and Quintard 1996). Under these circumstances, although the deterministic structure is available, it may be impractical to solve flow and transport equations in such a system because of computational limitations. This may be the case in near-field simulations, particularly because of the complex chemical reactions being modeled. In some instances, however, the domain can be re-discretized at a coarser scale by developing upscaled flow and transport equations (via volume averaging), and then calculating the associated effective parameters for each coarse grid block. Such a re-sampled system could then be solved with much less computational effort. Such approaches have been successfully employed to upscale deterministic structure in saturated systems (e.g., Ahmadi et

al., 1998), but have not yet been applied to the problems of identification of effective parameters for unsaturated systems.

Using an effective parameter value to represent a large volume of heterogeneous material assumes that the nature of the heterogeneity (whether random or deterministic) can be determined. If the degree of heterogeneity is underestimated, the derived effective parameter values may provide a poor representation of the actual flow and transport. Such difficulties can arise, for example, under conditions that produce preferential flow. Because the ILAW near-field materials are engineered, they are likely to be less heterogeneous than the far-field materials. In addition, a properly functioning surface cover will not only lower the water content in those materials beneath the cover, but it will also reduce temporal variations in flow. These conditions reduce the potential for significant preferential flow. With the larger water flux from a degraded cover and increasing heterogeneity from material degradation, preferential flow may become more important. This possibility can be examined in future work.

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7.0 Conclusions

This report has discussed issues related to the appropriate hydraulic and transport parameters to use in simulations of the ILAW disposal facilities for the 2001 ILAW PA. This report is limited to those materials, both natural and man-made, that will be used within the excavated zone of the ILAW disposal facilities. Values for physical, hydraulic, and transport parameters are provided, although the transport parameters are limited to dispersivity and apparent diffusion coefficients. The apparent diffusion coefficients lump physical and chemical effects together. The current best-estimate parameter values are given along with a justification for their selection. In addition, the uncertainty of these parameters is discussed and reasonable upper and lower bounds are given for many of the parameters. These bounding values and the uncertainty information provided may prove useful in sensitivity or uncertainty analyses carried out as part of the 2001 ILAW PA. The report also includes a discussion of changes in material properties over time and how these changes are expected to affect the parameter values.

The parameter values provided in this report provide a starting point for the PA simulations. Changes in facility design, additional information and data that may become available, and unanticipated considerations may require that these parameter values be altered in the PA simulations. If this occurs, the new parameter values should be justified and the issues related to uncertainty and changes over time should be addressed for the new parameter values. Related parameters may also be used in other data packages being assembled for the 2001 ILAW PA. These data packages have not all been reviewed for consistency with this report.

Studies are ongoing as part of the ILAW PA project to better define the parameters of the near-field materials and to improve the analyses needed for completion of the PA. The PA will use the most current information available, which may supersede the contents of this report. This data package will be updated to collect all new information in a single source for use in future PAs.

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8.0 References

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APPENDIX M

FAR-FIELD HYDROLOGY DATA PACKAGE

FOR

IMMOBILIZED LOW-ACTIVITY TANK WASTE PERFORMANCE ASSESSMENT

Raz Khaleel
Fluor Daniel Northwest, Inc.
P.O. Box 1050
Richland, WA 99352

December, 1999

EXECUTIVE SUMMARY

A number of data packages are being assembled as part of 2001 Immobilized Low-Activity Tank Waste (ILAW) Performance Assessment (PA). This data package deals with the far-field hydrology data needed to perform vadose zone flow and transport modeling for the ILAW PA.

The ILAW PA shall be conducted for two sites; the new ILAW disposal site and the existing disposal site east of the new ILAW site in 200 East Area. Site characterization data are available for both sites. This report presents the laboratory measurements on physical and hydraulic properties for soil samples at the disposal sites, and results on application of stochastic theory to small-scale measurements. The effective (upscaled) parameter estimates are derived for saturated hydraulic conductivity, soil moisture retention and unsaturated hydraulic conductivity, bulk density, unretarded macrodispersivity and sorption-enhanced macrodispersivity. These parameters will serve as input to VAM3DF, a variably saturated vadose zone flow and transport code; VAM3DF will generate 'mean' solutions for the pressure head and contaminant concentration.

The stratigraphy at both disposal sites is dominated by two distinctly different sediment sequences. The upper part of the vadose zone is characterized by a sandy sequence, whereas the lower part is characterized primarily by a gravel sequence. At saturation, compared to the gravel-dominated sequence, the sand-dominated sequence is described by a smaller log-conductivity variance. However, compared to the gravel-dominated sequence, the log-unsaturated conductivity variance for the sand-dominated sequence is higher. Consequently, the macroscopic anisotropy relations for the sandy and gravelly sediments are different. The differences in the characteristics of the two sediment sequences also result in different macrodispersivity estimates. Overall, compared to sandy soils, gravelly soils are characterized by a much smaller saturated water content, higher bulk density, higher log-conductivity variance, smaller log-unsaturated conductivity variance, a much smaller macroscopic anisotropy and smaller macrodispersivities.

A methodology is presented to estimate uncertainties in model predictions. For far-field hydrology, three sources contribute to uncertainty estimates: (a) variations in model configurations, (b) uncertainties in the calculated mean solution for concentration, and (c) uncertainties around the calculated mean solution for concentration. The following approach will be used to evaluate these uncertainties. First, uncertainty will be defined for the 'mean' solutions for concentration distribution at the water table (as a function of position and time). The combined contribution to uncertainty in the mean solution due to model configuration and effective parameter (i.e., unsaturated hydraulic conductivity and macrodispersivity) variations will be investigated. A methodology developed by Kapoor and Gelhar (1994a,b) will then be used to estimate the uncertainty around the mean solution.

Model configurations will include variations in stratigraphy and clastic dike networks. Base case and uncertainty in stratigraphy and clastic dike network models will be provided in the geology data package. Selected VAM3DF runs will be performed to estimate the impact of these uncertainties on the resultant contaminant distribution at the water table. The uncertainty attributed to isotropy and sloped layering on calculated mean solutions will also be estimated.

Bounding estimates for concentrations at the water table will be provided through a choice of parameters and model configurations judged to provide a worst case representation of the system.

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1.0 INTRODUCTION

The *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* examines the long-term environmental and human health effects associated with the planned disposal of the vitrified low-level fraction of the waste presently contained in Hanford Site High-Level Waste Tanks. The objectives of the performance assessment are to provide a reasonable expectation that the disposal of the waste will be protective of the general public, groundwater resources, air resources, inadvertent intruder and surface water resources. A number of data packages are being assembled as part of 2001 Immobilized Low-Activity Tank Waste (ILAW) Performance Assessment (PA). This data package deals only with the far-field (Figure 1) hydrology data needed to perform vadose zone flow and transport modeling for the ILAW PA.

Figure 1 illustrates also the overall computational strategy for the ILAW PA. The near-field environment is defined as the domain through the vault to some distance below the floor of the disposal vault (Figure 1). A coupled unsaturated flow, chemical reactions, and contaminant transport simulator (STORM) will be used within the near-field (Bacon and McGrail 1997). The plume exiting the region near the vault is expected to be of high ionic strength and pH, and will migrate down into the near-field vadose zone for some distance. However, at some distance from the disposal vaults, geochemical conditions will approach those more typical of the Hanford vadose zone and for which simplifying assumptions (such as linear sorption, negligible precipitation/dissolution, no changes in hydraulic properties, and no density effects) can be used. This region is defined as the far-field environment and can be simulated using standard, nonreactive flow and transport codes. For the ILAW PA, computations in the far-field domain will be done by VAM3DF (Huyakorn and Panday 1995), a variably saturated flow and transport code. The primary reason for switching from the near-field simulator to VAM3DF is to apply a less complicated code for the far-field, and therefore a faster turnaround for the numerical simulations. The radionuclide flux exiting the far-field domain to the unconfined aquifer will be provided by VAM3DF and will be used as a boundary condition for the unconfined aquifer flow and transport simulator. The final step in the methodology is to compute the impacts, if any, from ingestion, inhalation, and external radiation to humans who become exposed to the contaminants by withdrawing water from the aquifer.

1.1 Scope of This Data Package

The scope for the far-field hydrology data package for the new ILAW disposal site and the existing disposal site include the following information:

- Stratigraphic cross-sectional models (Section 2.0). [Note that stratigraphic cross-sectional models are presented for context only; the scope of this data package does *not* include stratigraphic cross-sectional models. Such geologic models shall be provided as part of a separate data package (i.e., Reidel and Horton 1999)]

- Data on laboratory measurements for moisture retention, particle-size distribution, saturated and unsaturated hydraulic conductivity, and bulk density (Section 2.0).

- Effective (upscaled) moisture retention, saturated and unsaturated hydraulic conductivity, bulk density, diffusivity, and macrodispersivity estimates for geologic formations (Section 3.0).

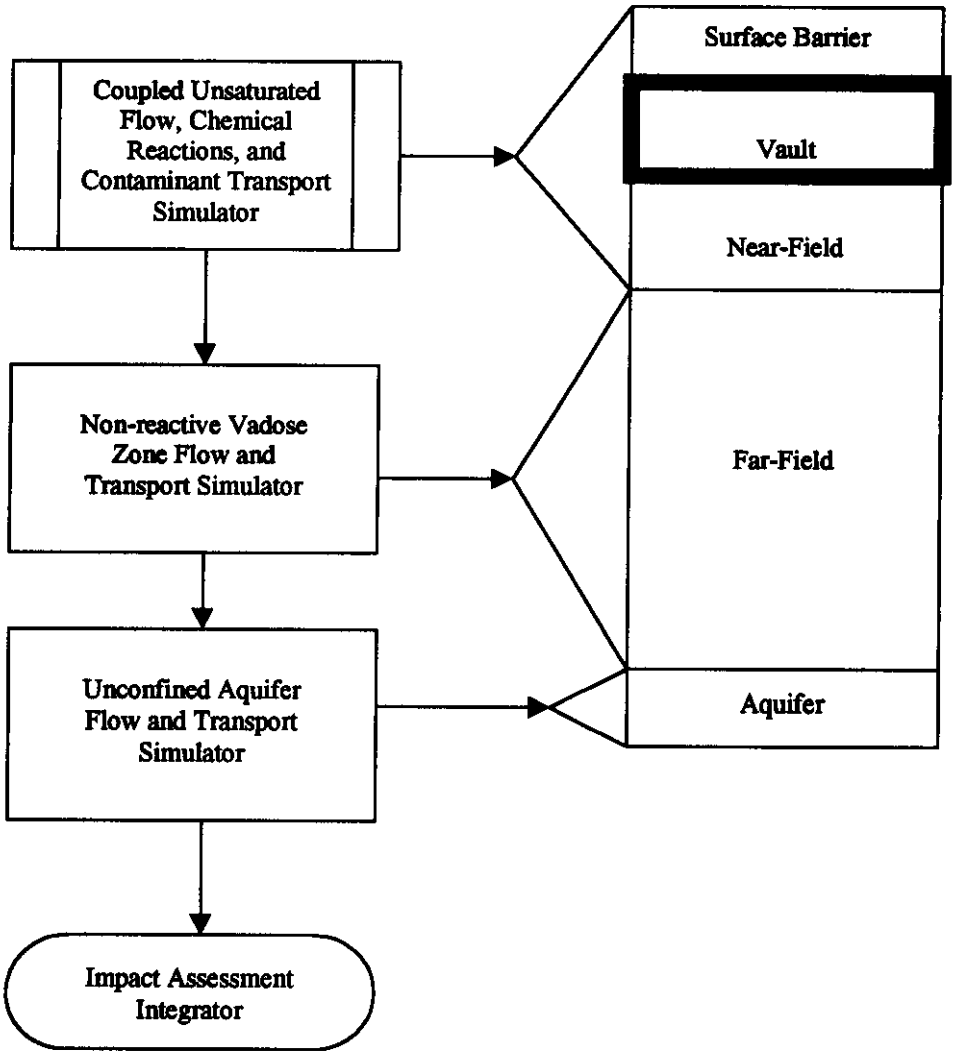

Figure 1. Modeling strategy for assessing ILAW disposal system impacts (after McGrail et al. 1998).

- Sorption-enhanced macrodispersivity estimates for selected radionuclide species (Section 3.0).

- Moisture retention, saturated and unsaturated hydraulic conductivity, bulk density, and macrodispersivity estimates for clastic dike infilling materials (Section 4.0).

- Bounding scenarios on model configurations and uncertainty estimates about the calculated mean concentration and around mean concentration (Section 4.0).

For the ILAW disposal facility with a capillary barrier and a surface barrier on top, the vadose zone water contents beneath the facility are expected to approach the natural moisture regime for arid soils. Field moisture contents are expected to be less than 10% (by volume); matric potentials of the order of -1000 cm and recharge rates of the order of 0.1 cm/yr. Under such arid conditions, the features and processes identified in the scope carry significant importance for the ILAW PA calculations. For example, the layered heterogeneous soils in 200 Areas are expected to show bulk anisotropic behavior, with the hydraulic conductivity parallel to the layers being larger than that normal to the layers. Furthermore, the degree of anisotropy increases rapidly with increasing tension or decreasing moisture content, becoming large in dry soils of the kind expected beneath the disposal facility. Also, the infiltrating water diverted around the vaults by the capillary barrier can potentially move beneath the vaults, creating moist conditions and enhancing contaminant movement to the water table. In addition, recent theoretical work and field experiments have shown that spreading of contaminants undergoing heterogeneous linear equilibrium sorption can be significantly larger than that of the non-sorbing tracer. Dispersivity enhancement can cause early arrival at the water table before they have had an opportunity to decay. Also, clastic dikes are of concern because they can potentially create preferred pathways.

2.0 LABORATORY MEASUREMENTS FOR SOIL PHYSICAL AND HYDRAULIC PROPERTIES

The purpose of this section is to summarize available data on laboratory measurements for moisture retention, particle-size distribution, saturated and unsaturated hydraulic conductivity, and bulk density for sediment samples from both new ILAW and existing disposal sites.

2.1 New ILAW Disposal Site

As part of site characterization activity for the new ILAW disposal site, sediment samples were obtained in fiscal year 1998 via a borehole drilling and sampling program (Reidel and Reynolds 1998). The borehole was drilled in the spring of 1998 (Reidel et al. 1998); Figure 2 shows the geologic cross section. The Hanford formation sandy sequence is about 200 ft thick and is the dominant facies at the site. The lower gravelly sequence is about 70 ft thick. For purposes of this data package, no distinction is made on gravel-dominated sequences of the lower Hanford formation and the upper Ringold Formation. The sediments from both of these formations have similar physical and hydraulic properties, and are characterized essentially as sandy gravel, with a significant gravel fraction (Khaleel and Freeman 1995a,b).

A work plan was prepared that provides details on the measurement and analysis of the hydraulic properties for the ILAW borehole sediment samples (Khaleel 1998)[1]. Details on sampling, laboratory procedures, and analysis of samples are provided in. Fayer et al. (1998)[2], and are included as Appendix A. The following summary is based on details provided in Appendix A.

A total of 45 cores were collected in liners, with core diameters ranging from 3.25- to 3.75- in. The total internal volume of the 3.25-in (8.26-cm) diameter cores was 803 cm^3; it was 1,069 cm^3 for the 3.75-in (9.53-cm) diameter core. It should be noted that, during drilling, sample recovery was less than 100% (Reidel et al. 1998), thereby biasing the recovered samples toward the finer fraction. Also, no vadose zone cores were collected below 242 ft because this zone was open framework gravel (i.e., gravel that supports itself with little to no finer grained material) and could not be sampled with the method used. Figure 2 shows the sampling locations relative to the geologic cross-section derived from the borehole data; twenty samples from these locations were used to obtain physical and hydraulic properties for the sandy sequence. As described later, for the gravel-dominated sequence, data on hydraulic properties from elsewhere on the Hanford Site were used as surrogates.

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[1] Khaleel, R. 1998. Work plan for measurement and analysis of hydraulic properties for clastic dikes and ILAW Borehole No. 1 sediment samples. January, 1998. Fluor Daniel Northwest, Inc. Richland, WA.

[2] Fayer, M.J., A.L. Ward, J.S. Ritter, and R.E. Clayton. 1998. Physical and hydraulic measurements of FY 1998 borehole cores. Letter Report to Fluor Daniel Northwest, Inc. September, 1998. Pacific Northwest National Laboratory. Richland, WA.

The procedures used to analyze the twenty samples are listed in Appendix A. Because several tests were performed on the same core, the following test sequence was established: saturated conductivity, multistep outflow, and steady state unsaturated conductivity. The multistep and steady state methods were used to obtain moisture retention and unsaturated conductivity data. Both methods were performed on the same core using the same sensor locations (see Appendix A for details). In addition to cumulative outflow, the multistep method, which is an improvement over the one-step method of Kool et al. (1985a, b), provides water content-matric potential (θ-ψ) pairs. These data were used in conjunction with the MULSTP program (Eching and Hopmans 1993), a numerical inversion procedure, to determine the optimal set of van Genuchten model (Appendix A) parameters. The steady-state method, described by Klute and Dirksen (1986), provides water content-matric potential-unsaturated conductivity (θ-ψ-K) triplets; the method was primarily used as a check on the multistep method.

Table 1 shows the van Genuchten model (van Genuchten 1980) parameters determined using the MULSTP program and data from the multistep test. The pore-size distribution parameter ℓ (Mualem 1976) was kept fixed at 0.5. Also listed in Table 1 are saturated conductivity and bulk density measurements for the 20 samples primarily from the sandy sequence. The particle-size distribution data are shown in Figure 3. The fitted moisture retention curves and unsaturated conductivity curves for the 20 samples from the sandy sequence are shown in Figure 4. Most of the borehole samples were fitted for α and n; eight of the samples were also fitted for θ_s.

2.1.1 100 Area Samples

As discussed earlier, no site-specific data on soil moisture characteristics are available at the disposal sites for sediments in the gravel-dominated sequence. However, as part of the Environmental Restoration Project, moisture retention and unsaturated conductivity data for sandy gravel sediments are available elsewhere (100 Area along the Columbia River) on the Hanford Site. Fifteen samples having a large gravel fraction were chosen. These samples ranged in gravel content from 43 to 75 percent and were used as surrogate to represent the hydraulic properties for the gravel-dominated sequence.

Standard laboratory and Westinghouse Hanford Company quality assurance procedures were used to analyze these gravelly samples. The moisture retention data for the fine fraction (< 2 mm) and for the drainage cycle of up to -1,000 cm of pressure head were measured using "Tempe" pressure cells; the rest of the drainage data up to -15,000 cm was measured using the pressure plate extraction method (Klute 1986). Saturated hydraulic conductivities for the bulk samples (including gravels) were measured in the laboratory using constant-head permeameter. A variation of the unit gradient method (Klute and Dirksen 1986; Khaleel et al. 1995) was used to measure unsaturated hydraulic conductivities for the bulk samples. The laboratory measured data on < 2mm size fraction were corrected for the gravel fraction (Gardner 1986; Khaleel and Relyea 1997).

No correction was needed for the saturated and unsaturated conductivities, since these were measured on the bulk sample.

The van Genuchten parameters were obtained via RETC (van Genuchten et al. 1991) and a simultaneous fit of both laboratory-measured moisture retention and unsaturated conductivity data; all five unknown parameters θ_r, θ_s, α, n, and K_s, with m=1-1/n (van Genuchten 1980), were fitted to the data. The pore size distribution factor, ℓ (Mualem 1976) was kept fixed at 0.5 during the simultaneous fitting. The laboratory data, following gravel-correction of the moisture retention data, are included in Appendix B for the 15 samples. Appendix B serves as the input data file for RETC. The fitted moisture retention curves and unsaturated conductivity curves for the 15 samples for the gravel sequence are shown in Figure 5. Note that, unlike the borehole samples, the 100 Area samples were fitted for θ_r, θ_s, α, n, and K_s.

Table 1. Van Genuchten parameters (based on the multistep method), saturated hydraulic conductivity, and bulk density data for 20 ILAW borehole samples from the sandy sequence (after Fayer et al. 1998).

Sample	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Saturated Hydraulic Conductivity (cm/s)	Bulk Density (g/cm^3)
7A	0.377	0.0404	0.0290	1.825	1.04E-03	1.70
10A	0.413	0.0279	0.1161	1.784	2.95E-03	1.62
12A	0.363	0.0309	0.0650	1.755	2.15E-03	1.74
14A	0.416	0.0324	0.0445	1.728	1.99E-03	1.58
15A	0.380	0.0254	0.0487	1.844	2.09E-03	1.69
16A	0.420	0.0228	0.0682	1.710	9.57E-03	1.58
17A	0.423	0.0382	0.0689	1.899	1.99E-03	1.57
19A	0.444	0.0279	0.2010	1.542	4.31E-03	1.52
20A	0.419	0.0321	0.0305	2.081	2.54E-03	1.58
21A	0.403	0.0276	0.0545	1.926	2.94E-03	1.62
22A	0.352	0.0252	0.1078	1.585	5.06E-03	1.78
23A	0.371	0.0411	0.0079	1.553	2.65E-04	1.72
24A	0.321	0.0413	0.0130	1.684	5.69E-04	1.85
25A	0.345	0.0267	0.0842	2.158	5.40E-03	1.80
27A	0.377	0.0354	0.0830	1.532	8.14E-03	1.71
29A	0.359	0.0317	0.0784	1.732	3.75E-03	1.76
31A	0.418	0.0444	0.0058	2.012	8.21E-04	1.60
32A	0.359	0.0401	0.0931	1.703	6.71E-03	1.78
34A	0.316	0.0324	0.0819	2.398	1.32E-02	1.92
35A	0.299	0.0428	0.0897	2.160	1.06E-02	1.98

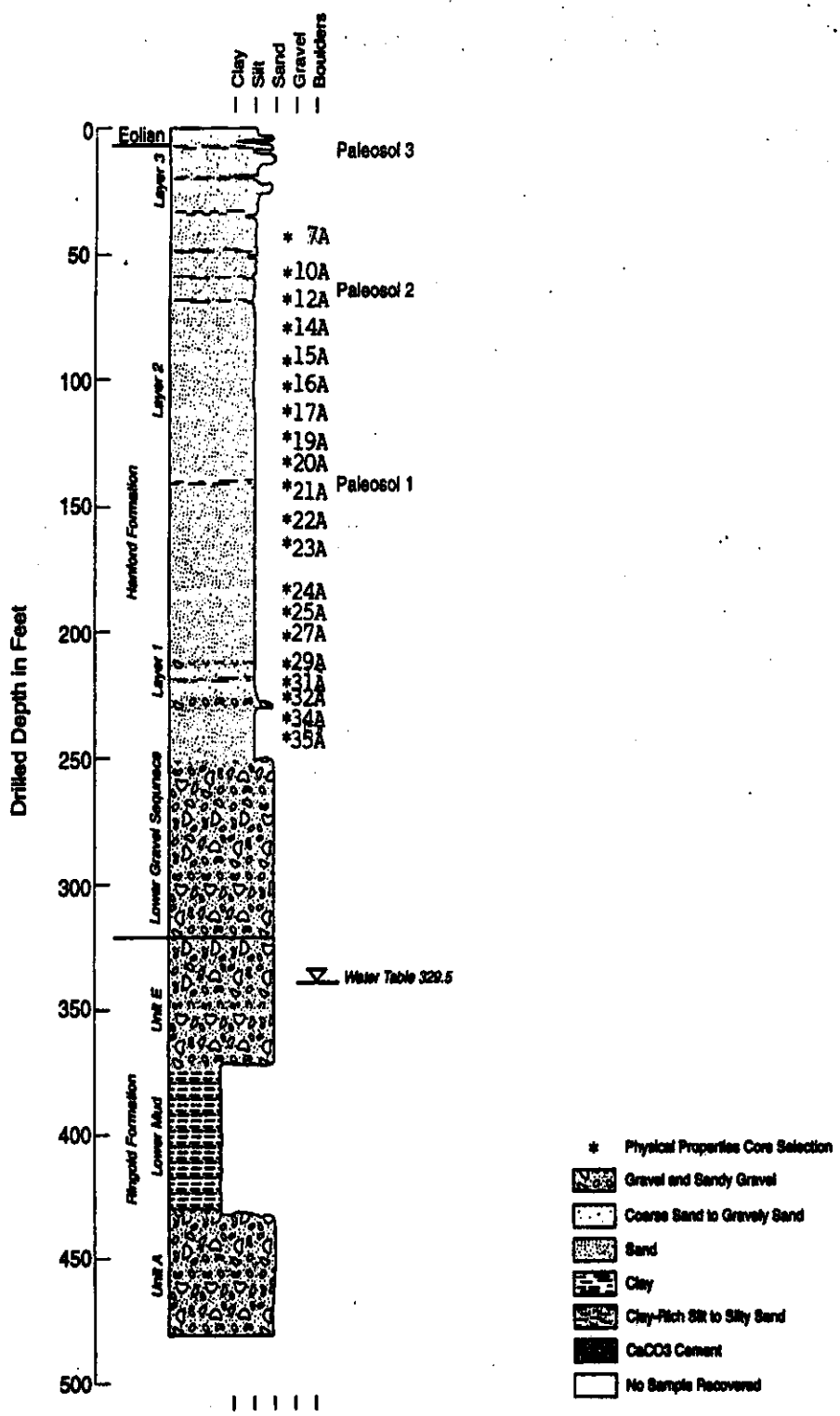


Figure 2. Geologic cross section of the new ILAW disposal site (after Reidel et al. 1998).

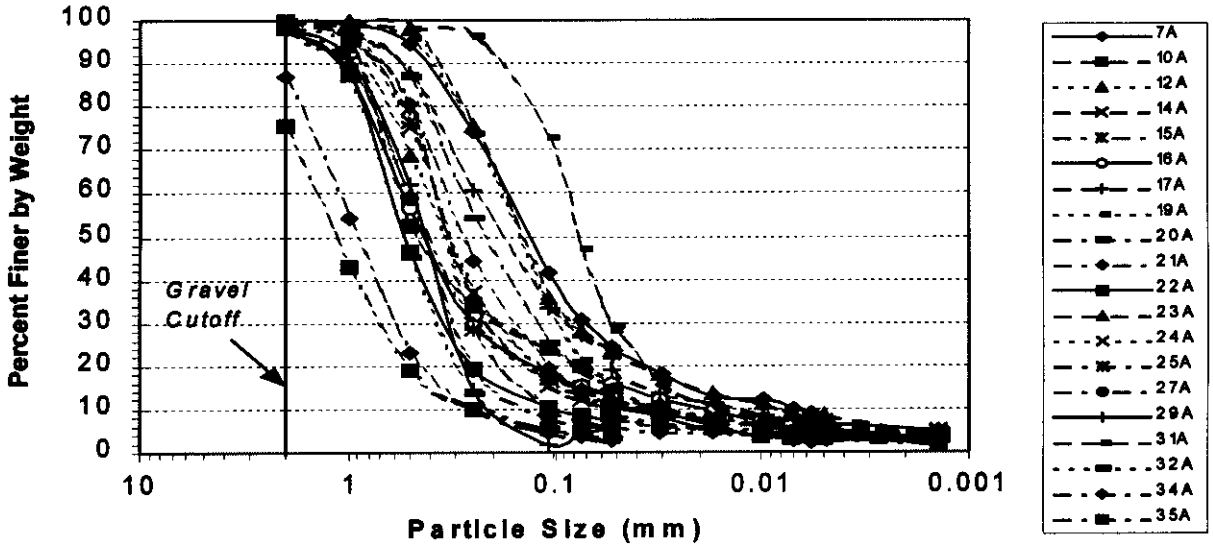


Figure 3. Particle-size distribution for 20 samples from the sand-dominated sequence at the new ILAW disposal site.

Table 2. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for 15 sandy gravel samples.

Sample	Operable Unit	Well Number	Depth (m)	Percent Gravel	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm^3)
2-1307	100-HR-3	199-D5-14	18.90	43	0.236	0.0089	0.0130	1.447	1.29E-04	2.15
2-1308	100-HR-3	199-D5-14	30.64	58	0.120	0.0208	0.0126	1.628	6.97E-05	2.13
2-1318	100-HR-3	199-D8-54A	15.54	60	0.124	0.0108	0.0081	1.496	1.67E-04	2.16
2-2663	100-BC-5	199-B2-12	8.20	61	0. 135	0.0179	0.0067	1.527	6.73E-05	2.38
2-2664	100-BC-5	199-B2-12	24.84	73	0.125	0.0136	0.0152	1.516	1.12E-04	2.25
2-2666	100-BC-5	199-B4-9	21.49	71	0.138	0.00	0.0087	1.284	1.02E-04	2.10
2-2667	100-BC-5	199-B4-9	23.93	75	0.094	0.00	0.0104	1.296	1.40E-04	2.16
3-0570	100-KR-1	116-KE-4A	3.50	60	0.141	0.00	0.0869	1.195	2.06E-02	2.12
3-0577	100-FR-3	199-F5-43B	7.16	66	0.107	0.00	0.0166	1. 359	2.49E-04	2.32
3-0686	100-FR-1	116-F-14	6.49	55	0.184	0.00	0.0123	1.600	5.93E-04	2.17
3-1702	100-DR-2	199-D5-30	9.78	68	0.103	0.00	0.0491	1.260	1.30E-03	2.33
4-1086	100-K	199-K-110A	12.77	65	0.137	0.00	0.1513	1.189	5.83E-02	2.26
4-1090	100-K	199-K-111A	8.20	50	0.152	0.0159	0.0159	1.619	4.05E-04	2.21
4-1118	100-K	199-K-109A	10.30	66	0.163	0.00	0.2481	1.183	3.89E-02	2.12
4-1120	100-K	199-K-109A	18.90	63	0.131	0.0070	0.0138	1.501	2.85E-04	2.06

2.2 Existing Disposal Site

The geologic cross-section in the vicinity of the existing disposal site is shown in Figure 6 (Kincaid et al. 1995). The cross-section appears to be very similar to that of the new ILAW disposal site. Again, for purposes of this data package, no distinction is made on gravel-dominated sequences of the lower Hanford formation and the Ringold Formation. Physical and hydraulic properties' information on sediments from borehole 299-E25-234 was obtained. Such information included particle-size distribution, bulk density, moisture retention, and saturated hydraulic conductivity. Unlike the new ILAW site, notably absent were any measurements of unsaturated hydraulic conductivity. It is, however, well recognized that estimated unsaturated conductivities, based on saturated conductivity and the van Genuchten retention model, can differ by up to several orders of magnitude with measured conductivities at the dry end (e.g., Khaleel et al. 1995). Therefore, it was decided to use, as much as possible, the new ILAW site sediment properties for the existing disposal site, since the geology for the two sites is not significantly different and measurements of both moisture retention and unsaturated conductivity are available for sediments at the new ILAW site. In fact, the average particle-size distribution for the sandy sequence sediments at the two sites is very similar: <1% gravel, 91% sand, 9% silt and clay for the existing disposal site and <2% gravel, 88% sand, 10% silt and clay for the new ILAW site. Similar to the new ILAW site, the gravel-dominated sequence at the existing disposal site is comprised primarily of sandy gravel. In summary, as indicated in Table 3, the soil physical and hydraulic properties at the new ILAW and existing disposal sites are similar.

Table 3. Comparison of mean parameter estimates for the sandy sequence at the new ILAW and existing disposal sites.

Parameter	New ILAW Disposal Site	Existing Disposal Site
θ_s	0.379	0.420
θ_r	0.033	0.023
K_s (geometric mean), cm/sec	0.0029	0.0016
Bulk Density, g/cm^3	1.71	1.58

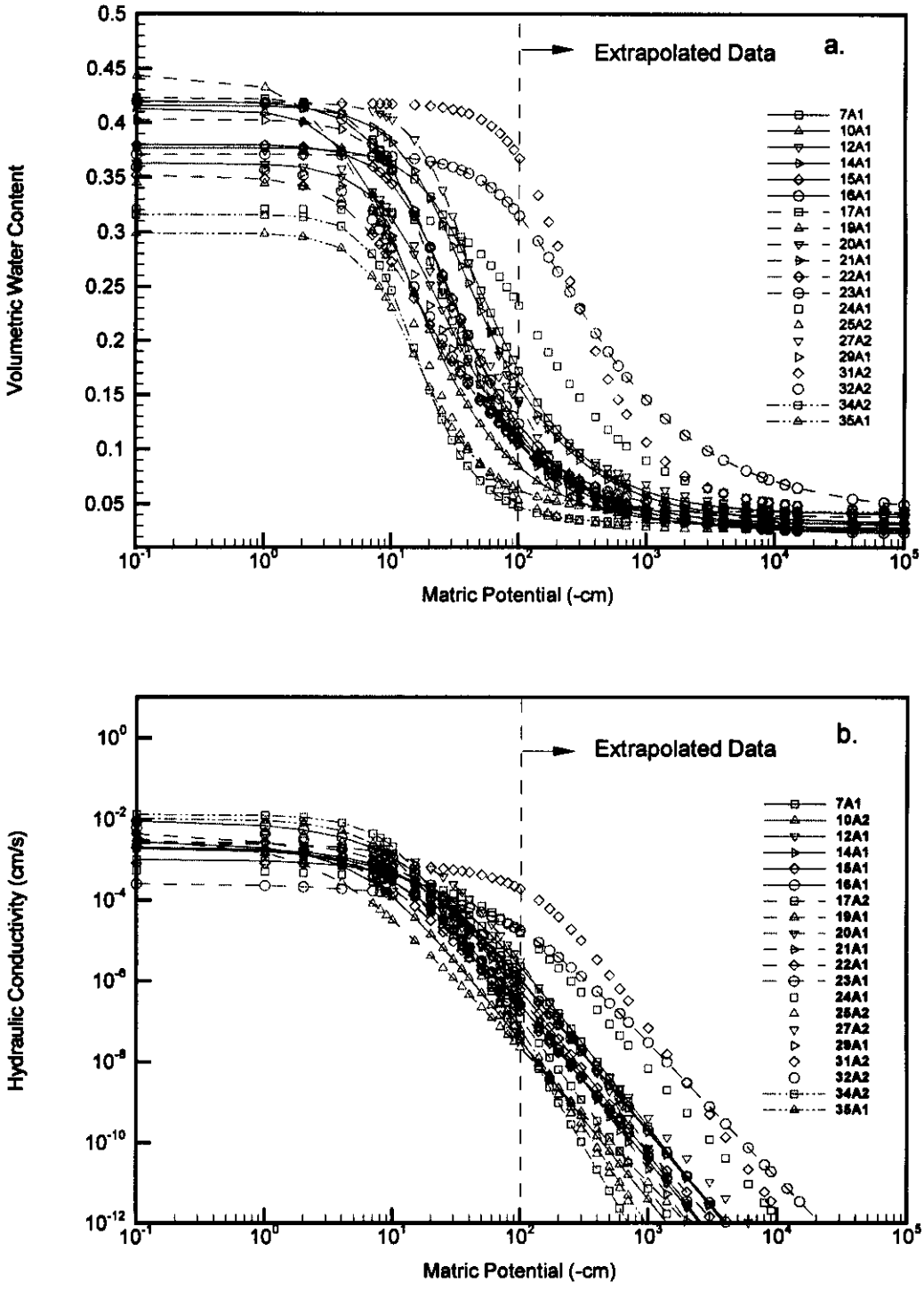


Figure 4. Fitted moisture retention and unsaturated conductivity curves for 20 samples for the sand-dominated sequence (the symbols represent various samples, not experimental data).

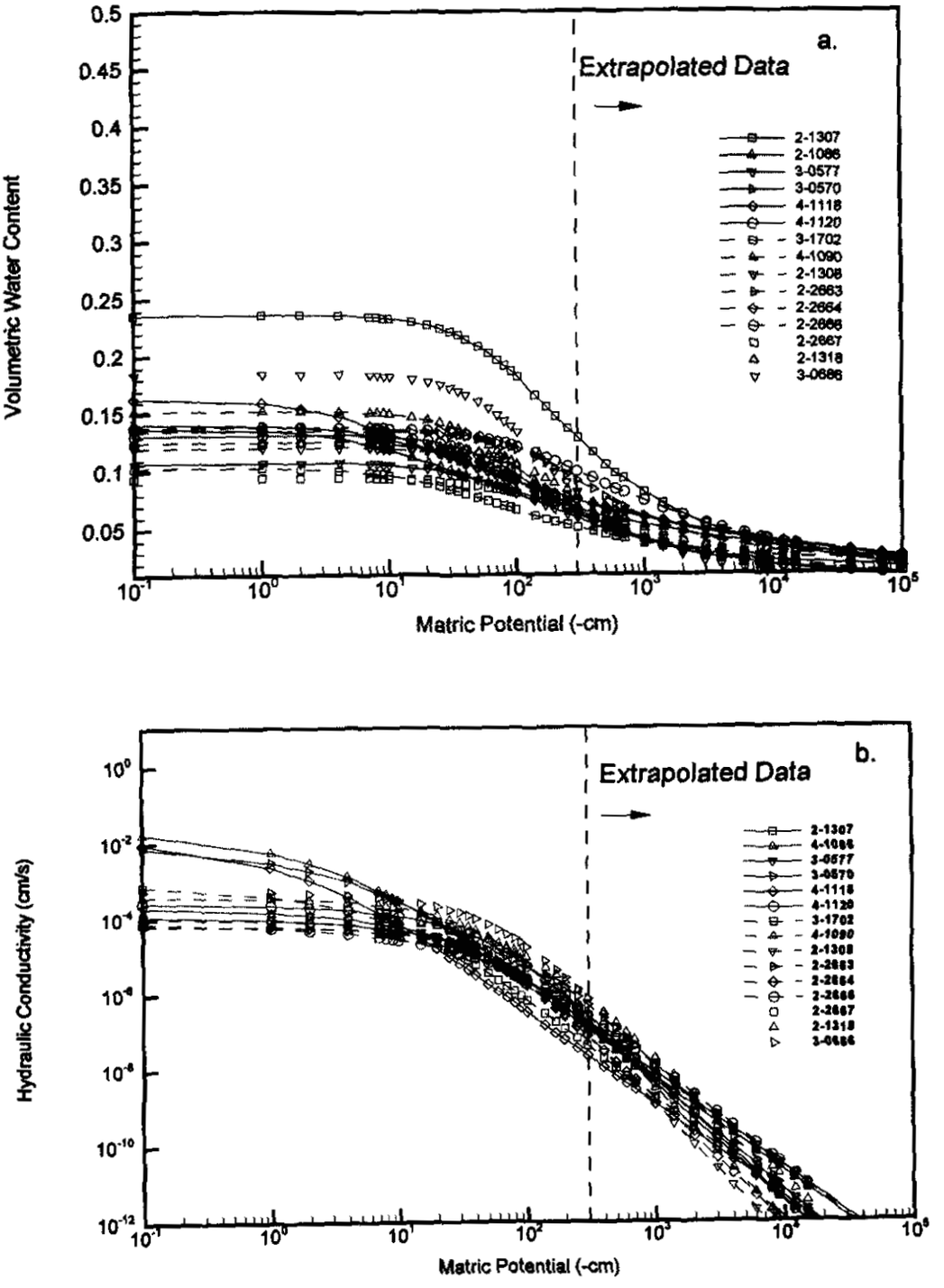


Figure 5. Fitted moisture retention and unsaturated conductivity curves for 15 samples for the gravel-dominated sequence (the symbols represent various samples, not experimental data).

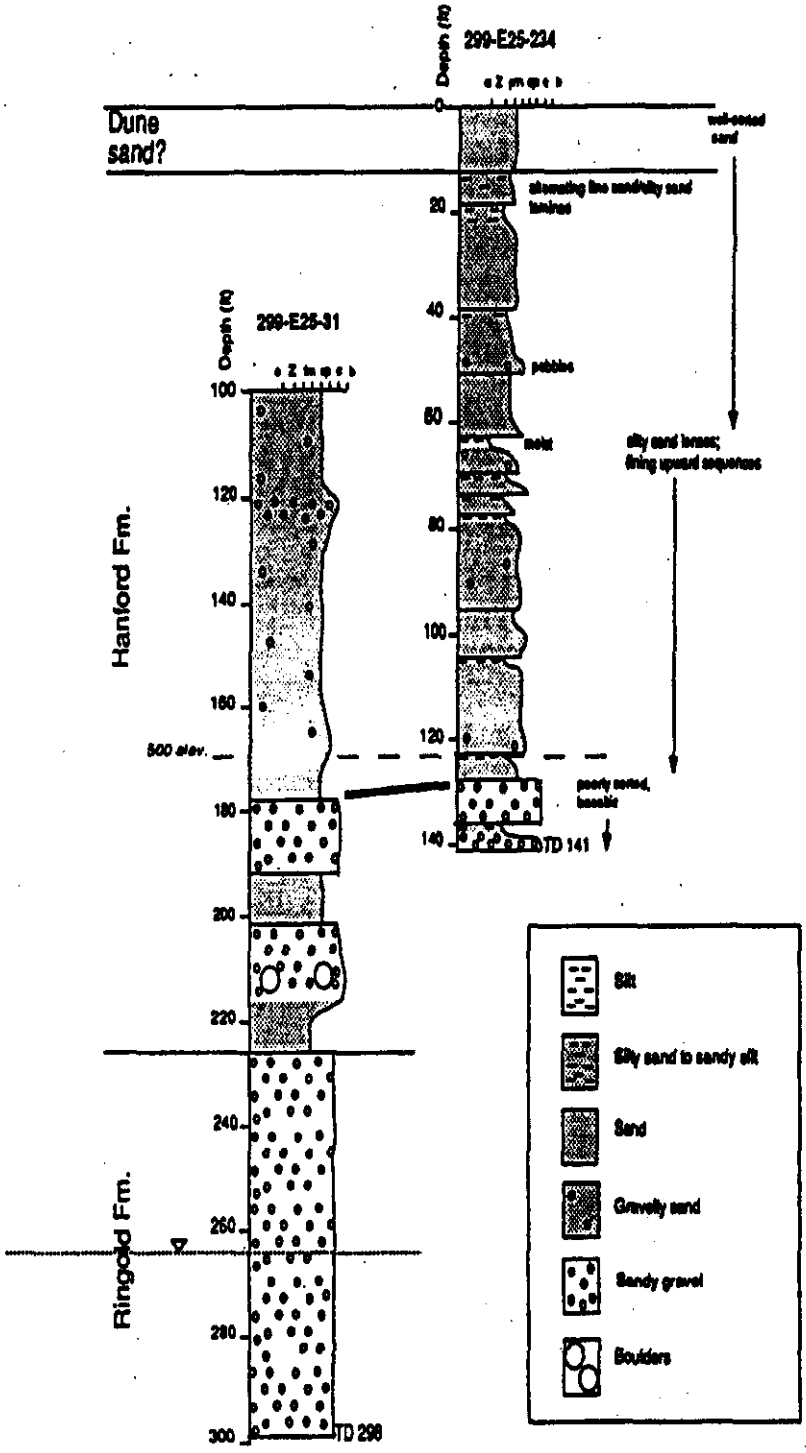


Figure 6. Geologic cross section of the existing disposal site (after Kincaid et al. 1995).

3.0 EFFECTIVE (UPSCALED) FLOW AND TRANSPORT PROPERTIES

Data on hydraulic properties, described in the preceding section, were obtained via laboratory tests on core samples (scales of the order of a few cm). However, numerical models of fluid flow and contaminant transport in the unsaturated zone require specifying hydraulic properties for each discretized grid block (scales of the order of meters). Therefore, the scale of the grid blocks is usually much larger than the scale at which the unsaturated properties were measured. The process of defining large-scale properties for the numerical grid blocks based on small, measurement-scale point measurements is called upscaling.

This section provides effective (upscaled) values of flow and transport parameters for the far-field vadose zone. Specific flow parameters include moisture retention, saturated and unsaturated hydraulic conductivity. Transport parameters include bulk density, diffusivity, and macrodispersivity. Sorption coefficients are included as part of another data package.

3.1 Effective (Upscaled) Flow Parameters

Any attempt at upscaling is confronted with the issue of spatial variability of hydraulic properties due to small-scale soil heterogeneities. The presence of spatial variability in hydraulic properties of Hanford soils has been well documented (e.g., Khaleel and Freeman 1995a). A fundamental issue is then how best to incorporate the effects of natural heterogeneity in modeling. A traditional approach is to use deterministic models and attempt to incorporate the overall heterogeneity of the system such as layering while neglecting the small-scale heterogeneity. The considerable spatial variability of Hanford soils makes complete characterization of the hydraulic properties at the field scale an almost impossible task, as an enormous amount of data is required for proper representation of the actual media heterogeneities.

An alternative approach is to define an equivalent homogeneous medium with average, effective (upscaled) hydraulic properties that are related to the local small-scale heterogeneities and thereby predict the mean flow and transport behavior of the field-scale, larger media. However, to represent a heterogeneous medium by its homogeneous equivalent, we need to estimate the effective hydraulic properties that represent this equivalent homogeneous medium. A straightforward approach would be to use statistical averages (arithmetic or geometric) of the local soil hydraulic properties, but such simple estimates may not always be able to properly describe the complicated nonlinear behavior in heterogeneous soils.

3.1.1 Stochastic Upscaling

For saturated media, an averaging of the heterogeneities in geologic media at a smaller scale leads to an effective hydraulic conductivity value, at the larger (macroscopic) scale, with the lateral hydraulic conductivity being much larger than the vertical conductivity (Freeze and Cherry 1979). For unsaturated media, theoretical (e.g., Mualem 1984, Yeh et al. 1985a, b; c, Bear et al. 1987; Mantoglou and Gelhar 1987; Green and Freyberg 1995) and experimental analyses (e.g., Stephens and Heerman 1988; Yeh and Harvey 1990; McCord et al. 1991) of field-scale unsaturated flow indicates that in stratified sediments, the effective hydraulic conductivity tensor is anisotropic with a tension-dependent (or moisture-dependent) degree of anisotropy. The anisotropy ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity increases with decreasing moisture content. Variable, moisture-dependent anisotropy in unsaturated soils is therefore an effective, large-scale (macroscopic) flow property which results from media heterogeneities at a smaller scale, and provide a framework for upscaling laboratory-scale measurements to the effective (upscaled) properties for the large-scale vadose zone.

3.1.2 Field Observations

Field observations in the vicinity of the new ILAW and existing disposal sites do indeed provide evidence of saturation-dependent anisotropy and lateral migration. A test facility comprising an injection well at the center and a radial array of 32 monitoring wells was constructed in 1980 south of PUREX in 200 East Area. The facility was used in late 1980 and early 1981 to conduct an infiltration and multiple tracer (i.e., chloride, nitrate, barium, rubidium, Sr-85 and Cs-134) test, in which 45,000 L of liquid (in 11 increments) were injected at a depth of 4.7 m over a period of 133 days (Sisson and Lu 1984). Three-dimensional water content profiles in layered, coarse sediments were monitored to a depth of 18 m by down-hole neutron probe measurements. The initial water contents were measured at 30-cm increments over the 30- to 1800-cm depths in all 32 observation wells. In situ gamma energy analysis data were collected to determine the distribution of radioactive tracers. The unique three-dimensional nature of the experiment and the measured water content profiles provide evidence of tension-dependent anisotropy. The field data clearly show lateral spreading that occurred during injection. The horizontal wetting patterns dominated the experiment. In fact, numerical modeling results (Sisson and Lu 1984), based on the assumption of a uniform and isotropic model, showed a much deeper penetration of the moisture profile than occurring in the field (Sisson and Lu 1984). The degree of spreading was remarkable considering the apparent uniform lithology at the site.

3.1.3 Composite Macroscopic Relationships

Figures 4 and 5 show that moisture retention data show spatial variability, although the degree of variation at a given tension is more modest than that of hydraulic conductivity. Based on data in Tables 1 and 2, composite parameters for the moisture retention

relations were determined. For both sandy and gravelly soils, the composite van Genuchten parameters were obtained via RETC (van Genuchten et al. 1991) and a simultaneous fit of both moisture retention and unsaturated conductivity predictions; all four unknown parameters θ_r, θ_s, α, and n with m=1-1/n (van Genuchten 1980), were fitted to the data. The pore size distribution factor ℓ was kept constant at 0.5 during the simultaneous fitting. The saturated conductivity, K_s, was also kept constant as geometric mean of the sample estimates.

The fitted composite moisture retention and unsaturated conductivity curves are shown as Figures 7 and 8, respectively, for the sandy and gravelly sequences. Table 3 shows the fitted parameters. Equivalent horizontal and vertical hydraulic conductivities are derived using macroscopic anisotropy relations.

Table 4. Composite van Genuchten-Mualem parameters for the sand- and gravel-dominated sequences.

Formation	Number of samples	θs	θr	α (1/cm)	n	ℓ	K_s (cm/s)
Sandy	20	0.375	0.041	0.057	1.768	0.5	2.88E-03
Gravelly	15	0.138	0.010	0.021	1.374	0.5	5.60E-04

3.1.3.1 Stochastic Model for Macroscopic Anisotropy

As discussed earlier, variable, tension-dependent anisotropy provides a framework for upscaling small-scale measurements to the effective (upscaled) properties for the large-scale vadose zone. A stochastic model is used to evaluate tension-dependent anisotropy for sediments at the new ILAW site.

Yeh et al. (1985b) analyzed steady unsaturated flow through heterogeneous porous media using a stochastic model; parameters such as hydraulic conductivity are treated as random variables rather than as deterministic quantities. The Gardner (1958) relationship was used by Yeh et al. to describe unsaturated hydraulic conductivity (K) as a function of saturated hydraulic conductivity (K_s) and tension (ψ), i.e.,

$$K(\psi) = K_s \exp(-\beta\psi) \quad (1)$$

where β is a fitting parameter. Equation (1) can be written as

$$\ln K(\psi) = \ln K_s - \beta\psi \quad (2)$$

Equation (2) is referred to as the log-linear model, since lnK is linearly related to ψ through the constant slope β. However, such a constant slope is often inadequate in describing $\ln K(\psi)$ over ranges of tension of practical interest for field applications. As an alternative, the slope β can be approximated locally by straight lines over a fixed range of tension. The "$\ln K_s$" term in equation (2) can then be derived by extrapolating the local slopes back to zero tension.

Using a linear correlation model between the log-conductivity zero-tension intercept and β, Polmann (1990) presents a generalized model that accounts for the cross-correlation of the local soil property (i.e., $\ln K_s$ and β) residual fluctuations. Compared to uncorrelated $\ln K_s$ and β model, partial correlation of the properties is shown to have a significant impact on the magnitude of the effective parameters derived from the stochastic theory. The Polmann (1990) equations for deriving the effective parameters are as follows.

$$
\begin{aligned}
&< LnK >=< LnK_s > -A < \psi > -\sigma^2_{LnKs}\lambda[p - p^2 < \psi > -\zeta^2 < \psi >]/(1 + A\lambda) \\
&\sigma^2_{LnK} = \sigma^2_{LnKs}[(1 - p < \psi >)^2 + \zeta^2 < \psi >^2]/(1 + A\lambda) \\
&K_h^{eq} = \exp[< LnK > +(\sigma^2_{LnK}/2)] \\
&K_v^{eq} = \exp[< LnK > -(\sigma^2_{LnK}/2)]
\end{aligned}
\qquad (3)
$$

where σ^2_{LnK} = variance of log unsaturated conductivity (which depends on mean tension),

$<\psi>$ = mean tension,

σ^2_{LnKs} = variance of $\ln K_s$

$<\ln K_s>$=mean of $\ln K_s$,

p = slope of the β versus $\ln K_s$ regression line,

$\zeta = \sigma_\delta/\sigma_{\ln Ks}$,

σ_δ = standard deviation of the residuals in the β versus $\ln K_s$ regression,

A = mean slope, β, for $\ln K_s$ vs. ψ,

λ = vertical correlation lengths for $\ln K_s$ (assumed to be same as that of β),

K_h^{eq} = equivalent unsaturated horizontal conductivity, and

K_v^{eq} = equivalent unsaturated vertical conductivity.

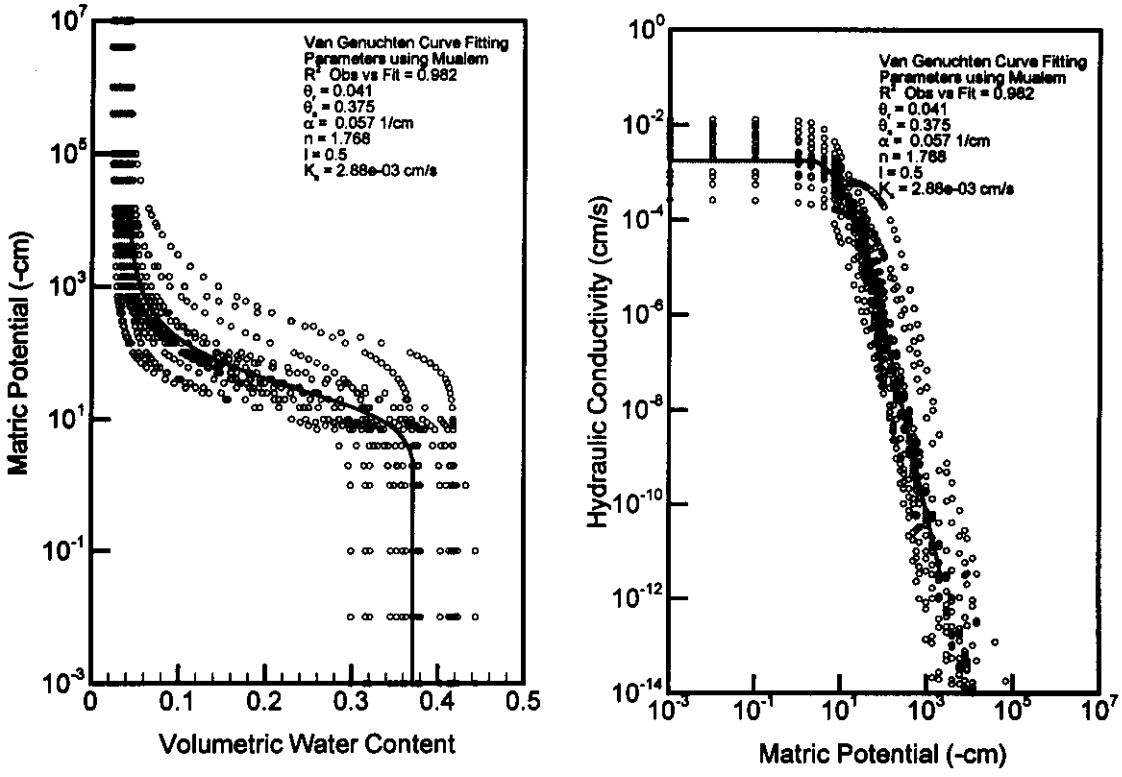


Figure 7. Composite moisture retention and unsaturated conductivity curves for the sand-dominated sequence.

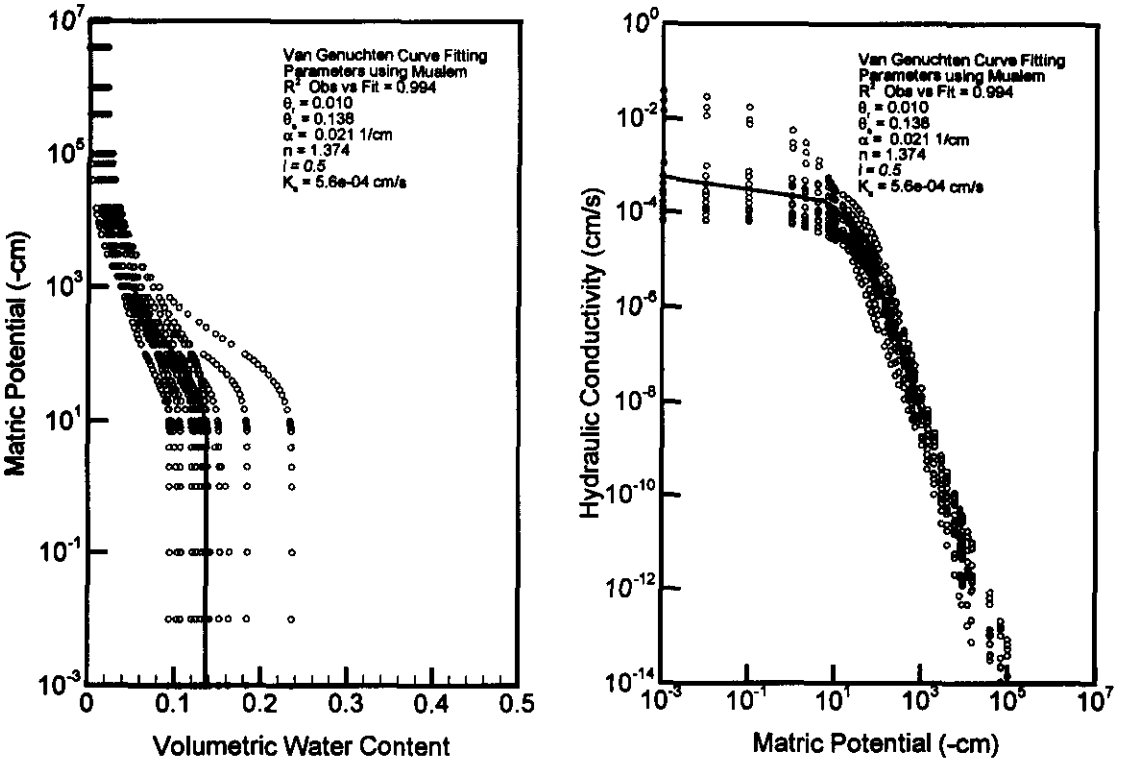


Figure 8. Composite moisture retention and unsaturated conductivity curves for the gravel-dominated sequence.

3.1.3.2 Macroscopic Anisotropy Relations

Results of application of equation (3) for variable anisotropy are presented below. The same 20 samples (Table 1) of the sandy sequence were used to obtain parameters $\langle \ln K_s \rangle$, $\sigma^2_{\ln K_s}$, p, ζ, and A. The slope and pseduo $\ln K_s$ estimates, discussed in the preceding section, were evaluated for the moisture regime of interest (i.e., tension range of 500 cm to 700 cm for the sandy sequence and 700 cm to 1000 cm for the gravelly sequence). It should be noted, however, that no experimental data are available for unsaturated conductivities in the tension range of interest; β and $\ln K_s$ estimates were based on the fitted van Genuchten-Mualem curves (Figures 7 and 8). The tension ranges are consistent with a base case recharge estimate of about 0.1 cm/yr (Figures 7 and 8).

An estimate of the correlation length, λ, is needed for anisotropy calculations. Most of the measurements in the vicinity of the ILAW site have been obtained at sampling intervals that are too coarse to yield a reasonable estimate for the correlation length. However, one data set is available that provides saturated conductivity estimates at about 30 cm intervals for a depth of 18 m within the Hanford formation; the site is located about 1/2 mile east of the ILAW site. Figure 9 shows the experimental variogram and the

fitted spherical variogram model for saturated conductivities. The fitted spherical variogram suggests a correlation length, λ, of about 50 cm; i.e., the distance at which the variogram drops to [1-(1/e)] times the sill (Figure 9). The correlation length, λ, for both lnKs and β were assumed to be equal.

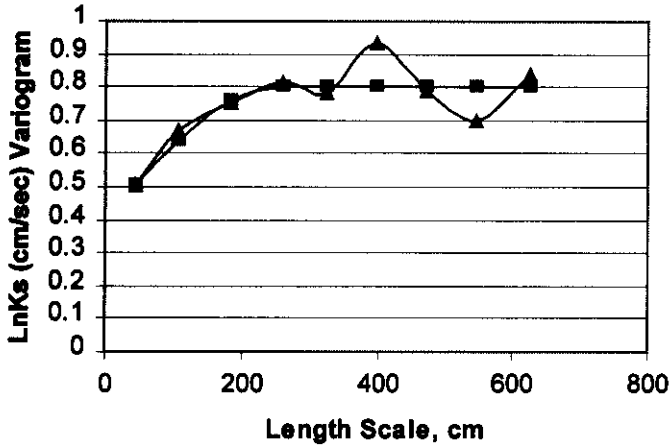


Figure 9. Experimental (triangles) and fitted theoretical (squares) variogram for LnKs.

The Polmann parameters for both sandy and gravel-dominated sequences are shown in Table 5. Note that, compared to the sandy soils, mean slope, A, <lnKs>, $\sigma^2_{LnK_s}$, and ζ values for the gravelly soils are significantly lower; σ_β^2 for the gravelly samples was also almost two orders of magnitude lower. Because of these different characteristics, the macroscopic anisotropy relations for the sandy and gravelly sediments are quite different. Figures 10 and 11 illustrate the macroscopic anisotropy relations for the two sediments. The anisotropy for the gravelly soils is much less compared to that for sandy soils. In fact, for the tension range of interest for ILAW PA modeling, anisotropy ratio is about two. Note that, for gravelly soils, no data were available for a variogram analysis. However, a smaller λ value (30 cm) is used (Table 5) because of a much higher variance of $\ln K_s$ for the gravelly soils than for the sandy soils.

Table 5. Macroscopic anisotropy parameters for the sand- and gravel-dominated sequences.

Formation	Number of samples	$<LnK_s>$	$\sigma^2_{LnK_s}$	p	ζ	λ (cm)	A
Sandy	20	-17.3	2.89	-1.4E-4	3.18E-4	50	0.00680
Gravelly	15	-15.6	1.03	1.9E-4	4.24E-4	30	0.00354

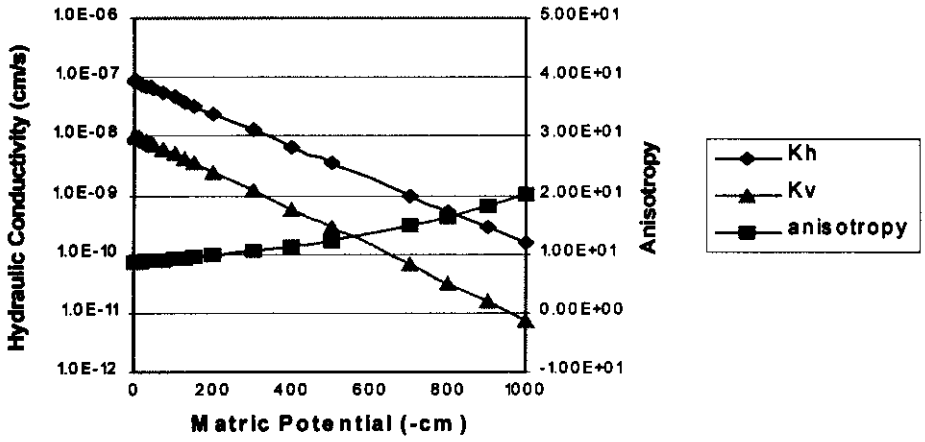


Figure 10. Calculated macroscopic anisotropy (equation 3) as a function of mean pressure head for the sand-dominated sequence.

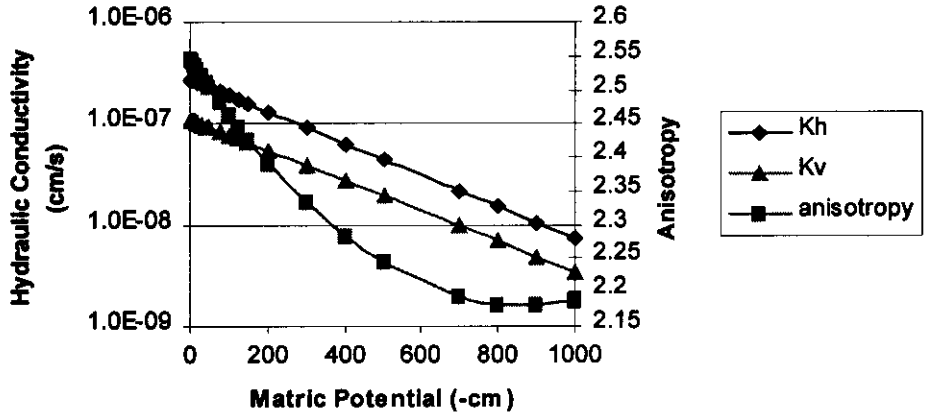


Figure 11. Calculated macroscopic anisotropy (equation 3) as a function of mean pressure head for the gravel-dominated sequence.

3.2 Effective Transport Parameters

Base case effective transport parameter (bulk density, diffusivity, and dispersivity) estimates are presented in this section. Because of natural variability, the transport parameters are all spatially variable. The purpose is again, similar to the flow parameters, to evaluate the effect of such variability on the large-scale transport process.

3.2.1 Bulk Density

Both bulk density (ρ_b) and K_d estimates are needed to calculate retardation factors for different species. The effective, large-scale estimate for the product [$\rho_b K_d$] is the average of the product of small-scale laboratory measurements for bulk density and K_d (Gelhar 1993). The laboratory measurements for ρ_b are shown in Tables 1 and 2, respectively, for the sandy and the gravel-dominated sequences, whereas the K_d measurements are available in Kaplan et al. (1998). Table 6 provides the effective, large-scale estimates.

Table 6. Effective parameter estimates, E[$\rho_b K_d$], for the product of bulk density (g/cm^3) and K_d (cm^3/g) at the new ILAW and existing disposal sites.

Species	E[$\rho_b K_d$]	
	Sandy	Gravelly
Cs	3473	1700
Sr	25.20	12.20
U	1.05	0.51
Se	11.32	5.56

3.2.2 Diffusivity

It is assumed that the effective, large-scale diffusion coefficients for both sandy and gravel-dominated sequences at both sites are a function of volumetric moisture content, θ. VAM3DF uses the Millington-Quirk (1961) empirical relation:

$$D_e(\theta) = D_0 \frac{\theta^{10/3}}{\theta_s^2} \qquad (4)$$

where $D_e(\theta)$ is the effective diffusion coefficient of an ionic species, and D_0 is the effective diffusion coefficient for the same species in free water. The molecular diffusion coefficient for all species in pore water is assumed to be 2.5 x 10^{-5} cm^2/sec (Kincaid et al.1995).

3.2.3 Dispersivity

An extended review is provided on the rationale of choice for vadose zone dispersivity estimates. Readers who are familiar with the state-of-the-art can proceed directly to Section 3.2.3.4.

A variety of factors such as the size of the flow domain, the flow regime (saturated versus unsaturated flow), field heterogeneities, and the contaminant species (retarded versus nonretarded) need to be recognized in estimating dispersivities. The objective of this section is to provide appropriate guidance on the choice of vadose zone dispersivity estimates for use in ILAW PA.

It should be noted that laboratory data would be of little use in estimating field-scale dispersivities. While well-designed, large-scale tracer experiments would provide useful information, limited field data are available at this time. Therefore, the dispersivity estimates needed for modeling are essentially based on literature values and the available stochastic equations.

Literature data suggest that much more information is available on dispersion in saturated media than in unsaturated media. Therefore, first the available data on dispersivities in saturated media are summarized (Gelhar et al. 1992). Second, available data on vadose zone dispersivities are presented, including results of small-scale tracer experiments in the vicinity of the new ILAW site in 200 East Area. Third, the stochastic framework used in obtaining dispersivity estimates is reviewed, and estimates are provided for use in ILAW PA.

3.2.3.1 Saturated Media Dispersivities For Field Sites

A critical review of dispersivity observations from 59 different field sites was performed by Gelhar et al. (1992). Extensive tabulations of information were included by Gelhar et al. on aquifer type, hydraulic properties, flow configuration, type of monitoring network, tracer, method of data interpretation, overall scale of observation and longitudinal, horizontal transverse and vertical transverse dispersivities from original sources. The information was then used to classify the dispersivity data into three reliability classes: low, intermediate, and high. Overall, the data indicate a trend of systematic increase of the longitudinal dispersivity with observation scale but the trend is much less apparent when the reliability of data (Figure 12) is considered. The longitudinal dispersivity ranged from 10^{-1} to 10^{5} m, but the largest scale for high reliability data was only 250 m. When the data are classified according to porous versus fractured media, no significant differences were apparent between these aquifer types. At a given scale, the longitudinal dispersivity values were found to range over 2 to 3 orders of magnitude and the higher reliability data approached the lower portion of this range. The high reliability dispersivity data ranged from a low of about 0.6 m at a scale of 15 m to about 1 m at a scale of 250 m; some data are on the order of 2 to 3.5 m at a scale of 30 m (Figure 12). It is not appropriate to represent the longitudinal dispersivity data by a single universal line.

The variations in dispersivity reflect the influence of differing degrees of aquifer heterogeneity at different sites. The data on transverse dispersivities are more limited but clearly indicate that vertical transverse dispersivities are typically an order of magnitude smaller than horizontal transverse dispersivities (Gelhar et al. 1992). Reanalysis of data from several of the field sites showed that improved interpretations most often lead to smaller dispersivities (Gelhar et al. 1992). Overall, Gelhar et al. concluded that longitudinal dispersivities in the lower part of the indicated range are more likely to be realistic for field situations. This suggests that, for conservative species, a longitudinal dispersivity of the order of a meter is a reasonable estimate for saturated media domains that are a couple of hundred meters in scale. Note that the estimates are for saturated media and conservative species. As discussed later, dispersivity estimates are enhanced due to heterogeneous sorption in both saturated and unsaturated media.

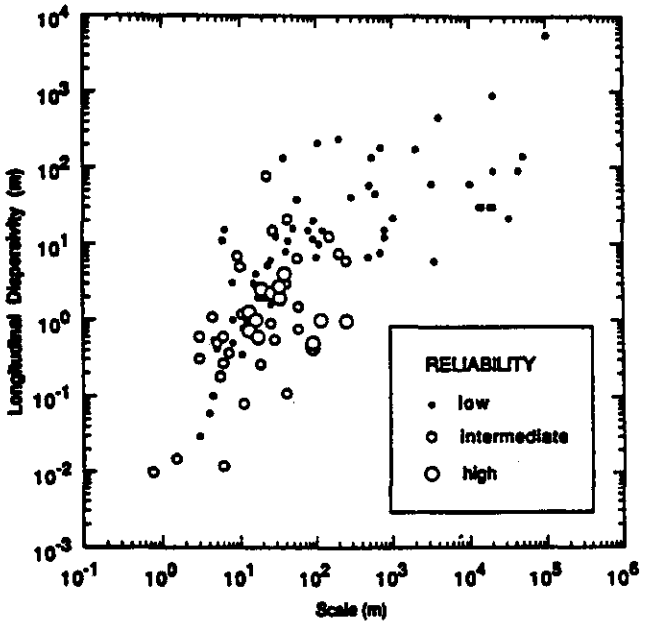


Figure 12. Longitudinal macrodispersivity in saturated media as a function of overall problem scale with data classified by reliability (after Gelhar et al. 1992).

3.2.3.2 Vadose Zone Dispersivities For Dry Desert Environment

As discussed earlier, for an engineered waste disposal facility with a capillary barrier and a surface barrier on top, the vadose zone water contents beneath the disposal facility are expected to approach the natural moisture regime for arid soils. Although exceptional precipitation events may cause transient high water contents near the soil surface, the source of the infiltration is not likely to be sustained at great depths within the vadose zone.

This inference is supported by the results of artificial tracer experiments on much shorter time scales. For example, two massively instrumented solute transport experiments were performed in desert soils near Las Cruces, New Mexico (Wierenga et al. 1991; Hills et al. 1991). Drip emitters were used to irrigate a plot adjoining a deep trench in a heterogeneous soil possessing well in excess of one order of magnitude standard deviation in saturated hydraulic conductivity. Monitoring of the trench face showed a spatially uniform progression of the wetting front and did not reveal indications of preferential flow (Wierenga et al. 1991). Hills et al. (1991) found that a dispersivity of 5 cm provided reasonably realistic simulations of ^{3}H and Br tracer distributions.

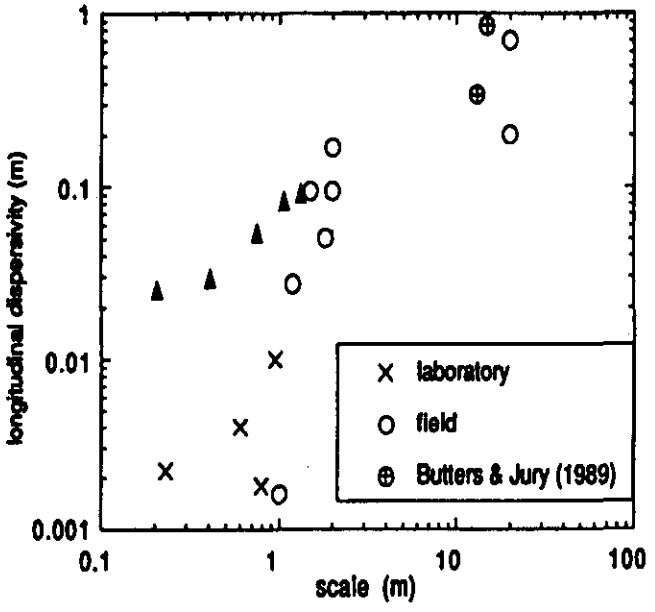


Figure 13. Longitudinal macrodispersivity in unsaturated media as a function of overall problem scale (after Gelhar 1993). [Note that the triangles are data from Ward et al. 1998]

For unsaturated flow, long-term environmental tracer studies at several arid southwestern sites indicate dispersivities of less than 10 cm. Phillips et al. (1988) assessed the degree of mixing in desert soils using the conventional advection-dispersion modeling, yielding

a dispersion coefficient of 50 cm^2/yr. This compares with the calculated effective diffusion coefficient of 25 cm^2/yr. A similar study by Scanlon (1992), at another southwestern arid site, obtained a dispersion coefficient of about 14 cm^2/yr. These, then, lead to effective dispersivities of about 7 and 4 cm, at the two arid sites, and Peclet numbers (displacement divided by dispersivity) of 23 and 17.

Ward et al. (1998)[3] obtained dispersivity estimates via field measurements at a location close to the ILAW site, using KCl as a tracer. Analysis of the data provided dispersivities that ranged from 1.3 to 7.8 cm for travel distances ranging from 25 to 125 cm (Appendix C). Dispersivity increased with depth to about 0.75 m, after which it essentially became constant. Although these estimates are for the Hanford formation similar to the ILAW site, the transport distance within the vadose zone is indeed of limited extent. Nevertheless, results based on the limited data are consistent with the concept of a scale-dependent dispersivity. Thus, although no data exist on large-scale dispersivities near the ILAW site, it is expected that they will be larger than those based on the small-scale tracer experiment of Ward et al. (1998).

Based on a survey of literature, Gelhar (1993) presented, as shown in Figure 13, the longitudinal vadose zone dispersivities as a function of the scale of the experiment. The figure shows a lack of data for scales larger than 2 m. Nevertheless, similar to saturated flow, Figure 13 show an increase of dispersivity with an increase in scale. Also, shown in Figure 13 are results from the Ward et al. experiment; their data are in close agreement with others.

3.2.3.3 Stochastic Models and Macrodispersivities for Large-Scale Media

Field-scale dispersivities are referred to as macrodispersivities. The heterogeneities that exist at various length scales result in a scale dependence of macrodispersivities. Stochastic models have been developed which relate the macrodispersive spreading to the spatial variability of saturated hydraulic conductivity field in a saturated porous media (e.g., Gelhar and Axness 1983; Dagan 1984). The Gelhar and Axness (1983) model provides the asymptotic estimates of macrodispersivity, while the Dagan (1984) model describes the preasymptotic estimates of macrodispersivities for the near-source, early-time period. The Dagan (1984) model predicts that under steady state flow with a uniform mean hydraulic gradient, the ensemble longitudinal macrodispersivity increases with time and displacement distance as the solute first enters the flow domain. A constant, asymptotic value (i.e., Fickian behavior) is eventually reached after the solute travels a few tens of correlation scales of the hydraulic conductivity field.

For prediction of contaminant transport during early time or for short travel distances, simulating effects of scale-dependence on macrodispersion is a consideration. The dispersivities increase with time (or equivalently with distance) until they tend to

[3] Ward, A.L., R.E. Clayton, and J.S. Ritter. 1998. Determination of in situ hydraulic parameters of the upper Hanford formation. Letter Report to Fluor Daniel Northwest, Inc. December, 1998. Pacific Northwest National Laboratory. Richland, WA.

converge on their unique asymptotic (large time) values. The second-moment evolution curve or the time-dependent, preasymptotic macrodispersivities are of particular interest, since it can take a long time (e.g., years or decades) for the asymptotic Fickian approximation to take hold. However, the early time scale dependence are of little consequence in simulations involving long times or large mean travel distances such as those for ILAW PA. For these predictions over large travel distances or large times, the use of a constant (asymptotic) dispersivity is considered to be adequate. An estimate of the maximum or asymptotic value of macrodispersivity for saturated media can be based on Gelhar and Axness' (1983) stochastic solution:

$$A_L = \sigma^2_{LnKs}\lambda \tag{5}$$

where λ is the vertical correlation scale (i.e., average distance over which conductivities are correlated) for log saturated hydraulic conductivity.

In addition to the size of flow domain and vadose zone soil heterogeneities, dispersivities are expected to be a function of soil moisture content (or matric potential). Macrodispersivities are expected to increase with a decrease in saturation (e.g., Polmann 1990; Gelhar et al. 1994). Russo (1993) suggests that vadose zone macrodispersivities can be defined in a manner similar to saturated media estimates. This is based on his finding that the product of the variance and the correlation scale of log conductivity for both saturated and unsaturated media are of similar magnitude. In other words, an increase in the variance of log conductivity (and, concurrently, in the velocity variance) as moisture content decreases is compensated in part by a decrease in the correlation scale of log conductivity (and, concurrently, in the correlation scale of the longitudinal component of the velocity). Such an approximation (a) assumes use of Gardner's (1958) equation to describe unsaturated conductivity as a function of matric potential, and (b) holds as long as the correlation scale of β in Gardner's equation is relatively small compared with that of log saturated conductivity.

3.2.3.4 Macrodispersivity Estimates For Non-Reactive Species

The Gelhar and Axness equation can be used to estimate asymptotic values of macrodispersivity. However, to account for effects of unsaturated flow, a modified version is used for both disposal sites:

$$A_L(<\psi>) = \sigma^2_{LnK}\lambda \tag{6}$$

where the longitudinal macrodispersivity depends on the mean tension $<\psi>$. To apply equation (6), an estimate of the vertical correlation scale for unsaturated conductivity is needed. As discussed earlier, a correlation length of the order of about 50 cm was obtained for the sandy formation. However, compared to the saturated K's, an increase in the variance of log conductivity is expected to be compensated in part by a decrease in the correlation scale of log unsaturated conductivity. A correlation length of 30 cm is assumed for both sandy and gravelly formations. Table 6 provides the log unsaturated

conductivity variances (at a recharge rate of about 0.1 cm/yr) and the estimated longitudinal (A_L) and transverse (A_T) macrodispersivities for the two formations. The transverse dispersivities are estimated as $1/10^{th}$ of the longitudinal values (Gelhar et al. 1992). Gelhar (1993) presented results of stochastic analysis of macrodispersion in unsaturated media by Mantoglou and Gelhar (1985). The large-scale macrodispersivity estimates in Table 7 are of similar magnitude to those reported in Gelhar (1993) for Panoche and Maddock soil types.

Table 7. Non-reactive macrodispersivity estimates for soils at the new ILAW and existing disposal sites.

Formation	σ^2_{LnK}	Correlation length, λ (cm)	A_L (cm)	A_T (cm)
Sandy	5.51	30	~200	20
Gravelly	0.96	30	~30	3

3.2.3.5 Heterogeneous Sorption Enhanced Macrodispersivities

As expected, the net effect of sorption is to retard the velocity of the contaminant in the soil. Because sorption for specific contaminants may be a function of soil properties, as the soil properties experience spatial variability, the sorption also varies (Gelhar 1993; Talbott and Gelhar 1994). The variation directly affects the velocity of the contaminant, which, in turn, enhances the spreading of the plume. The enhanced spreading is defined by a larger reactive longitudinal macrodispersivity, different from the non-reactive longitudinal macrodispersivity, as discussed in the preceding section. The increased plume spreading due to heterogeneous sorption (over and above the result for no sorption) is defined as the macrodispersivity enhancement. Stochastic theory and field data on contaminant plumes suggest that the effect of macrodispersivity enhancement only occurs in the longitudinal direction. The transverse macrodispersivity is unaffected by sorption variability (Garabedian et al. 1991). The results presented in this section will support the use of species-dependent enhanced longitudinal macrodispersivities in the ILAW PA modeling.

The radioisotopes considered are Cs-137, Sr-90, U, and Se. The objective is to evaluate differences in macrodispersivity enhancement due to a long-lived mobile radionuclide (e.g.,U) and a short-lived relatively immobile radionuclide (e.g., Sr-90). During the laboratory analysis, measurements of K_d for each species have been obtained on the same soil samples, as are measurements of unsaturated hydraulic conductivity.

Based on laboratory measurements of unsaturated conductivity, K (Fayer et al. 1998; see footnote on p. 4) and K_d (Kaplan et al. 1998) for the same 20 samples for the Hanford

sandy sequence, a direct correlation of K and K_d was derived for Cs-137, Sr-90, U, and Se. Stochastic theory developed by Gelhar (1993) was evaluated to determine the importance of varying longitudinal macrodispersivity by contaminant species on the basis of sorption heterogeneity and correlation with hydraulic conductivity. An enhancement of macrodispersivity can have significant effects on the expected contaminant predictions for numerical models.

In order to understand clearly the importance of heterogeneous, spatially variable sorption, a number of parameters were defined. The variable K_d may be prescribed by a mean (K_d) and a standard deviation (σ_{Kd}). Further, a retardation factor, R, was related to K_d by the following:

$$R = 1 + \frac{\rho_b K_d}{\theta} \tag{7}$$

where R may be described statistically by an effective retardation, $\overline{R}$ = E[R], and its standard deviation, σ_R.

By analyzing the mean and standard deviation of a sample data set of a measured soil property, and by showing a relationship between the soil property and R, $\overline{R}$ and σ_R were calculated as a function of the soil property data set.

The net result of the variation in the retardation and the relationship between the retardation and ℓnK is to increase the longitudinal macrodispersivity of the sorbed species according to the following equation given by Talbott and Gelhar (1994):

$$A_{11} = A_0 \left\{ \left[1 + \gamma \frac{\sigma_R}{\overline{R}\sigma_{LnK}} \sqrt{\zeta} \right]^2 + (1-\zeta) \frac{\sigma_R^2 \lambda_n}{\overline{R}^2 \sigma_{LnK}^2 \lambda_1} \gamma^2 \right\} \tag{8}$$

where A_0 is the non-reactive longitudinal macrodispersivity, λ_1 is the horizontal correlation scale, $\lambda_n \approx \lambda_1$, and γ is defined as the ratio of harmonic to geometric mean for unsaturated K.

Equation (8) is identical to that in Talbott and Gelhar (1994), except that the appropriate variables are evaluated for unsaturated conditions. Equation (8) assumes random K_d but constant bulk density and moisture content. However, using the more general case (p. 256, Gelhar 1993) when all three (i.e., K_d , bulk density and moisture content) vary, it was found that the contribution to equation (8) from variations of bulk density and moisture content were negligibly small, compared to variations of K_d.

The LnK versus R relation for the four species for the sandy sequence are shown in Figure 14. The result of stochastic analysis for macrodispersivity enhancement for the Hanford sandy sequence is shown in Table 8. Note that the unsaturated K's were

evaluated at -100 cm via the fitted van Genuchten-Mualem relation. As expected, the log conductivity variance, σ^2_{LnK} at a matric potential of -100 cm is much higher (~5.5) compared to the σ^2_{LnKs} (~1.0) for the same 20 samples at saturation. The macrodispersivity enhancement, A_{11}/A_o ranges from about 1.06 for Se to about 2.12 for U.

Table 8. Macrodispersivity enhancement for the sandy sequence at the new ILAW and existing disposal sites [ρ_b in g/cm^3 and K_d in cm^3/g].

Species	$\overline{K_d}$	$\sigma_{Kd}/\overline{K_d}$	$\overline{R}$	$\sigma_R/\overline{R}$	$\overline{\rho_b}$	$\overline{\theta}$	σ^2_{LnK}	γ	ζ	λ_n/λ_1	A_{11}/A_o
Cs-137	2055	0.29	31002	0.50	1.71	0.138	5.51	0.22	0.52	1	1.07
Sr-90	14.7	0.11	241	0.62	1.71	0.138	5.51	0.22	0.45	1	1.08
U	0.62	0.20	11.1	0.52	1.71	0.138	5.51	0.22	0.53	1	2.12
Se	6.73	0.28	98.5	0.28	1.71	0.138	5.51	0.22	0.68	1	1.06

The LnK versus R relation for the four species for the gravelly sequence are shown in Figure 15. The result of stochastic analysis for macrodispersivity enhancement for the Hanford gravelly sequence is shown in Table 9. Again, the unsaturated K's were evaluated at -100 cm via the fitted van Genuchten-Mualem relation for the 15 gravelly samples. No data are available on the measurements of sorption coefficients for the gravel-dominated sequence. Based on the information for the sandy samples, all gravelly samples were first assigned the same average sorption coefficient for their respective species. This resulted in the coefficient of variation (i.e., Col. 3 in Table 9) to be identically zero for all four species. The bulk (gravel and fine fraction) retardation coefficients are then based on a correction of the actual surface area available for sorption, based on the individual gravel fraction for the 15 samples. Unlike for the sandy sequence, the log conductivity variance, σ^2_{LnK} at a matric potential of -100 cm is much lower (~0.96) compared to the σ^2_{LnKs} (~5.31) for the same 15 samples at saturation. The macrodispersivity enhancement, A_{11}/A_o varies over a very narrow range -- from about 1.05 for U to about 1.07 for Cs-137.

Table 9. Macrodispersivity enhancement for the gravelly sequence at the new ILAW and existing disposal sites [ρ_b in g/cm^3 and K_d in cm^3/g].

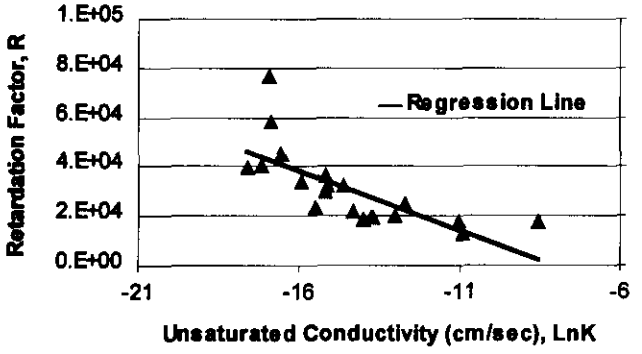
Species	$\overline{K_d}$	$\sigma_{Kd}/\overline{K_d}$	$\overline{R}$	$\sigma_R/\overline{R}$	$\overline{\rho_b}$	$\overline{\theta}$	σ^2_{LnK}	γ	ζ	λ_m/λ_1	A_{11}/A_o
Cs-137	2055	0	17148	0.21	2.19	0.10	0.96	0.62	0.033	1	1.07
Sr-90	14.7	0	124	0.20	2.19	0.10	0.96	0.62	0.033	1	1.06
U	0.62	0	6.13	0.17	2.19	0.10	0.96	0.62	0.033	1	1.05
Se	6.73	0	57.12	0.20	2.19	0.10	0.96	0.62	0.033	1	1.06

3.2.3.6 Numerical Considerations

A complicating factor in numerical modeling of contaminant transport in porous media is that both finite-difference and finite-element solutions are affected by "numerical dispersion," which refers to artificial dispersion caused by errors associated with discretization of the flow domain. To minimize such errors, the grid should be designed so that the Peclet number (P_e = discretized distance/dispersivity) is less than or equal to one, although acceptable solutions can be obtained with P_e as high as 10 (Huyakorn and Pinder 1983). With low dispersivities within the vadose zone, the Peclet number criterion results in grid spacings that are not very practical to implement. This is why numerical modelers often resort to higher values of dispersivity. An alternative is to consider use of "upwinding" option (Huyakorn and Pinder 1983) to control numerical dispersion.

Another consideration is discretization of simulation time so that the Courant number (C_r = pore velocity*time interval/grid spacing) is less than or equal to one. That is, the time step should be selected so that the chosen time interval is less than the value obtained by the ratio of grid spacing to pore velocity. Thus, the time step should be selected so that it is less than the time it takes for the solute to move one grid spacing. Note that, for a three-dimensional problem, the P_e and C_r criteria are applicable to transport in all three directions.

(a)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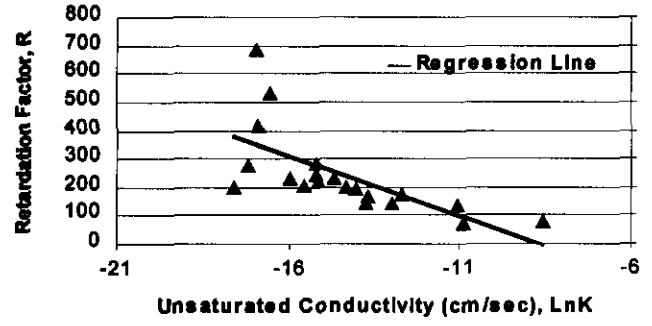
8.E+04
6.E+04
4.E+04
2.E+04
0.E+00
Retardation Factor, R
Regression Line
-21
-16
-11
-6
Unsaturated Conductivity (cm/sec), LnK

(b)


800
700
600
500
400
300
200
100
0
Retardation Factor, R
Regression Line
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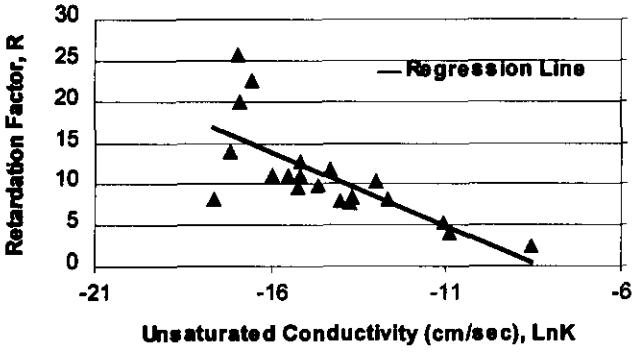
-16
-11
-6
Unsaturated Conductivity (cm/sec), LnK

(c)


30
25
20
15
10
5
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Retardation Factor, R
Regression Line
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-16
-11
-6
Unsaturated Conductivity (cm/sec), LnK

(d)

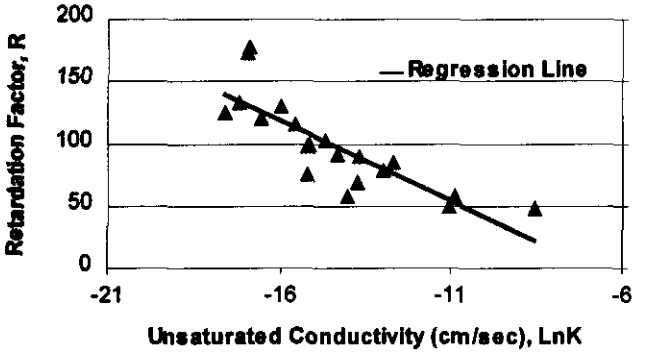
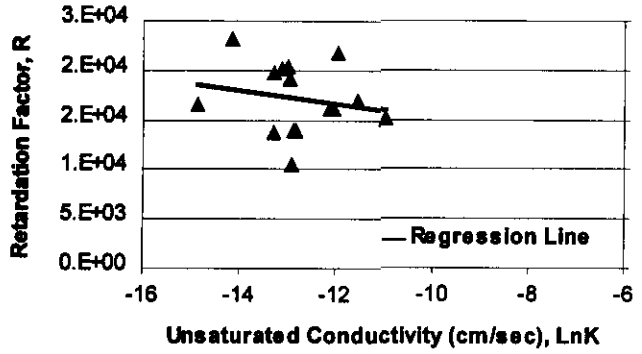
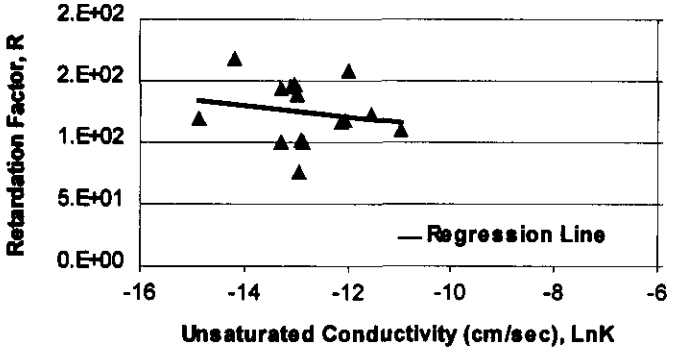


Figure 14. LnK versus R for (a) Cs-137, (b) Sr-90, (c) U, and (d) Se for the sand-dominated sequence.

(a)


3.E+04
2.E+04
2.E+04
1.E+04
5.E+03
0.E+00
Retardation Factor, R
— Regression Line
-16
-14
-12
-10
-8
-6
Unsaturated Conductivity (cm/sec), LnK

(b)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5.E+01
0.E+00
Retardation Factor, R
— Regression Line
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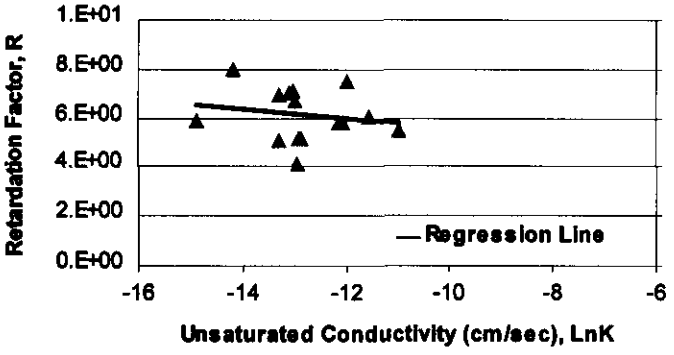
-14
-12
-10
-8
-6
Unsaturated Conductivity (cm/sec), LnK

(c)


1.E+01
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6.E+00
4.E+00
2.E+00
0.E+00
Retardation Factor, R
— Regression Line
-16
-14
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-10
-8
-6
Unsaturated Conductivity (cm/sec), LnK

(d)

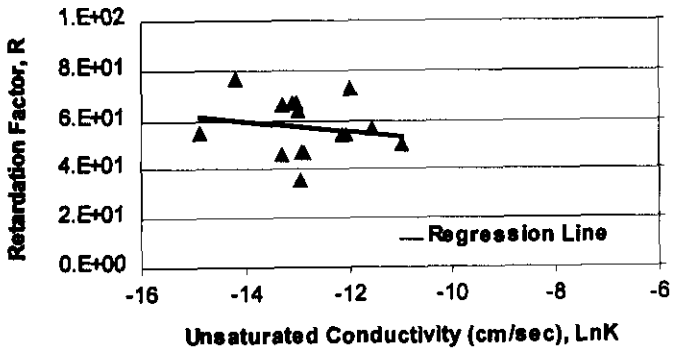

Figure 15. LnK versus R for (a) Cs-137, (b) Sr-90, (c) U, and (d) Se for the gravel-dominated sequence.

4.0 UNCERTAINTIES IN MODEL PREDICTIONS

As discussed in the preceding sections, the application of stochastic theory resulted in effective (upscaled) parameter estimates for saturated hydraulic conductivity, soil moisture retention and unsaturated hydraulic conductivity, bulk density, unretarded macrodispersivity and sorption-enhanced macrodispersivity. These parameters will serve as input to VAM3DF (Huyakorn and Panday 1995), a variably saturated flow and transport code; VAM3DF will generate 'mean' solutions for the pressure head and contaminant concentration.

The breakthrough curve due to contaminants released from the disposal facility is expected to appear as a "step" function at the water table, with the shape of the rise of the step function primarily governed by vadose zone heterogeneity, macrodispersivity, sorption, and radionuclide decay. Because of the long release time for the contaminants from the disposal facility, compared to the travel time through the vadose zone, it is reasonable to approximate the contaminant release as a step input function.

Three sources contribute to uncertainty calculations: (a) variations in model configurations, (b) uncertainties *in* the calculated mean concentration distribution at the water table, and (c) uncertainties *around* the calculated mean concentration distribution at the water table. Figure 16 illustrates the expected concentration distribution at the water table. The sigmoid-shaped mean concentration distribution (Figure 16) is calculated by VAM3DF, based on a particular conceptual model configuration and sensitivities to effective input parameters. However, the mean solution should be viewed as being an average of many 'realizations.' In other words, the expected peak concentration is not necessarily the calculated mean concentration (Figure 16). There is variation among different realizations, because of vadose zone heterogeneities. The variance (σ_C^2) about the mean characterizes such variation *around* a particular mean solution. While the uncertainties *in* the mean solution are calculated directly by VAM3DF, uncertainties *around* the calculated mean solution will be estimated based on available stochastic solutions, as described later.

4.1 Model Configurations

4.1.1 Variations in Stratigraphy

At this time, a basic layered geologic model is being postulated for VAM3DF base case calculations. Such a model is based on the most recent geologic information (Reidel et al.1998; Kincaid et al. 1995) available on the stratigraphy at the two sites. Dips and inclines (as identified in the geology data package) of the various strata will be considered as part of variations of base case model configurations for both disposal sites. Such variations of the basic stratigraphic cross-sections at the two sites are part of the geology data package.

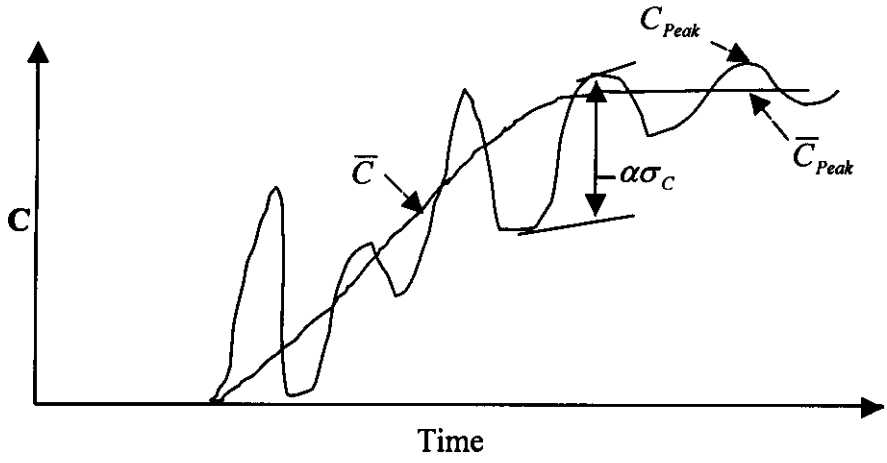

Figure 16. Schematic of concentration (C) distribution at the water table.

[$\overline{C}$ =calculated mean concentration, $\overline{C}_{Peak}$ =calculated mean peak concentration, C_{Peak} = peak concentration, σ_C =standard deviation of variation around the calculated mean solution, $\alpha\sigma_C$ =multiple of variation around the calculated mean solution for a particular model configuration and input effective parameters.]

4.1.2 Clastic dikes

Clastic dikes are ubiquitous sedimentary structures observed in outcrops and trenches that expose the Hanford formation in the 200 Areas. Their distribution, orientation, and other important characteristics are provided as part of the geology data package. The dikes are believed to represent dewatering structures that developed during compaction and settling of cataclysmic flood deposits during or soon after floodwaters drained from the Pasco Basin. The true nature and extent of clastic dikes are difficult to determine, because the dikes are rarely detected or observed in vertically oriented boreholes. Often they form a polygonal pattern where they intersect the ground surface.

An extensive atlas developed by Fecht et al. (1999)[4] addresses a subset of dikes (i.e., clastic injection dikes) that have been formed as a result of sediments in fissures. Clastic injection dikes are fissures which may total a meter or more in thickness. These dikes are typically filled with poor to well-sorted sand, but may also contain silt, clay, and gravel.

[4] Fecht, K.R., K.A. Lindsey, B.N. Bjornstad, D.G. Horton, G.V. Last, and S.P. Reidel. 1999. Clastic Injection Dikes of the Pasco Basin and Vicinity. BHI-01103 Rev. 0. July, 1999. Bechtel Hanford Inc. Richland, WA.

These dikes are of particular interest to the ILAW PA because they occur as near-vertical tabular bodies filled with multiple layers of unconsolidated sediments. Thin clay/silt linings separate the margins of most dikes and internal layers within dikes.

It is important to develop an understanding of the potential presence of these discrete structures in the vicinity of disposal sites such that uncertainties in flow and transport calculations can be adequately accounted for. Such an understanding on the presence of clastic dike networks in the vicinity of disposal sites will be provided as part of the geology data package. The potential for clastic injection dikes to provide preferential pathways will be examined as part of variations of model configurations at both disposal sites.

One particular scenario will be considered to provide a bounding estimate: presence of a near-vertical (or otherwise as characterized in geology data package) clastic dike directly below a vault and extending through the Hanford formation (or as identified in the geology data package). The width of the dike will be based on information in the geology data package.

Data on physical and hydraulic parameters are needed for clastic dike infilling materials to model their effects on flow and contaminant transport. Such physical and hydrologic properties (e.g., bulk density, particle-size distribution, moisture retention, saturated and unsaturated hydraulic conductivities) for clastic dike infilling materials are included in Fayer and Ritter (1999)[5]. A summary of the physical and hydraulic parameters is given in Table 10. As suggested in Table 10, the measured properties represent fine material. Other database (e.g., Fecht et al. 1998) will be consulted for possible presence of coarse infilling materials in a clastic dike.

Table 10. Van Genuchten parameters (based on the multistep method), saturated hydraulic conductivity, and bulk density for seven clastic dike samples (after Fayer and Ritter 1999).

Sample	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Saturated Hydraulic Conductivity (cm/s)	Bulk Density (g/cm^3)
1	0.424	0.063	0.0839	1.33	5.97E-04	1.57
2A	0.446	0.019	0.0762	1.98	4.70E-03	1.50
2B	0.443	0.023	0.0741	1.84	3.14E-03	1.51
3A	0.424	0.025	0.0143	2.49	3.41E-03	1.46
3B	0.448	0.050	0.0593	1.54	1.14E-03	1.52
4A	0.454	0.030	0.0092	1.97	1.84E-03	1.49
4B	0.425	0.021	0.0823	2.09	5.43E-03	1.57

[5] Fayer M.J. and J.S. Ritter. 1999. Physical and hydraulic measurements of FY 1998 clastic dike samples. Letter Report to Fluor Daniel Northwest, Inc. March, 1999. Pacific Northwest National Laboratory. Richland, WA.

4.1.3 Isotropy

The base case simulations will consider a layer-cake stratigraphy and tension-dependent anisotropy. This is expected to result in more of lateral than vertical migration of contaminants. A variation of the base case will consider an isotropic case. This is expected to result in enhanced vertical migration, compared to the base case.

4.1.4 Sloped Layering

Another case that will be considered has to do with the combined effects of variation in stratigraphy and anisotropy. For unsaturated flow, the degree of anisotropy depends not only on the variability of soil hydraulic properties, but also on the orientation of the soil layers relative to the mean hydraulic gradient. The tension-dependent anisotropy relationships will be reevaluated for dips and inclines identified (in geology data package) for variations in base case stratigraphy, and their effects examined via VAM3DF simulations.

4.2 Uncertainties in the Mean Solution due to Variations of Effective Parameter Estimates

As mentioned earlier, uncertainties in the mean solution are due to variations in conceptual model configuration and sensitivities to effective input parameters. Variations in conceptual model configuration have been discussed in the preceding section. Sensitivities to effective input parameter variations are discussed in this section.

The sensitivity of the model predictions to uncertainties in the effective parameters will be considered for two important parameters, i.e., unsaturated conductivity and macrodispersivity. Sensitivity of these two effective parameters and their estimated effects on the mean solution are discussed below. Note that variations in saturated conductivity will not be considered, since the moisture regime within the far-field vadose zone for the disposal sites is not expected to be at or near saturation. It should also be noted that recharge and variations in recharge estimates are another source of uncertainty. However, sensitivities to recharge estimates will be propagated via changes in effective parameter estimates for unsaturated conductivity and macrodispersivity.

The stratigraphy at both disposal sites is dominated by two distinctly different sediment sequences. The upper part of the vadose zone is characterized by a sandy sequence, whereas the lower part is characterized primarily by a gravel sequence. At saturation, compared to the gravel-dominated sequence, the sand-dominated sequence is described by a smaller log-conductivity variance. However, compared to the gravel-dominated sequence, the log-unsaturated conductivity variance for the sand-dominated sequence is higher. The variations in unsaturated conductivities for both sandy and gravelly sequences are discussed in detail earlier. Variabilities in unsaturated conductivities lead to macroscopic anisotropy relations for the sandy and gravelly

sediments that are quite different. Consequently, VAM3DF simulations incorporating variations in macroscopic anisotropy relations will produce different mean concentration distributions at the water table.

A much more important parameter that will affect mean concentration distribution, for a given model configuration, is macrodispersivity. Typically, in modeling transport, the same unretarded dispersivity value is assumed for all transported (retarded and unretarded) species. VAM3DF simulations will consider, for the transported species, comparisons of enhanced longitudinal macrodispersivity with that of a nonretarded macrodispersivity. The variability in these estimates, along with professional judgement (e.g., an increase or decrease of 25% of estimated macrodispersivities), will be used to quantify uncertainties in the mean solution.

Note that each VAM3DF-calculated mean solution incorporates effects due to model configuration variations and sensitivities to effective input parameter variations. The goal will be to limit the number of VAM3DF runs. Nevertheless, once the mean solutions are obtained for various VAM3DF runs, they can be used to obtain variance estimates for the mean solutions, and therefore characterize the uncertainty in the mean solutions.

4.3 Uncertainties Around the Mean Solution

As described earlier, since the effective concentration predictions represent a mean solution, fluctuations about this mean, due to heterogeneity, are another source of uncertainty. The variations in concentrations around the mean concentration can be characterized through a stochastic evaluation of the concentration variance. It will be assumed that the developed theory for the nonretarded species is applicable to the case with spatially variable sorption, provided that the enhanced macrodispersivity is used for the sorbing species. The concentration variance tends to be large in regions close to the source where concentration gradients are large. Using stochastic approaches described by Kapoor and Gelhar (1994a,b), the coefficient of variation of concentration will be estimated at the water table. Detailed equations are presented in Kapoor and Gelhar, but briefly the concentration variance is directly proportional to the mean concentration gradient for the VAM3DF-calculated mean concentration distribution at the water table and the longitudinal macrodispersivity, and inversely proportional to the local dispersivity values.

4.4 Bounding Estimates

Note that the cumulative effect of uncertainties is not additive. Rather, bounding scenarios will be based on combinations of various worst case conditions. For example, a bounding scenario may be postulated as the one having isotropic material properties for both sand- and gravel-dominated sequences, high recharge, clastic dike, and minimum values of macrodispersivity. In other words, bounding estimates will be dictated by

selected model configuration and effective parameter estimates that produce a higher mean concentration at the water table.

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6.0 PEER REVIEW

Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:
Title: FAR-FIELD HYDROLOGY DATA PACKAGE FOR IMMOBILIZED LOW-ACTIVITY TANK WASTE PERFORMANCE ASSESSMENT
Author: RAZ KHALEEL
Date: DECEMBER 3,1999
Scope of Review:

Yes	No*	NA	
[x]	[ ]	[ ]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[x]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[x]	Accident scenarios developed in a clear and logical manner.
[x]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[x]	[ ]	[ ]	Computer codes and data files documented.
[x]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[x]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[x]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[x]	[ ]	[ ]	Models appropriate and used within range of validity, or use outside range of established validity justified.
[x]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[x]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[x]	[ ]	[ ]	Software output consistent with input and with results reported in document reviewed.
[x]	[ ]	[ ]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[x]	Safety margins consistent with good engineering practices.
[x]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[x]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]	[ ]	[x]	Format consistent with applicable guides or other standards.
[ ]	[x]**		Review calculations, comments, and/or notes are attached.
[x]	[ ]	[ ]	Document approved (for example, the reviewer affirms the technical accuracy of the document).

Eugene Freeman — Reviewer (printed name and signature)

December 3,1999 — Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated, and attached to this checklist. The material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

APPENDIX A

Physical and Hydraulic Measurements of FY1998 Borehole Cores

Physical and Hydraulic Measurements of FY 1998 Borehole Cores

MJ Fayer, AL Ward, JS Ritter, and RE Clayton
10 September 1998

Introduction

Pacific Northwest National Laboratory (PNNL) assists the Lockheed Martin Hanford Company (LMHC) in designing and assessing the performance of disposal facilities for radioactive wastes stored in single and double shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as immobilized low-activity waste (ILAW) is to vitrify the waste and place the product in a near-surface, shallow-land burial facility. The current plans are that some of the ILAW will be placed in the existing vaults (built by the former Grout Project); the majority will be placed in the ILAW Disposal Site, to be located southwest of the PUREX Plant. The LMHC project to assess the performance of these two disposal facilities is known as the Hanford ILAW Performance Assessment (PA) Activity, hereafter called the ILAW PA.

Regulatory and public acceptance of ILAW disposal at Hanford depends on demonstrating that public health and the environment are adequately protected. This goal is achieved by predicting contaminant migration from the facility and using the predictions to calculate the impacts to public health and the environment. To predict contaminant migration requires estimates of the physical and hydraulic properties of sediments within the vadose zone beneath and around the disposal facility. These properties include water retention and hydraulic conductivity of the major sediment types as well as descriptions of their spatial variability. In addition to supporting the PA, these data and parameters can be used to support remediation and closure activities at sites such as tank farms and specific retention basins that have similar geology.

As part of site characterization activity for the ILAW disposal facility, sediment samples were obtained in fiscal year 1998 via a borehole drilling and sampling program (Reidel and Reynolds 1998). A work plan was also prepared that provides details on the measurement and analysis of the hydraulic properties for the ILAW borehole sediment samples (Khaleel 1998)[1].

As part of the work plan, a PNNL task was initiated, entitled "Hydraulic Property Lab Tests for ILAW Samples." The objective of this task is to provide the measured data for various geologic formations and soil types at the disposal sites (LMHC 1997; Reidel and Reynolds 1998). These data will provide the basis for upscaling of laboratory data to field estimates (Khaleel 1998), which will be used to predict the movement of contaminants from the disposal

[1] Khaleel R, January 1998. "Work plan for measurement and analysis of hydraulic properties for clastic dikes and the ILAW Borehole No. 1 sediment samples," Fluor Daniel Northwest, Inc., P.O. Box 1050, Richland, Washington.

facility to the groundwater. The objective of this letter report is to document the physical and hydraulic properties for the first characterization borehole.

Properties

Physical and hydraulic properties are required for each of the major geologic materials identified by Reidel and Reynolds (1998), namely, the Hanford sandy sequence, the Hanford lower gravel, and the Ringold Unit E. Multiple measurements of these properties are required to give some estimate of the degree of variability within each geologic material. The properties, which are required (directly or indirectly) by the models used for the ILAW PA, are:

Particle Size Distribution. Particle size distribution (PSD) refers to the fractions of the various particle-size classes (e.g., the fraction of particles with diameters between 1 and 2 mm).

Particle Density (ρ_p). Particle density is the mass of the sediment or construction material particles per unit volume of the same sediment or material. This property is used to relate the bulk density to the porosity.

Bulk Density (ρ_b). Bulk density is the mass of oven-dry material per unit bulk volume. The unit bulk volume is the combined volume of material, water, and air prior to oven drying.

Porosity (ϕ). Porosity is the volume of voids per unit bulk volume.

Water Retention. Water retention refers to the retention of water by the sediment at various matric potentials. Mathematical functions are fit to the retention data and the resulting parameters are used directly in computer models for predicting water and contaminant movement. Numerous functions are available, but the van Genuchten function is most commonly used:

$$\theta = \theta_r + (\theta_s - \theta_r)\left[(1 + (\alpha h)^n\right]^{-m}$$

where θ_s = saturated water content (cm^3/cm^3)
θ_r = residual water content (cm^3/cm^3)
h = matric potential (-cm)
α, n, m = empirical fitting parameters (α units are 1/cm; n and m are dimensionless)

Typically, m is approximated as $m = 1 - 1/n$

Saturated Hydraulic Conductivity (K_s). Saturated hydraulic conductivity is the proportionality constant in the Darcy equation that relates the flux density to a unit potential gradient.

Unsaturated Hydraulic Conductivity [$K = f(\theta, \psi)$]. Unsaturated hydraulic conductivity is the proportionality factor in the Richards equation that relates the flux density to a unit potential gradient at a specific water content. Because the water content varies in the unsaturated zone, the unsaturated conductivity varies also.

Mathematical functions are used to represent the unsaturated conductivity data; these functions are typically estimated using the water retention functions and saturated conductivity. When measured unsaturated conductivity values are available, the conductivity and retention data can be fit to optimize both the retention and conductivity functions. Several functions are available, but the Mualem conductivity function is most commonly used (in conjunction with the van Genuchten retention function, assuming $m = 1 - 1/n$):

$$K = K_s \frac{\left\{1-(\alpha h)^{n-1}\left[1+(\alpha h)^n\right]^{-m}\right\}^2}{\left[1+(\alpha h)^n\right]^{\ell m}}$$

The K_s value and the pore interaction term (ℓ) are the only requirements for this model. The parameter ℓ is typically assigned a value of 0.5.

Borehole Cores

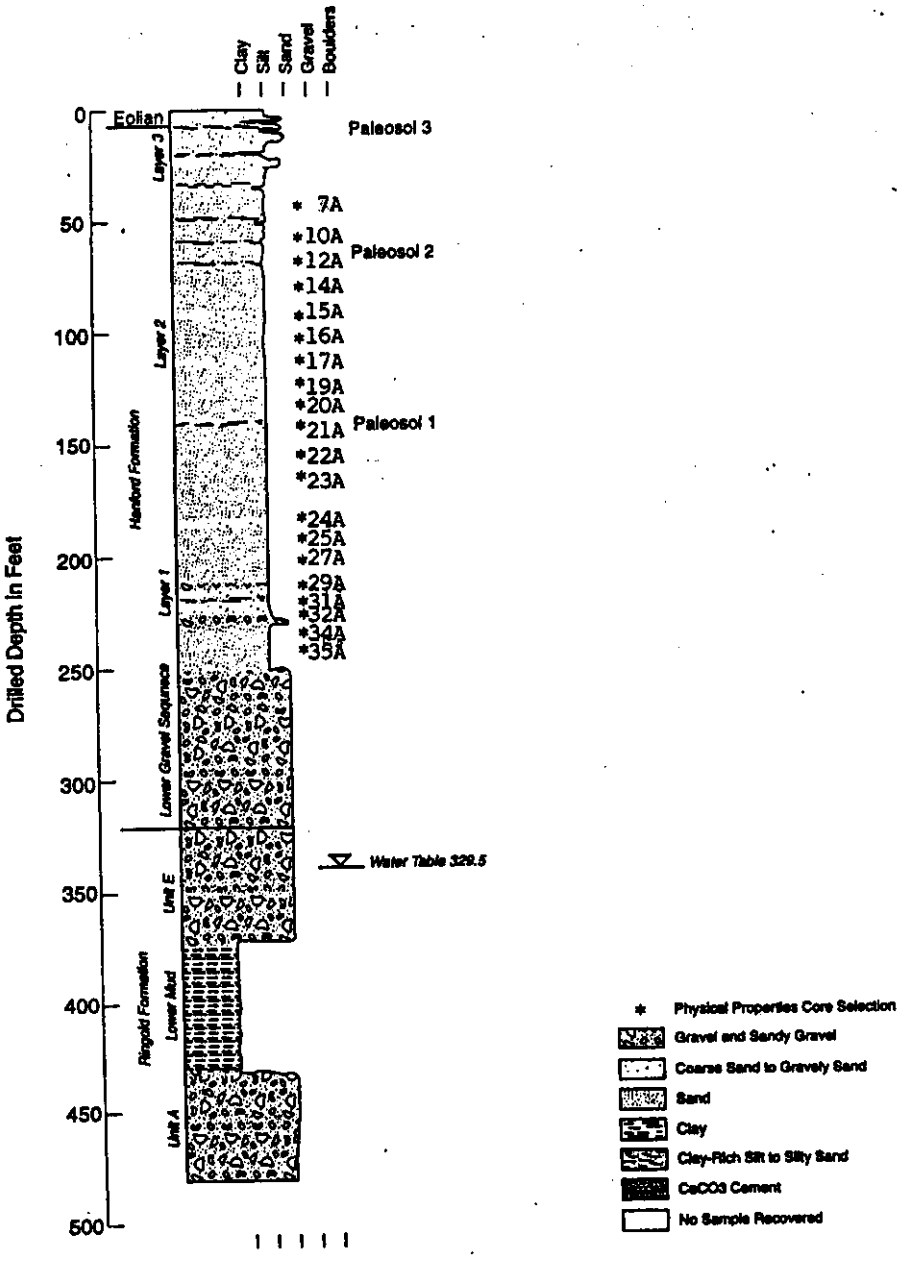
The FY 1998 borehole was drilled in the spring of 1998 (Reidel et al. 1998). A total of 45 cores were collected in liners. Thirty of the 45 liners had a 8.26-cm (3.25-inch) internal diameter and came from depths between 45 and 175 ft. The remaining fifteen liners had a 9.53-cm (3.75-inch) internal diameter and came from depths between 175 and 242 ft. All of the sediment from the depth interval from 0 to 45 ft went to the tracer task for tracer-specific analyses. The decision was made that undisturbed cores from this interval were not necessary for hydraulic property measurements because these sediments will not exist in their current state once the disposal facility is built. No vadose zone cores were collected below 242 ft. because this zone was open framework gravel (i.e., gravel that supports itself with little to no finer grained material) and could not be sampled with the method used.

PNNL was requested to analyze twenty of the FY 98 borehole cores for hydraulic and physical properties. Each of the 45 liners was inspected to verify whether a 15-cm (6-inch) long undisturbed section could be obtained. Thirteen liners did not meet this requirement because they were either incompletely filled, the sediments were disturbed, or the liner material was damaged. These liners will be stored for possible future testing. Of the remaining 32 acceptable liners, twenty liners were chosen for testing by the FDNW principal investigator for the ILAW PA far-field hydrology task, in consultation with the PNNL principal investigator. These twenty liners were chosen on the basis of providing somewhat evenly spaced coverage of the sampled vadose zone. Table 1 lists the sample numbers, depths, and diameters. Figure 1 shows the location of the liners relative to the geologic cross-section derived from the borehole data.

Table 1. Liner samples analyzed for the first characterization borehole

Sample ID	Total Depth Interval ft	Internal Diameter in.	Depth Interval of Intact Core ft
B8500-07A	45.9 to 47.9	3.25	46.3 to 46.8
B8500-10A	57.8 to 59.8	3.25	58.0 to 58.5
B8500-12A	69.4 to 70.95	3.25	69.8 to 70.3
B8500-14A	80.3 to 82.8	3.25	80.8 to 81.3
B8500-15A	90.5 to 93.0	3.25	90.8 to 91.3
B8500-16A	100.5 to 103.0	3.25	102.0 to 102.5
B8500-17A	109.8 to 112.2	3.25	111.3 to 111.8
B8500-19A	121.0 to 123.5	3.25	122.6 to 123.1
B8500-20A	129.7 to 132.0	3.25	131.1 to 131.6
B8500-21A	141.5 to 144.0	3.25	141.8 to 142.3
B8500-22A	151.9 to 154.4	3.25	153.7 to 154.2
B8500-23A	160.4 to 162.9	3.25	162.1 to 162.6
B8500-24A	180.7 to 182.7	3.75	181.9 to 182.4
B8500-25A	189.7 to 191.7	3.75	190.9 to 191.4
B8500-27A	199.3 to 201.3	3.75	200.5 to 200.9
B8500-29A	209.4 to 211.4	3.75	210.6 to 211.1
B8500-31A	219.6 to 221.6	3.75	220.9 to 221.3
B8500-32A	226.1 to 228.1	3.75	227.4 to 227.9
B8500-34A	236.1 to 238.1	3.75	237.2 to 237.7
B8500-35A	239.5 to 241.5	3.75	240.7 to 241.2

Figure 1. Geologic cross section of the disposal site based on the borehole samples (after Reidel et al. 1998).



Methods

Two types of subsamples were removed from each liner. One subsample was an intact portion of the liner that retained its undisturbed nature. This intact core was used for the unsaturated conductivity tests and for determining bulk density and porosity. The depth intervals of these intact cores are listed in Table 1. A second subsample was taken from a 4 to 5 inch portion of the liner next to the intact core. This loose material, which ranged from 850 to 1200 g, was placed in a sealed bag and mixed thoroughly. It was used for the tests of particle size distribution, particle density, initial water content, and water retention using pressure plates and vapor adsorption, as well as the sorption tests that were conducted by another task under this project.

Intact Core Preparation

Each 0.6-m-long liner was inspected to identify portions that displayed no visible disturbance such as cracking or mixing. Within the undisturbed portion, a 15-cm length was chosen for the unsaturated conductivity test. The liner was marked where the base plate would go. A band saw was used to cut most of the way through the liner, then a thin metal plate was advanced into the cut as the blade proceeded around the liner for the final cut. This technique kept sediment loss to a minimum. When completely cut, the sample was placed vertically upside down and the bottom end cap was attached[2]. The sample was then placed horizontally, marked, and cut in the same manner as before. The sample was then placed vertically upright and the upper end cap was attached. The entire assembly was weighed. The total internal volume of the 3.25-in diameter cores was 803 cm^3; it was 1,069 cm^3 for the 3.75-in diameter core.

Two holes were drilled horizontally into the liner and tapped to yield threads for the tensiometer assemblies. The holes were positioned 1.5 cm from each end plate. Each tensiometer was 0.62 cm in diameter and 6.4 cm long, which allowed the tensiometers to penetrate about 75% of the core diameter. The sediment was fairly soft so each tensiometer was pushed directly into the sample without removing any material.

Two additional holes were drilled horizontally into the liners to accommodate the time-domain reflectometry (TDR) probes. The holes were offset 90 degrees laterally from the tensiometers and about 1 cm from the plane of the tensiometers and towards the core center. Because of the thinness of the liner, plexiglass blocks were glued to the outside of the liner in the TDR location to provide enough material to tap and provide threads for the TDR assemblies. The TDR rods were 0.23 cm in diameter and 8 cm long, which allowed the TDR rods to penetrate about 95% of the core diameter. Like the tensiometers, the TDR rods were pushed directly into the samples without removing material.

Figure 2 shows the final assembly with tensiometers, TDR rods, end plates, and two ports on either end plates to facility liquid and gas addition or removal from the core. Each assembly was tested at 0.5 bar positive pressure to identify leaks prior to conducting the conductivity tests.

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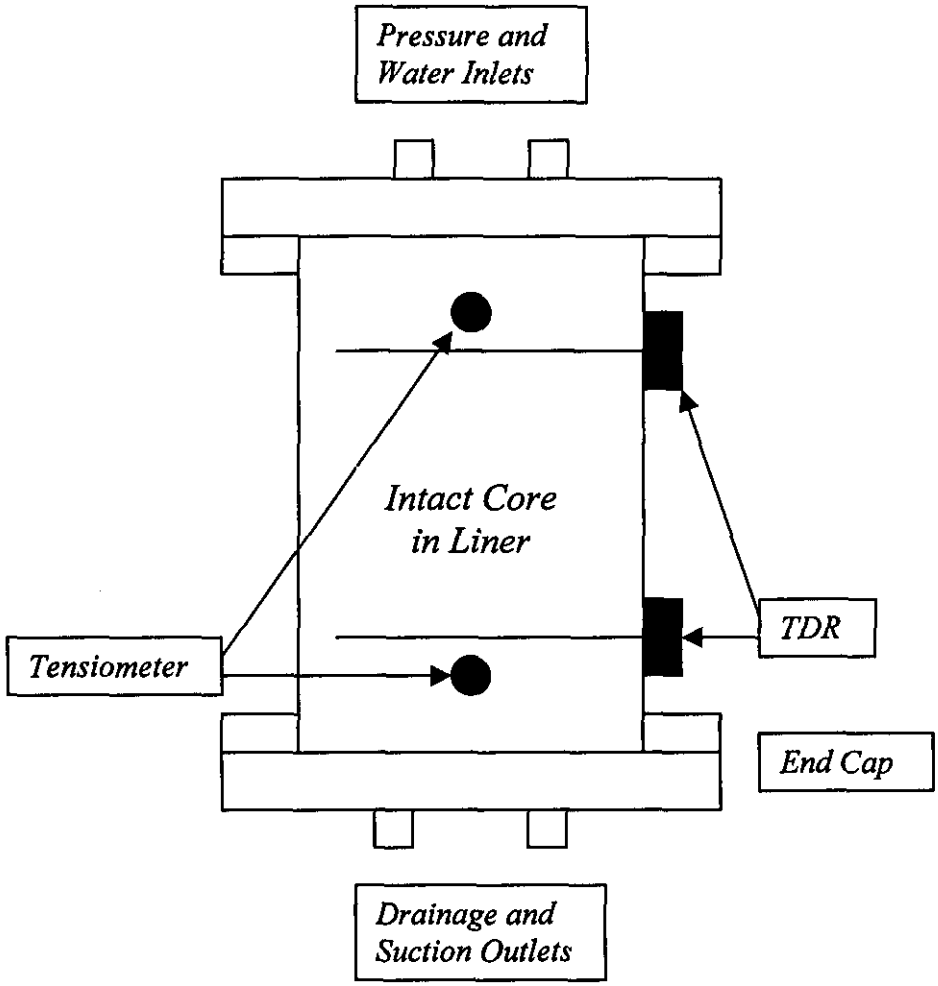
[2] End caps were purchased from Soil Measurements Systems of Tucson, Arizona. Each end cap contained a rubber gasket and rubber O-ring to ensure a tight seal with the core liner.

Figure 2. Conductivity testing cell



Leaks were eliminated using Teflon™ tape, vacuum grease, and Silly Putty™. After leak testing, a vacuum was applied to one of the upper ports of each assembly. The entire assembly was then wetted from below using a solution comprising tap water and 5 g thymol per 20 L of water for control of bacterial growth. Wetting in this manner placed the samples on the primary drainage path.

Procedures

Table 2 lists the procedures used to analyze the samples. Additional details for each procedure are discussed below.

Particle Density. Two replicates of the particle density test were performed using 30 g of the loose subsample for each test using the pycnometer method (Blake and Hartge 1986a).

Initial Water Content. Two replicate measurements of the initial water content were made using the loose subsample for each test using the method of Gardner (1986).

Particle Size Distribution. The PSD test was performed using 40 g of the loose subsample for each test using the methods ASTM 1985 and Gee and Bauder (1986).

Bulk Density. A single measurement of bulk density was made using the intact core. Following the conductivity test, the sediment in the core was oven dried and weighed. Dividing this weight by the volume of the core yielded the bulk density, as per the method of Blake and Hartge (1986b).

Porosity. A single estimate of porosity was made using the bulk density of intact core and the average particle density. The formula used was $\phi = 1 - \rho_b / \rho_s$ (Freeze and Cherry 1979).

Water Retention. Water retention data were obtained using the pressure-plate extraction and vapor equilibrium methods described by Klute (1986). Additional measurements were obtained during the unsaturated conductivity tests.

Saturated Hydraulic Conductivity. Saturated hydraulic conductivity was measured on the intact core prior to the unsaturated conductivity tests using the method of Klute and Dirksen (1986). The measurement of saturated conductivity was conducted several times to verify that a steady value of conductivity was achieved.

Unsaturated Hydraulic Conductivity. The multistep and steady state methods were used to measure unsaturated conductivity. Both methods were performed on the same core using the same sensor locations. The multistep method, which is an improvement of the one-step method of Kool et al. (1985 a,b), provides θ-ψ pairs and cumulative outflow. These data were used in conjunction with the MULSTP program (Eching and Hopmans 1993) to determine the optimal set of hydraulic parameters. MULSTP employs a numerical inversion procedure to find the set

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Table 2. Procedures for measuring physical and hydraulic properties.

Number	Title	Comment
PNL-MA-567, SA-2	Sieve Procedure	For materials > 50 μm effective diameter
PNL-MA-567, SA-3	Particle-Size Analysis	Hydrometer method for materials < 50 μm effective diameter
PNL-MA-567, SA-4	Constant Head Hydraulic Conductivity (HC)	Laboratory measurement for materials with HC> 10^{-6} cm/s
PNL-MA-567, SA-5	Falling Head--Saturated Hydraulic Conductivity (HC)	Laboratory measurement for materials with HC <10^{-6} cm/s
PNL-MA-567, SA-6	Water Retention Procedure	Laboratory method for core or bulk sample (saturation to air dry)
PNL-MA-567, SA-7	Water Content	Necessary for constant head hydraulic conductivity
PNL-MA-567, SA-8	Clod Density/Bulk Density	Necessary for constant head hydraulic Conductivity
PNL-MA-567, SA-9	Determining Particle Density	Necessary for constant head hydraulic conductivity
Klute (1986)	Water Retention: Laboratory Methods	Pressure plate and vapor adsorption methods
Klute and Dirksen (1986)	Hydraulic Conductivity and Diffusivity: Laboratory Methods	Steady-state flux control method for unsaturated conductivity
Eching and Hopmans (1993)	Unsaturated Hydraulic Properties	Multistep outflow method for unsaturated conductivity and water retention estimation

of parameters that minimizes the differences between simulated variables and those test variables contained in the objective function. For these tests, the objective function contained the cumulative outflow data and the matric potential data. Eching and Hopmans (1993) found that this objective function yielded excellent results when compared to independently measured data. Although this method relies on specific retention and conductivity functions and it does not yield specific values of conductivity, it promises to be quicker than the steady-state method and could represent a cost savings for future sample analyses.

The steady-state method, described by Klute and Dirksen (1986), provides θ-ψ-K triplets, which can be fitted with retention and conductivity functions. The value of this method is that it provides simultaneous triplets that are independent of retention and conductivity models. If the resulting parameter set for these functions is equivalent to the set derived by the multistep method, then the multistep method could be employed more frequently to achieve the same result.

Because several tests must be performed on the same core, the following test sequence was established: saturated conductivity, multistep unsaturated conductivity, and steady state unsaturated conductivity. Following the saturated conductivity test, the cores were re-wetted to saturation and analyzed using the multistep method. Two pressure changes were used: 0.06 and 0.3 bars. Changes in water content and matric potential were monitored with a datalogger every 0.1-h following each pressure change. Outflow was monitored manually at time intervals ranging from 3 minutes to 24 hours. The next change in pressure was initiated only after the most recent change outflow was less than 1% of the cumulative outflow since the last pressure change.

Following the multistep test, the cores were re-wetted to saturation and analyzed using the steady-state method. A Mariotte-type reservoir was used to provide a source of water at a pre-defined matric potential at the upper surface of the samples. Fluxes into each sample were unique and dependent on the unsaturated conductivity of the sample at the imposed matric potential. Concurrent with establishing the matric potential at the top of the sample, the matric potential at the bottom of the sample was set to the same value by lowering the outflow tube. Water content and matric potential were measured continuously. Once the matric potential values within the sample ceased changing, indicating steady flow conditions had been achieved, the matric potential at the top of the sample was lowered to the next value and the outflow tube was lowered a similar amount. After equilibrating with the final and lowest potential, the cores were opened and the bulk density values were determined.

Results

Table 3 shows that particle density varies between 2.71 and 2.82 g/cm^3 for this section of the Hanford formation. The average and median values are both 2.74 g/cm^3, which would indicate a normal distribution. However, the two deepest values are the highest. These two samples, as shown below, have a higher gravel content. Subsequent tests could be used to determine whether the gravel has a particle density that is higher than the finer sediment.

Table 3 also shows that the initial water contents of the loose subsample material ranged from 0.0119 to 0.0382 g/g. The average and median values were similar: 0.020 and 0.0196 g/g, respectively. These water content values are low but not atypical of the Hanford formation. They were measured two to three months after drilling and, during that interval, the liners were stored in a refrigerated container where they could have experienced some evaporative losses. However, the water content values in Table 3 are very similar to values measured by Ellyn Murphy, another ILAW project researcher. Dr. Murphy measured water contents on a small sample from the end of each core immediately after the cores were drilled. Her average water contents were about 10% less than what is shown in Table 3.

Table 4 shows the results for both the sieve and hydrometer methods. In all but two samples, the gravel content was less than 2%. In contrast, samples 34A and 35A had 13 and 25% gravel, respectively. These were the deepest samples that were analyzed (between 236 and 242 ft). As shown in Figure 1, this depth range corresponds to the lower gravel sequence of the Hanford formation. Figure 3 shows all of the data combined to highlight the degree of variability in particle size distribution.

Table 5 shows that the bulk density ranged from 1.52 to 1.98 g/cm^3. The mean and median were identical: 1.70 g/cm^3. The highest densities were associated with the two samples (34A and 35A) that had significant gravel contents. Khaleel and Relyea (1997) found a similar effect from high gravel contents. Table 5 also shows the porosity data, which ranged from 0.299 to 0.444 and had nearly identical mean and median values of 0.377 and 0.374, respectively.

When opened for the bulk density measurements, most of the cores appeared homogenous. However, several cores had noticeable layering. The most dramatic layering

occurred in sample 7A, which had about 7 cm of sand in the upper part of the core and 8 cm of finer-textured sand in the lower part of the sample. It appeared that the upper set of sensors penetrated the coarser material and the lower set penetrated the finer material. Sample 19A had a 1-mm thick, silty-looking layer located about 1 cm from the top of the sample. Layers in two other samples were less distinct and not recorded.

Another feature that we observed when the cores were opened was the presence of a layer of finer and denser material along the walls of roughly half of the liners. We had observed this effect when we were preparing the cores, but it was more obvious when the cores were wet. One possible explanation is that the drilling technique caused migration of fines to the wall, where the heat from drilling caused water to more towards the interior of the sample, thus allowing the fines to consolidate more densely. We estimated the thickness of this zone as no more than 2 mm, which accounts for less than 5% of the sample area. Because of the small area, we expect that this phenomenon did not have a major impact on the measurements reported here, but it should be looked at more closely if another borehole is drilled for samples.

Table 6 shows the pressure plate data for four pressures. As expected, samples that were finer-textured (e.g., 31A) had higher water contents at any given pressure. The mean values at each pressure are all greater than the mean value of the initial water contents reported in Table 3. This result suggests that the *in situ* matric potential values were less than -4,080 cm (4 bar), the lowest pressure tested.

Table 7 shows that the vapor adsorption data covered a significant range of matric potential, from -4,170 cm to as dry as -1,110,000 cm. The associated water contents ranged from 0.056 to 0.0 g/g. This range of water content encompasses the initial water contents reported in Table 4.

Table 8 shows the saturated hydraulic conductivity values for the intact cores. The values range from 2.65E-4 to 1.32E-2 cm/s, with average and median values of 4.30E-3 and 2.94E-3 cm/s, respectively. The two highest values were for the two deepest cores (34A and 35A), which contained the highest gravel content.

Table 9 shows the parameter estimates determined using the MULSTP program and data from the multistep test. Parameters α and n were fitted to matric potential data, drainage data, and a single retention point using a weighting scheme to adjust the importance of each; typical weightings were 1, 1, and 1, respectively. Some samples had weightings of 0.5 and 0 for tension data; these are identified in Table 9. During parameter estimation, θ_s and saturated K were fixed at measured values; θ_r was estimated for tension value of 15,300 cm using linear interpolation between pressure plate reading of 4,080 cm and wettest vapor adsorption value that was still drier than 15,300 cm.

Figure 3 shows how the predictive model, based on MULSTP-derived parameters, simulates the experimental data for matric potential and drainage for the 20 samples. In general, the comparison is good.

Table 10 shows the θ-ψ-K triplets that were generated using the steady state method. The measurements are all at matric potentials above -40 cm. Even so, unsaturated conductivity values were 1 to 2 orders of magnitude less than the saturated values. Because the potentials were so high, the water contents were also relatively high. Water contents were much lower at the end of the multistep test.

Summary

Twenty intact cores from the FY 98 ILAW PA borehole were analyzed for physical and hydraulic properties. These data and parameters will be used to predict the movement of contaminants from the disposal facility to the groundwater. Health and environmental impacts from the contamination will be calculated and the results used to ascertain the suitability of the disposal facility to protect the public and the environment. In addition to supporting the ILAW PA, these data and parameters can be used to support remediation and closure activities at sites such as tank farms and specific retention basins that have similar geology.

The twenty cores reported here were from the geologic unit known as the Hanford formation sandy sequence. The cores showed a fairly uniform set of properties deriving from the high percentage of medium to fine sand in nearly all of the cores. The variability among the twenty cores is within the range reported by Khaleel and Freeman (1995) for the 200 Areas. What is significant and valuable is that the data reported here give a true indication of the parameters and their variability *beneath the ILAW disposal site*. These data are also significant to the ILAW analysis for other reasons. First, a complete set of physical and hydraulic properties was measured on undisturbed cores. The tests included measurements of unsaturated conductivity and water retention in dry sediments. Secondly, a set of geochemical measurements was performed on the core material. Having a complete set of physical, chemical, and hydraulic data on site-specific cores is rare and should facilitate the PA calculations and enhance their credibility.

Two zones in the borehole were finer in texture and had lower saturated conductivity values than the other zones. These zones, or layers, could impact flow and transport calculations and increase lateral spreading. The results in this report will be considered in forming the conceptual model of the site. Additional boreholes planned for FY 1999 and FY 2000 will help to verify whether these and other particular layers are continuous across the disposal site.

A unexpected feature of the ILAW borehole site was the presence of a relatively thick open-framework gravel sequence below 250 ft. No data are available at present on the physical and hydraulic properties of this sequence. However, plans are in place to collect the necessary data for the gravelly sequence as part of the ILAW site characterization via boreholes No. 2 and 3.

Regarding parameter estimation of vadose zone hydraulic properties, several issues were raised by the 1997 external peer-review panel for the ILAW PA (Mann et al. 1998). These include a) use of the standard van Genuchten-Mualem approach with the saturated conductivity as a match point, b) correction for the presence of gravel in sediments, and c) upscaling of laboratory-measured data to block scale values in numerical models. Issues (a) and (b) are being

addressed as part of the analysis and parameter estimation of hydraulic properties for the borehole samples. The upscaling issue is being addressed as part of other FY98 tasks.

Table 3. Particle density and initial water content of material adjacent to the cores

Sample	Particle Density rep 1 (g/cm^3)	Particle Density rep 2 (g/cm^3)	Average Particle Density, g/cm^3	Initial Water Content, rep 1, g/g	Initial Water Content, rep 2, g/g	Average Initial Water Content, g/g
B8500-07A	2.718	2.717	2.72	0.0157	0.0176	0.0166
B8500-10A	2.747	2.745	2.75	0.0153	0.0152	0.0152
B8500-12A	2.740	2.737	2.74	0.0164	0.0174	0.0169
B8500-14A	2.716	2.711	2.71	0.0166	0.0163	0.0165
B8500-15A	2.720	2.722	2.72	0.0119	0.0120	0.0119
B8500-16A	2.728	2.727	2.73	0.0149	0.0148	0.0149
B8500-17A	2.720	2.721	2.72	0.0285	0.0268	0.0276
B8500-19A	2.728	2.731	2.73	0.0196	0.0199	0.0197
B8500-20A	2.720	2.722	2.72	0.0194	0.0203	0.0199
B8500-21A	2.721	2.723	2.72	0.0228	0.0213	0.0220
B8500-22A	2.751	2.750	2.75	0.0139	0.0146	0.0142
B8500-23A	2.731	2.736	2.73	0.0163	0.0162	0.0163
B8500-24A	2.731	2.731	2.73	0.0258	0.0236	0.0247
B8500-25A	2.748	2.745	2.75	0.0199	0.0197	0.0198
B8500-27A	2.747	2.745	2.75	0.0199	0.0189	0.0194
B8500-29A	2.733	2.736	2.74	0.0201	0.0204	0.0203
B8500-31A	2.756	2.750	2.75	0.0395	0.0370	0.0382
B8500-32A	2.753	2.752	2.75	0.0272	0.0275	0.0273
B8500-34A	2.793	2.797	2.80	0.0175	0.0178	0.0176
B8500-35A	2.822	2.822	2.82	0.0189	0.0217	0.0203

Table 4. Particle size distribution of material adjacent to the cores

Sample 7A		Sample 10A		Sample 12A		Sample 14A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.8	2000	100.0	2000	99.3	2000	99.8
1000	99.3	1000	95.6	1000	93.9	1000	96.5
500	94.7	500	52.3	500	68.6	500	76.5
250	74.2	250	33.8	250	36.1	250	34.1
106	41.5	106	24.1	106	17.3	106	15.2
75	30.7	75	19.8	75	13.8	75	12.2
53	24.3	53	14.4	53	11.5	53	10.4
52.0	23.4	53.4	13.7	53.2	11.4	53.7	11.1
30.4	18.0	31.1	10.0	30.9	9.3	31.1	9.1
16.9	12.7	17.1	7.2	17.0	8.1	17.1	6.6
9.8	12.1	9.9	6.5	9.8	8.1	9.9	6.3
6.9	9.8	7.0	5.5	6.9	7.0	7.0	6.3
5.7	8.9	5.7	5.2	5.7	5.8	5.7	5.2
4.9	6.8	5.0	5.0	4.9	5.1	5.0	5.0
1.4	5.2	1.4	2.7	1.4	4.4	1.4	4.5

Sample 15A		Sample 16A		Sample 17A		Sample 19A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.5	2000	98.5	2000	99.7	2000	100.0
1000	90.7	1000	87.5	1000	97.3	1000	99.1
500	58.6	500	56.7	500	87.9	500	95.8
250	29.7	250	29.3	250	60.8	250	73.6
106	17.9	106	18.0	106	33.5	106	33.1
75	14.9	75	15.4	75	27.0	75	21.4
53	13.0	53	13.3	53	22.0	53	15.4
53.4	12.4	53.4	15.9	52.4	19.1	52.6	15.1
31.0	10.0	31.1	12.3	30.7	13.8	30.8	10.2
17.1	7.2	17.2	9.6	16.9	11.3	16.9	8.3
9.9	6.0	10.0	7.2	9.8	8.8	9.8	6.2
7.0	4.8	7.1	6.2	7.0	7.4	7.0	4.9
5.7	4.8	5.8	6.5	5.7	6.4	5.7	4.5
5.0	4.5	5.0	5.3	5.0	5.5	4.9	4.5
1.4	4.8	1.4	2.9	1.4	5.1	1.4	3.2

Table 4. Particle size distribution of material adjacent to the cores (cont.)

Sample 20A		Sample 21A		Sample 22A		Sample 23A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.8	2000	99.6	2000	98.4	2000	100.0
1000	98.3	1000	96.6	1000	88.2	1000	99.9
500	87.1	500	80.7	500	46.5	500	98.2
250	54.2	250	44.5	250	19.3	250	75.5
106	25.3	106	19.5	106	10.6	106	35.6
75	19.0	75	14.7	75	8.7	75	28.1
53	14.8	53	11.6	53	7.3	53	23.5
53.1	14.0	53.4	11.2	54.2	10.5	53.0	23.2
31.0	10.2	30.9	10.8	31.3	9.2	31.0	18.2
17.1	7.6	17.1	7.1	17.3	5.9	17.1	13.4
9.9	6.4	9.9	6.0	10.0	3.6	9.9	11.5
7.0	4.7	7.0	4.3	7.1	3.3	7.1	8.9
5.7	4.0	5.7	3.0	5.8	3.6	5.8	8.4
5.0	4.5	5.0	3.2	5.0	3.3	5.0	8.4
1.4	4.3	1.4	4.1	1.4	1.6	1.4	3.6

Sample 24A		Sample 25A		Sample 27A		Sample 29A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.8	2000	99.7	2000	98.3	2000	98.8
1000	95.8	1000	96.5	1000	89.3	1000	93.7
500	75.0	500	79.5	500	58.9	500	68.5
250	37.3	250	28.6	250	18.9	250	27.8
106	17.0	106	10.1	106	8.3	106	12.5
75	13.4	75	7.5	75	6.6	75	10.1
53	11.0	53	5.9	53	5.5	53	8.9
54.2	13.2	54.2	7.8	54.1	8.4	56.3	5.9
31.5	9.7	31.4	6.4	31.4	6.4	32.7	4.5
17.3	8.5	17.2	5.4	17.2	5.7	18.0	2.6
10.0	7.9	10.0	4.2	10.0	4.4	10.4	1.6
7.1	8.2	7.1	4.7	7.1	4.7	7.4	1.4
5.8	7.3	5.8	4.7	5.8	4.9	6.1	0.5
5.0	7.3	5.0	4.0	5.0	4.9	5.3	0.3
1.4	2.9	1.4	2.6	1.4	3.7	1.5	0.1

Table 4. Particle size distribution of material adjacent to the cores (cont.)

Sample 31A		Sample 32A		Sample 34A		Sample 35A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.8	2000	98.2	2000	87.0	2000	75.7
1000	99.4	1000	86.3	1000	54.4	1000	42.8
500	98.4	500	45.4	500	23.1	500	18.8
250	96.4	250	13.7	250	10.1	250	9.8
106	72.9	106	5.5	106	4.6	106	5.5
75	46.9	75	4.1	75	3.5	75	4.5
53	28.2	53	3.2	53	2.9	53	3.8
51.7	29.2	54.3	7.6	53.6	5.9	53.2	8.5
30.8	15.8	31.5	5.9	31.1	4.5	30.8	6.7
17.0	10.8	17.3	4.8	17.0	4.5	16.9	5.7
9.9	8.3	10.0	3.8	9.8	4.1	9.8	5.0
7.0	7.2	7.1	3.8	7.0	2.7	6.9	4.5
5.7	7.0	5.8	3.8	5.7	2.3	5.7	4.7
5.0	6.2	5.0	3.3	4.9	2.5	4.9	4.5
1.4	5.2	1.4	2.5	1.4	1.8	1.4	2.0

Table 5. Core volume, bulk density, and porosity of the cores

Sample	Core Volume (cm^3)	Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)
B8500-07A	803	1.70	0.377
B8500-10A	803	1.62	0.413
B8500-12A	803	1.74	0.363
B8500-14A	803	1.58	0.416
B8500-15A	803	1.69	0.380
B8500-16A	803	1.58	0.420
B8500-17A	803	1.57	0.423
B8500-19A	803	1.52	0.444
B8500-20A	803	1.58	0.419
B8500-21A	803	1.62	0.403
B8500-22A	1,069	1.78	0.352
B8500-23A	1,069	1.72	0.371
B8500-24A	1,069	1.85	0.321
B8500-25A	1,069	1.80	0.345
B8500-27A	1,069	1.71	0.377
B8500-29A	1,069	1.76	0.359
B8500-31A	1,069	1.60	0.418
B8500-32A	1,069	1.78	0.359
B8500-34A	1,069	1.92	0.316
B8500-35A	1,069	1.98	0.299

Table 6. Water retention data from the pressure plate technique

7A		10A		12A		14A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
561	0.0503	561	0.0400	561	0.0374	561	0.0357
1020	0.0484	1020	0.0344	1020	0.0324	1020	0.0342
2040	0.0415	2040	0.0320	2040	0.0255	2040	0.0372
4080	0.0395	4080	0.0255	4080	0.0255	4080	0.0303

15A		16A		17A		19A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
561	0.0368	561	0.0403	561	0.0595	561	0.0421
1020	0.0316	1020	0.0338	1020	0.0475	1020	0.0336
2040	0.0307	2040	0.0287	2040	0.0400	2040	0.0265
4080	0.0241	4080	0.0232	4080	0.0366	4080	0.0260

Table 6. Water retention data from the pressure plate technique (cont.)

20A		21A		22A		23A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
561	0.0470	561	0.0334	561	0.0296	561	0.0669
1020	0.0378	1020	0.0284	1020	0.0223	1020	0.0525
2040	0.0351	2040	0.0257	2040	0.0209	2040	0.0421
4080	0.0281	4080	0.0234	4080	0.0191	4080	0.0342

24A		25A		27A		29A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
561	0.0425	561	0.0304	561	0.0291	561	0.0346
1020	0.0364	1020	0.0261	1020	0.0254	1020	0.0272
2040	0.0318	2040	0.0247	2040	0.0232	2040	0.0242
4080	0.0290	4080	0.0199	4080	0.0218	4080	0.0222

31A		32A		34A		35A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
561	0.0603	561	0.0357	561	0.0328	561	0.0329
1020	0.0472	1020	0.0333	1020	0.0290	1020	0.0309
2040	0.0402	2040	0.0342	2040	0.0268	2040	0.0281
4080	0.0375	4080	0.0284	4080	0.0204	4080	0.0214

Table 7. Water retention data from the vapor adsorption technique

7A		10A		12A		14A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
24145	0.0152	8781	0.0170	7396	0.0222	28908	0.0116
21945	0.0206	16766	0.0167	45690	0.0112	16298	0.0200
78701	0.0077	113305	0.0048	152030	0.0043	138301	0.0052
129149	0.0045	137994	0.0034	140282	0.0037	188749	0.0036
207546	0.0027	161833	0.0029	121521	0.0042	392007	0.0023
1075921	0.0000	1082660	0.0003	1087258	0.0006	1054326	0.0009

15A		16A		17A		19A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
10683	0.0405	32690	0.0093	7873	0.0230	4628	0.0375
22817	0.0124	39451	0.0107	33754	0.0170	4632	0.0291
364967	0.0023	182999	0.0038	203274	0.0048	238015	0.0038
168294	0.0034	188513	0.0019	221937	0.0038	186010	0.0039
1082928	0.0008	181075	0.0034	252444	0.0035	349726	0.0027
		1063482	0.0009	1070939	0.0009	1042683	0.0011

Table 7. Water retention data from the vapor adsorption technique (cont.)

20A		21A		22A		23A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
6485	0.0258	8349	0.0276	4633	0.0562	10211	0.0289
8341	0.0216	6021	0.0237	11175	0.0460	142403	0.0078
235350	0.0045	234127	0.0039	215747	0.0059	134462	0.0071
232477	0.0043	277628	0.0033	197216	0.0045	225253	0.0054
322711	0.0034	278460	0.0030	1090154	0.0015	223222	0.0048
1105338	0.0014	1092187	0.0008			1075491	0.0024

24A		25A		27A		29A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
4171	0.0392	18992	0.0140	17232	0.0206	5566	0.0268
120958	0.0118	245392	0.0064	55936	0.0148	32360	0.0156
135542	0.0112	316708	0.0061	248841	0.0099	226565	0.0068
257943	0.0088	258559	0.0051	277107	0.0083	250807	0.0068
251919	0.0078	285889	0.0052	252086	0.0085	247094	0.0059
1072363	0.0051	1062967	0.0034	1061386	0.0058	1054101	0.0037

31A		32A		34A		35A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
7894	0.0329	6033	0.0236	7432	0.0197	32783	0.0218
46384	0.0196	73280	0.0161	12568	0.0214	7432	0.0457
226164	0.0076	270140	0.0096	252391	0.0095	43717	0.0135
282406	0.0058	255850	0.0093	283862	0.0083	343812	0.0155
261127	0.0063	268249	0.0090	306591	0.0083	335749	0.0082
1047364	0.0030	1036466	0.0060	1023601	0.0047	1029646	0.0058

Table 8. Saturated hydraulic conductivity of the cores

Sample	Saturated Hydraulic Conductivity (cm/s)			Average Saturated Hydraulic Conductivity (cm/s)	Method
	Rep 1	Rep 2	Rep 3		
B8500-07A	7.81E-04	9.78E-04	1.35E-03	1.04E-03	Falling head
B8500-10A	1.96E-03	2.22E-03	4.68E-03	2.95E-03	Falling head
B8500-12A	2.27E-03	2.35E-03	1.82E-03	2.15E-03	Falling head
B8500-14A	1.47E-03	2.08E-03	2.41E-03	1.99E-03	Falling head
B8500-15A	1.50E-03	1.90E-03	2.87E-03	2.09E-03	Falling head
B8500-16A	8.37E-03	1.05E-02	9.87E-03	9.57E-03	Falling head
B8500-17A	1.88E-03	1.96E-03	2.12E-03	1.99E-03	Falling head
B8500-19A	3.74E-03	4.30E-03	4.88E-03	4.31E-03	Falling head
B8500-20A	2.24E-03	2.54E-03	2.83E-03	2.54E-03	Falling head
B8500-21A	2.84E-03	2.89E-03	3.09E-03	2.94E-03	Falling head
B8500-22A	4.89E-03	5.23E-03	5.05E-03	5.06E-03	Constant head
B8500-23A	2.57E-04	2.76E-04	2.61E-04	2.65E-04	Constant head
B8500-24A	5.88E-04	5.61E-04	5.58E-04	5.69E-04	Constant head
B8500-25A	5.37E-03	5.42E-03	5.43E-03	5.41E-03	Constant head
B8500-27A	8.22E-03	8.10E-03	8.09E-03	8.14E-03	Constant head
B8500-29A	3.77E-03	3.75E-03	3.73E-03	3.75E-03	Constant head
B8500-31A	8.49E-04	8.14E-04	8.01E-04	8.21E-04	Constant head
B8500-32A	6.68E-03	6.71E-03	6.74E-03	6.71E-03	Constant head
B8500-34A	1.32E-02	1.31E-02	1.32E-02	1.32E-02	Constant head
B8500-35A	1.07E-02	1.06E-02	1.06E-02	1.06E-02	Constant head

Table 9. Van Genuchten parameters (based on the multistep method) for 20 ILAW borehole samples from the sandy sequence. Parameters α and n were fitted to matric potential data, drainage data, and a single retention point using a weighting scheme to adjust the importance of each. The typical weightings were 1, 1, and 1, respectively. The superscript a indicates the weightings were 0.5, 1, and 1. The superscript b indicates the weightings were 0, 1, and 1. In these special cases, the matric potential weighting was reduced until the R^2 exceeded 0.6.

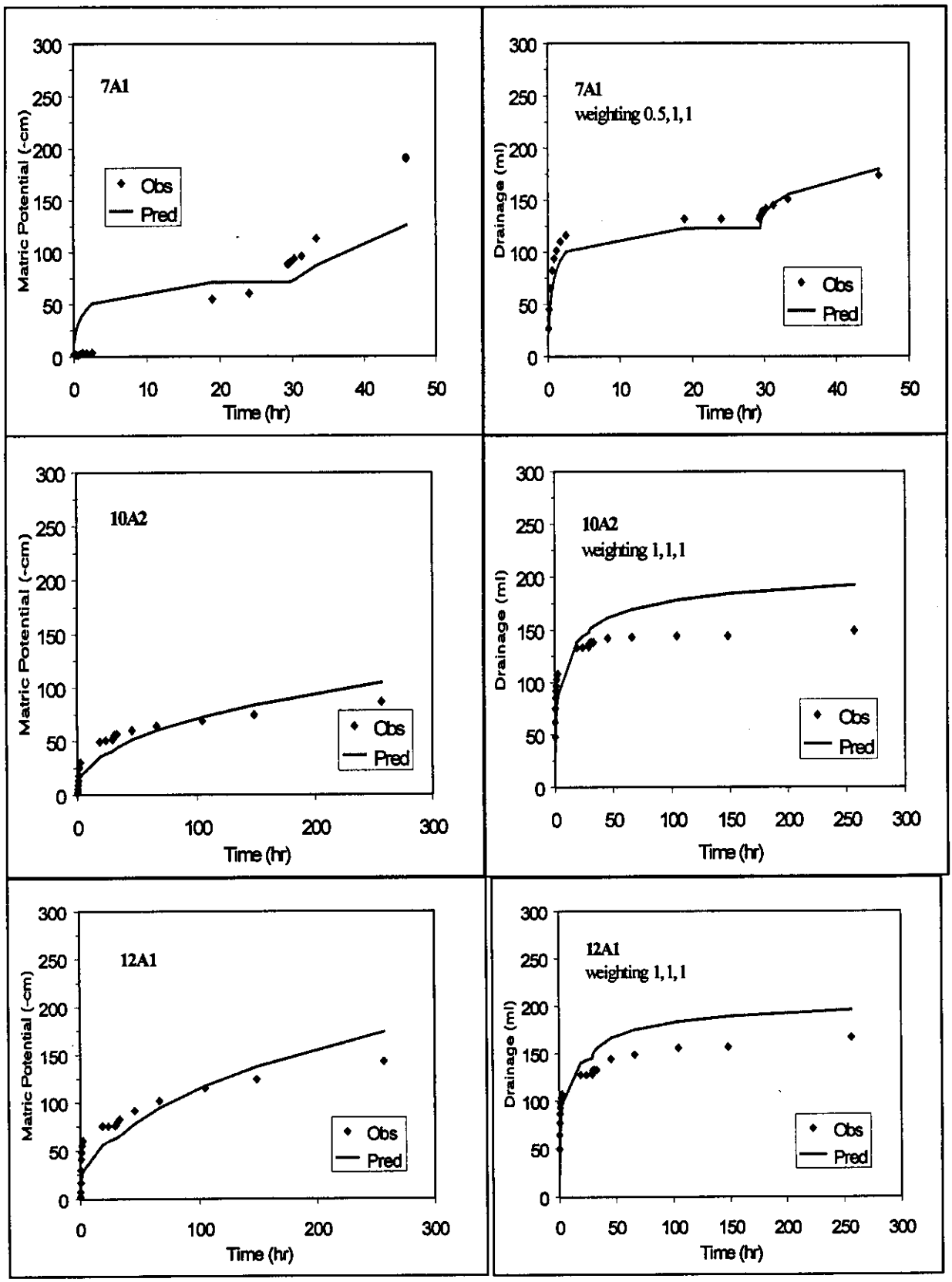
Sample	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	Fitted α (1/cm)	Fitted n (-)	R^2
7A1#	0.377	0.0404	0.0290[a]	1.825[a]	0.816
10A2#	0.413	0.0279	0.1161	1.784	0.687
12A1	0.363	0.0309	0.0650	1.755	0.621
14A1	0.416	0.0324	0.0445[b]	1.728[b]	0.966
15A1	0.380	0.0254	0.0487	1.844	0.744
16A1	0.420	0.0228	0.0682	1.710	0.862
17A2	0.423	0.0382	0.0689	1.899	0.741
19A1	0.444	0.0279	0.2010[a]	1.542[a]	0.715
20A1	0.419	0.0321	0.0305	2.081	0.942
21A1	0.403	0.0276	0.0545	1.926	0.813
22A1	0.352	0.0252	0.1078	1.585	0.879
23A1	0.371	0.0411	0.0079	1.553	0.900
24A1	0.321	0.0413	0.0130	1.684	0.983
25A2	0.345	0.0267	0.0842	2.158	0.930
27A2	0.377	0.0354	0.0830	1.532	0.884
29A1	0.359	0.0317	0.0784	1.732	0.777
31A2	0.418	0.0444	0.0058[a]	2.012[a]	0.915
32A2	0.359	0.0401	0.0931	1.703	0.826
34A2	0.316	0.0324	0.0819	2.398	0.854
35A1	0.299	0.0428	0.0897	2.160	0.945

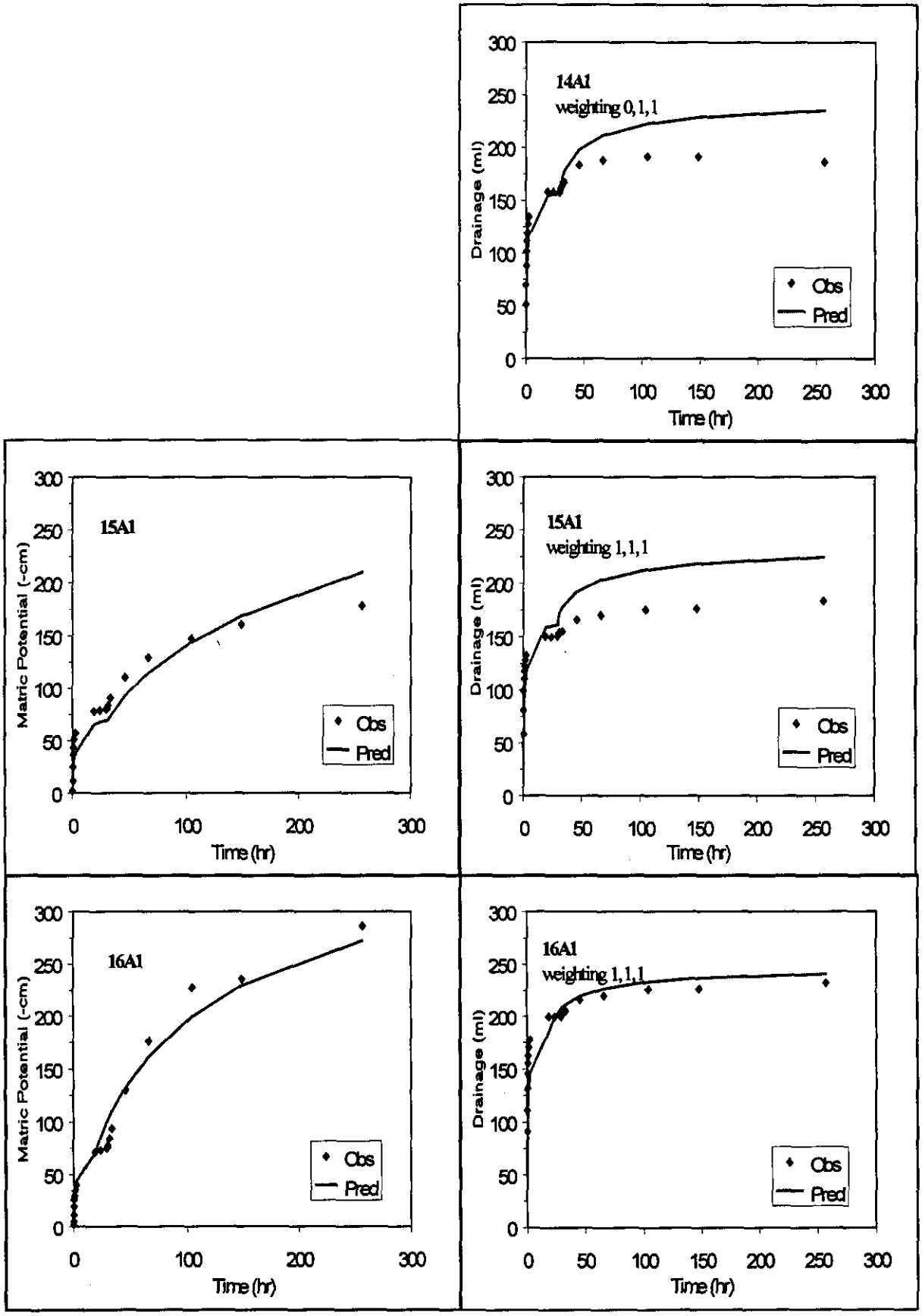
1 and 2 following A indicate tensiometer locations near the top and bottom, respectively (Fig. 2)

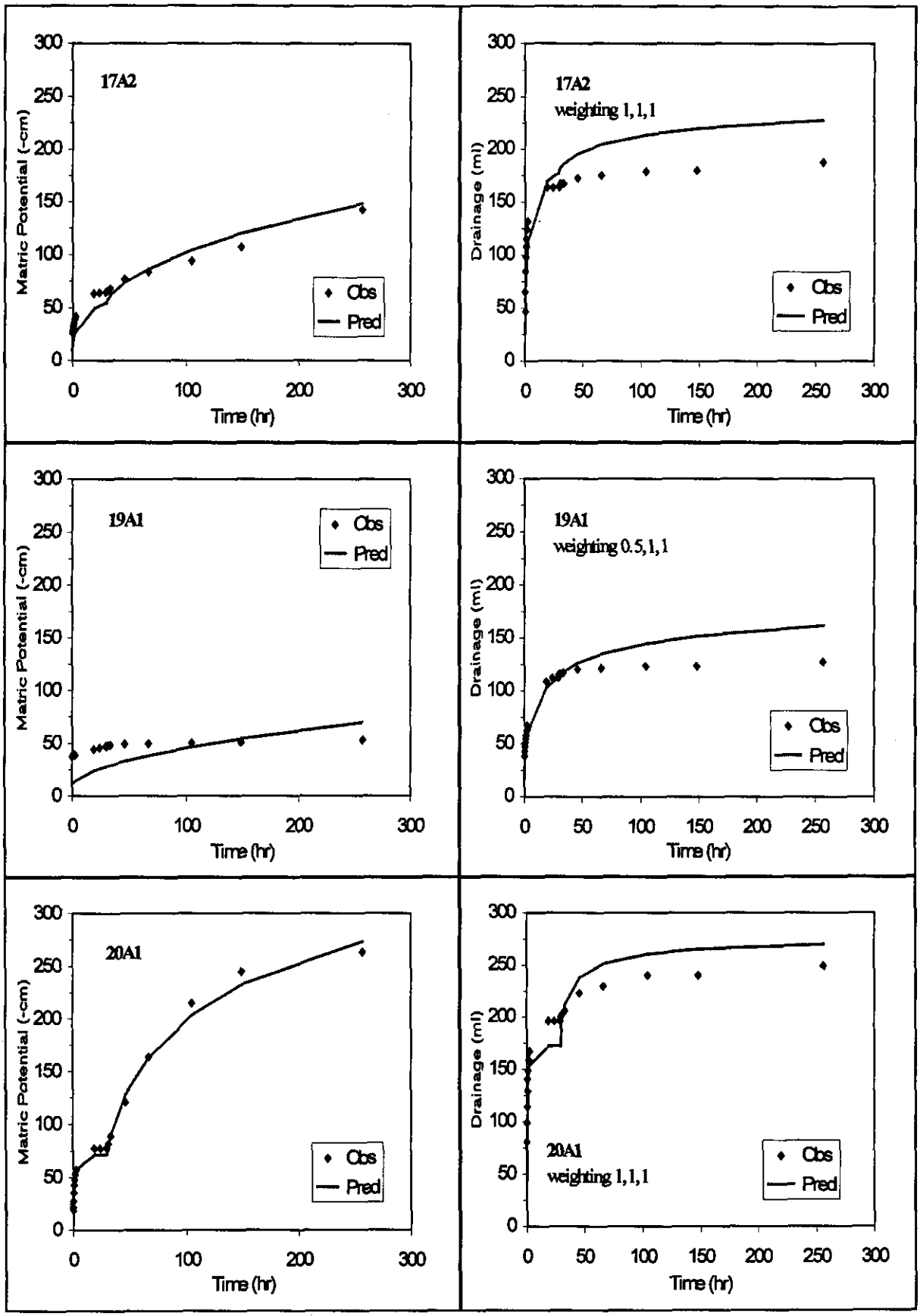
Table 10. Water retention and unsaturated conductivity data for each sample during the steady state tests (nd = no data)

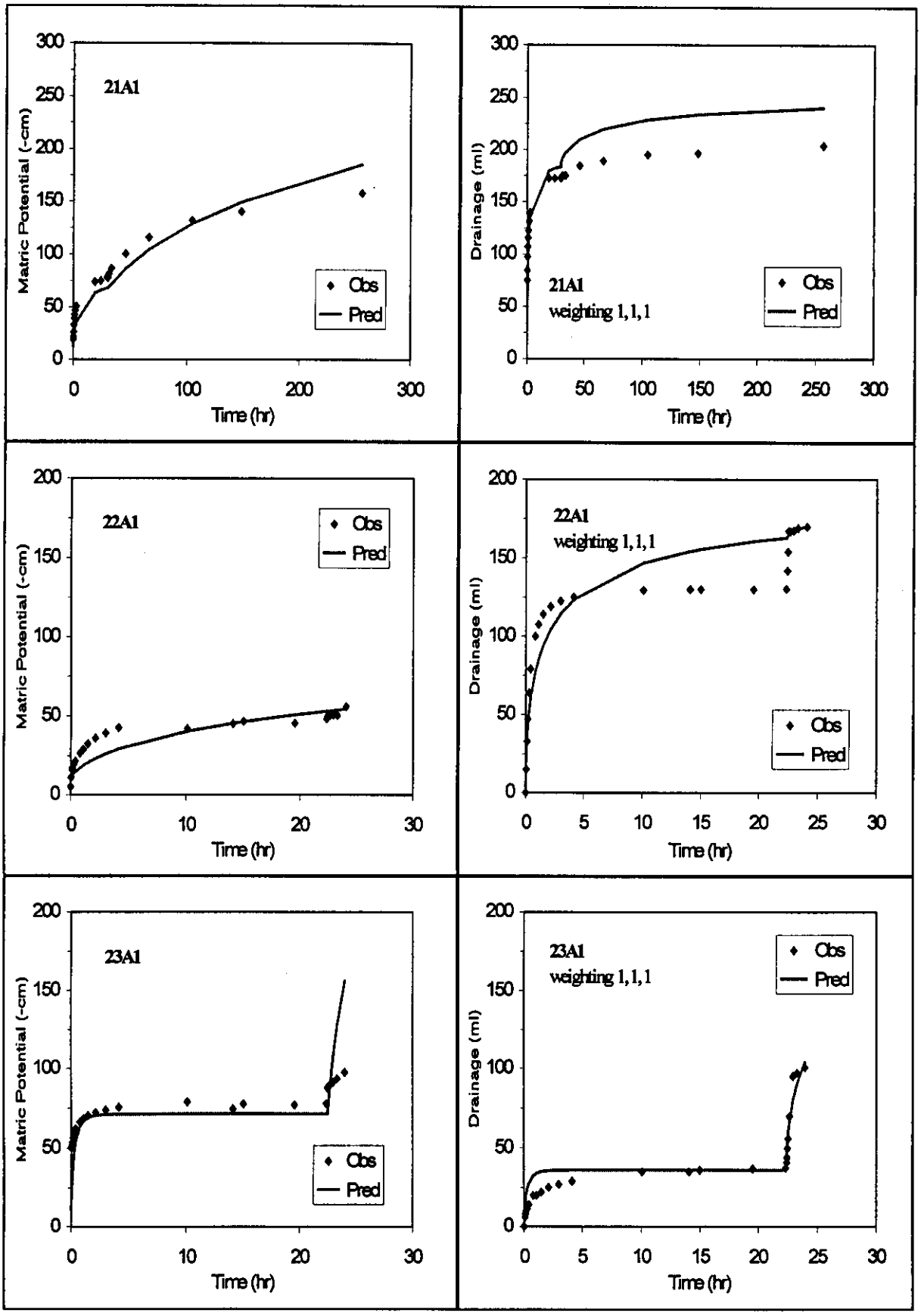
Sample	Matric Potential -cm	Water Content cm^3/cm^3	Unsaturated Hydraulic Conductivity cm/s
7A	-10.3	0.403	9.1E-04
7A	-13.5	0.405	9.5E-04
7A	-16.5	0.407	9.02E-4
7A	-19.9	0.406	9.0E-04
7A	-41.6	0.227	5.4E-05
10A	-6.1	0.391	1.1E-03
10A	-36.8	0.206	3.4E-05
12A	-8.5	0.336	9.7E-04
12A	-28.2	0.238	1.1E-04
12A	-29.8	0.234	1.1E-04
14A	-23.1	0.245	4.5E-05
15A	-8.8	0.392	2.2E-03
16A	-16.8	nd	2.0E-03
16A	-30.4	nd	2.9E-05
17A	-5.9	0.372	2.1E-04
17A	-23.3	0.249	6.5E-05
17A	-25.3	0.236	4.3E-06
19A	-6.4	0.422	2.3E-03
20A	-8.4	0.377	1.9E-03
21A	-20.8	0.289	6.7E-04
22A	-6.0	0.363	2.2E-03
22A	-22.8	nd	3.9E-04
22A	-25.6	nd	2.3E-04
23A	-20.2	0.374	1.6E-04
24A	-9.9	0.328	5.8E-04
24A	-25.3	nd	4.8E-04
25A	-8.8	0.326	5.1E-04
25A	-26.6	0.227	2.7E-04
27A	-12.7	0.298	2.4E-03
27A	-15.1	0.298	4.3E-04
27A	-19.7	0.285	2.9E-04
29A	-12.7	0.343	4.8E-04
29A	-14.0	0.315	1.0E-04
31A	-12.7	0.383	3.0E-04
31A	-20.3	0.369	3.0E-04
31A	-20.5	0.371	3.0E-04
31A	-28.2	0.370	2.9E-04
32A	-10.1	0.333	1.5E-03
32A	-12.3	nd	7.7E-04
34A	-6.9	0.313	6.3E-04
34A	-15.2	0.197	1.3E-04
35A	-20.3	0.278	1.9E-05

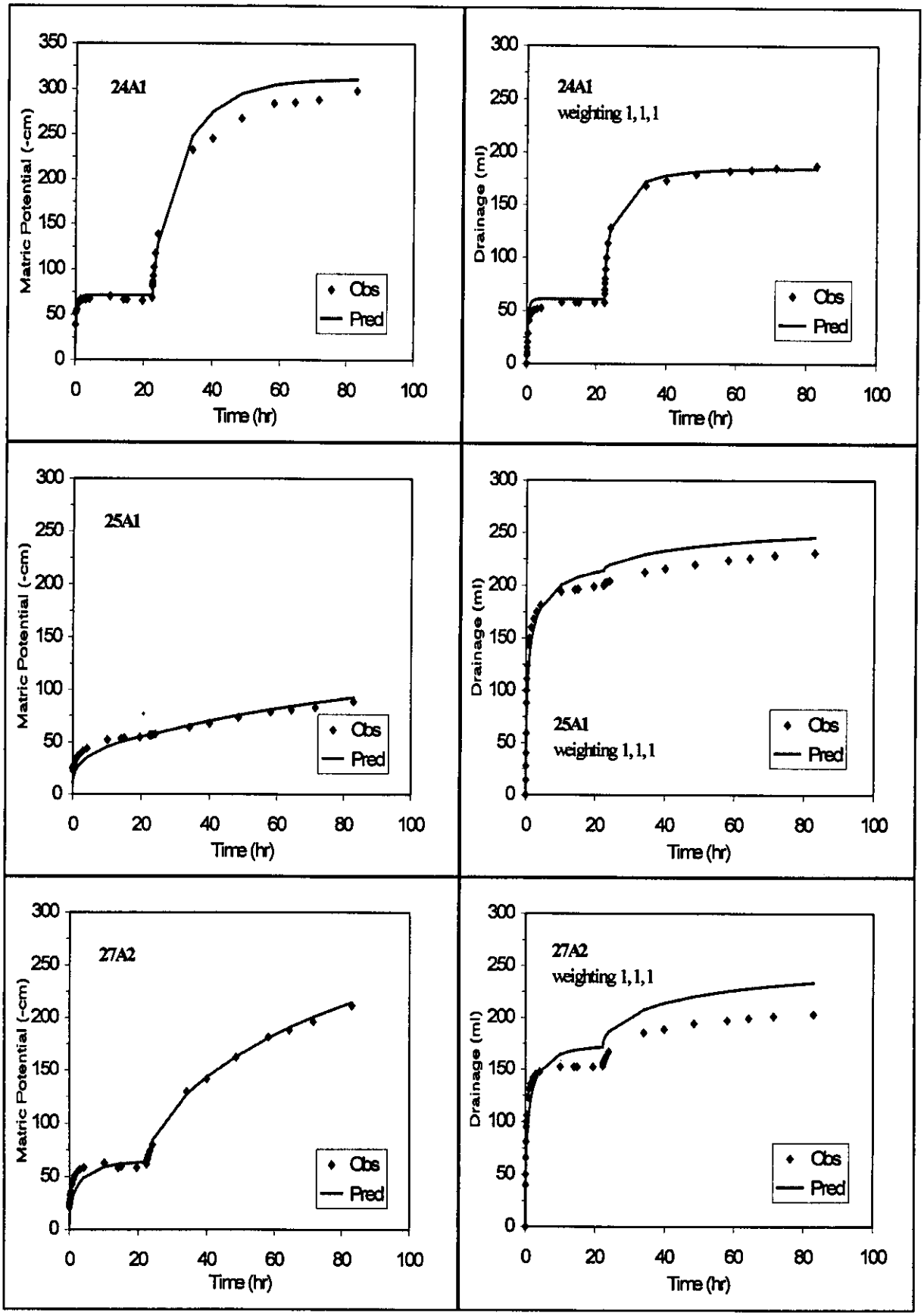
Figure 3. Comparison of predictive model, based on MULSTP-derived parameters, and observed data on matric potential (-cm) and cumulative drainage (mL) for 20 samples (No tension data were available for sample 14A1).

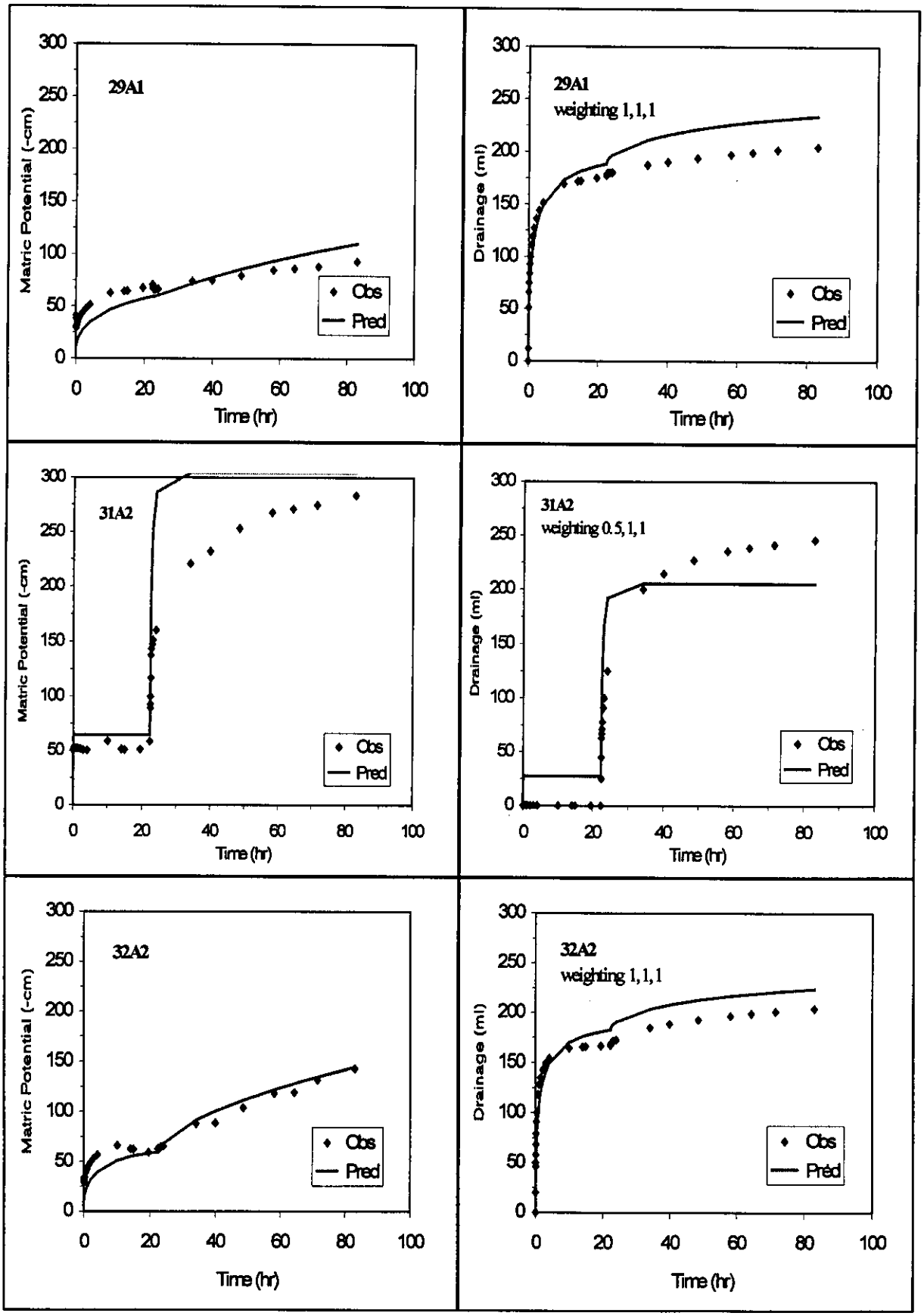


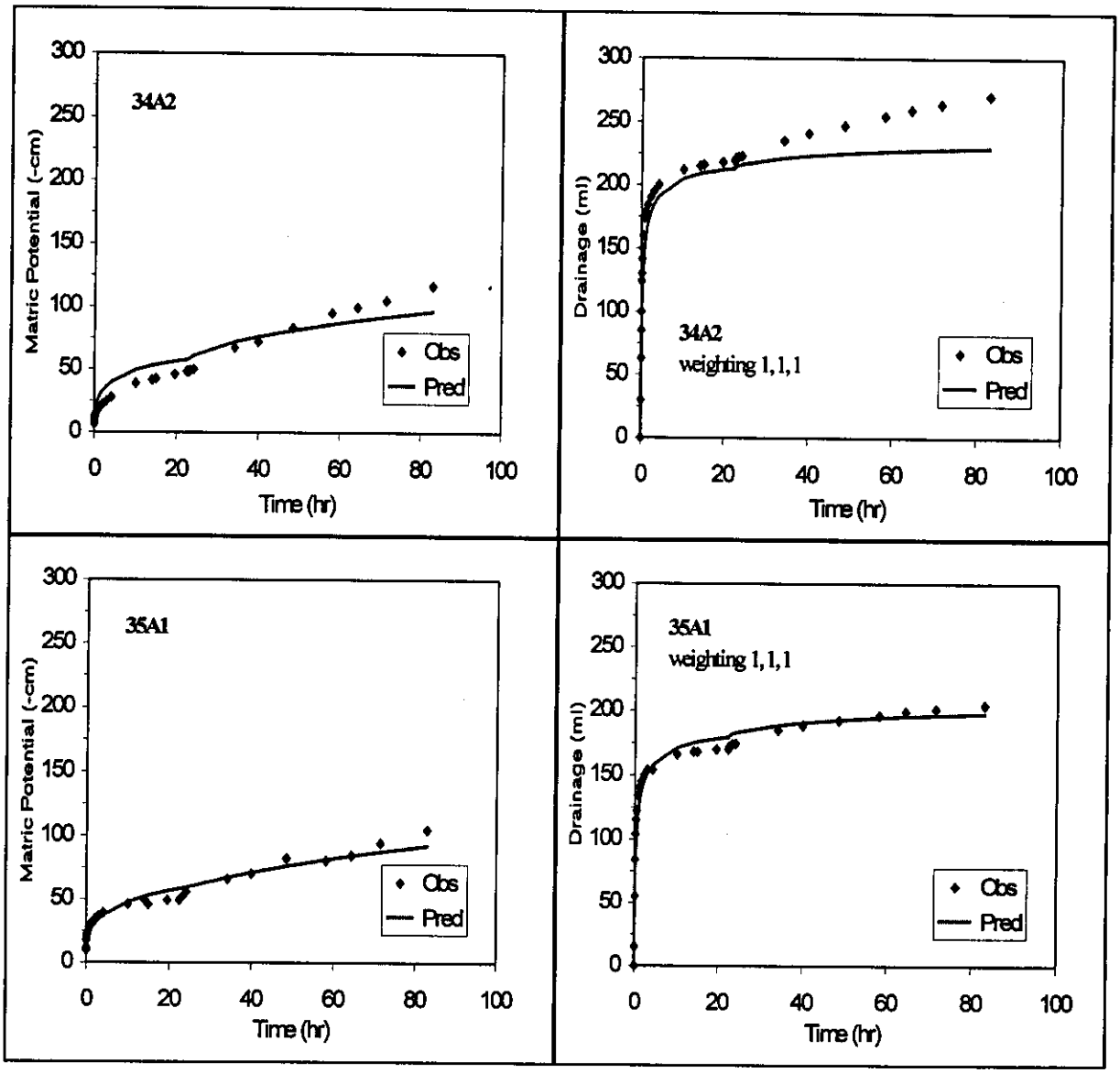

14A1
weighting 0,1,1
Drainage (ml)
Time (hr)
Obs
Pred
15A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
15A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred
16A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
16A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred


17A2
Matric Potential (-cm)
Time (hr)
Obs
Pred
17A2
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred
19A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
19A1
weighting 0.5,1,1
Drainage (ml)
Time (hr)
Obs
Pred
20A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
20A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred


21A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
21A1
weighting 1,1,1
Drainage (ml)
22A1
22A1
weighting 1,1,1
23A1
23A1
weighting 1,1,1


24A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
24A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred
25A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
25A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred
27A2
Matric Potential (-cm)
Time (hr)
Obs
Pred
27A2
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred


29A1
Matric Potential (-cm)
Time (hr)
Obs
Pred
29A1
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred
31A2
Matric Potential (-cm)
Time (hr)
Obs
Pred
31A2
weighting 0.5,1,1
Drainage (ml)
Time (hr)
Obs
Pred
32A2
Matric Potential (-cm)
Time (hr)
Obs
Pred
32A2
weighting 1,1,1
Drainage (ml)
Time (hr)
Obs
Pred


34A2
Matric Potential (-cm)
Time (hr)
Obs
Pred
34A2
weighting 1,1,1
Drainage (ml)
35A1
35A1
weighting 1,1,1

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APPENDIX B

Laboratory Data on Physical and Hydraulic Properties for 100 Area Samples (RETC Input File)

```
   15    1    8
2-1307: mass-based correction    : Drying curve
    1   20   24    3    4    0    1    1    8   30    2
    0.0352    0.2309    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.27E-03
2-1307
100-HR-3   : 43%gr, 46%cs, 11%fs,  0%silt,  0%clay
       0.1    0.2309
       7.5    0.2309
      21.0    0.2309
      33.0    0.2200
      52.5    0.2112
      69.0    0.2006
     100.5    0.1809
     202.5    0.1441
     300.0    0.1239
     500.0    0.1042
     500.0    0.1010
     700.0    0.0931
     700.0    0.0870
    1000.0    0.0831
    2010.0    0.0663
    3000.0    0.0575
    5000.0    0.0475
    7000.0    0.0346
    8700.0    0.0304
   14400.0    0.0352
      0.10   2.70E-4
      30.0   5.86E-6
      97.0   9.70E-7
     388.0   2.60E-7
2-1308: mass-based correction    : Drying curve
    1   19   23    3    4    0    1    1    8   30    2
    0.0186    0.1176    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.75E-04
2-1308
100-HR-3   : 58%gr, 22%cs,  9%fs, 11%silt,  0%clay
       0.1    0.1176
       7.5    0.1176
      21.0    0.1176
      33.0    0.1176
      52.5    0.1112
      69.0    0.1005
     100.5    0.0858
     202.5    0.0694
     300.0    0.0604
     500.0    0.0520
     500.0    0.0487
     700.0    0.0483
     700.0    0.0428
    1000.0    0.0398
    2000.0    0.0381
    3200.0    0.0329
    5000.0    0.0411
    7000.0    0.0211
   10000.0    0.0186
      0.10   7.50E-5
```

```
      34.0   3.94E-6
      90.0   1.05E-6
     374.0   2.88E-7
2-1318: mass-based correction    : Drying curve
    1   20   24    3    4    0    1    1    8   30    2
    0.0181    0.1207    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.11E-03
2-1318
100-HR-3   : 60%gr, 40%cs, 20%fs,  0%silt,  0%clay
       0.1    0.1207
       7.5    0.1207
      21.0    0.1207
      33.0    0.1207
      52.5    0.1207
      69.0    0.1171
     100.5    0.1039
     202.5    0.0859
     300.0    0.0746
     500.0    0.0639
     700.0    0.0588
     700.0    0.0553
    1000.0    0.0507
    1000.0    0.0510
    2000.0    0.0359
    3200.0    0.0512
    5000.0    0.0293
    7000.0    0.0229
   10000.0    0.0183
   15000.0    0.0181
      0.10   1.10E-4
      18.0   9.30E-5
      43.0   4.10E-5
     138.0   3.80E-6
2-2663: mass-based correction    : Drying curve
    1   21   24    3    4    0    1    1    8   30    2
    0.0298    0.1301    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.39E-03
2-2663
100-BC-5   : 61%gr, 35%cs,  4%fs,  0%silt,  0%clay
       0.1    0.1301
       8.0    0.1301
      11.0    0.1301
      23.5    0.1301
      31.5    0.1301
      53.5    0.1301
      72.1    0.1301
     101.0    0.1301
     203.0    0.1043
     300.0    0.0877
     500.0    0.0741
     700.0    0.0674
     700.0    0.0633
    1000.0    0.0602
    1000.0    0.0594
    2060.0    0.0482
    3020.0    0.0426
    5000.0    0.0370
```

```
    7000.0    0.0321
   10000.0    0.0297
   15000.0    0.0298
      0.10   3.90E-4
      27.0   1.40E-5
     101.0   1.60E-6
2-2664: mass-based correction    : Drying curve
    1   23   28    3    4    0    1    1    8   30    2
    0.0222    0.1214    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.46E-03
2-2664
100-BC-5   : 73%gr, 19%cs,  8%fs,  0%silt,  0%clay
       0.1    0.1214
       2.0    0.1214
       6.5    0.1214
      10.8    0.1214
      11.0    0.1214
      20.0    0.1214
      30.5    0.1214
      55.0    0.1111
      72.0    0.1047
     101.0    0.0911
     201.5    0.0700
     300.0    0.0593
     500.0    0.0504
     700.0    0.0458
     700.0    0.0512
     850.0    0.0442
    1000.0    0.0416
    1000.0    0.0417
    2000.0    0.0301
    3000.0    0.0291
    5000.0    0.0247
    7000.0    0.0233
   10000.0    0.0222
      0.10   4.60E-4
      16.0   8.60E-5
      90.0   7.40E-7
     100.0   5.70E-7
     296.0   5.80E-8
2-2666: mass-based correction    : Drying curve
    1   20   25    3    4    0    1    1    8   30    2
    0.0365    0.2300    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.14E-03
2-2666
100-BC-5 :71%gr, 19%cs,  7%fs,  3%silt,  0%clay
       8.0    0.1325
      11.0    0.1325
      23.5    0.1325
      31.5    0.1323
      53.5    0.1276
      72.1    0.1266
     101.0    0.1237
     203.0    0.1161
     300.0    0.1020
     500.0    0.0903
     700.0    0.0836
```

```
     700.0    0.0737
    1000.0    0.0753
    1000.0    0.0694
    2060.0    0.0610
    3020.0    0.0544
    5000.0    0.0466
    7000.0    0.0403
   10000.0    0.0358
   15000.0    0.0365
      0.10   1.40E-4
      32.0   3.00E-4
      93.0   3.60E-7
      98.0   4.50E-7
     294.0   2.20E-7
2-2667: mass-based correction    : Drying curve
    1   22   26    3    4    0    1    1    8   30    2
    0.0241    0.0906    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.33E-03
2-2667
100-BC-5    : 75%gr, 21%cs,  4%fs,  0%silt,  0%clay
      0.1    0.0906
      2.0    0.0906
      6.5    0.0906
     10.8    0.0906
     20.0    0.0906
     30.5    0.0906
     55.0    0.0906
     72.0    0.0906
    101.0    0.0899
    201.5    0.0684
    300.0    0.0597
    500.0    0.0530
    700.0    0.0488
    700.0    0.0563
    850.0    0.0467
   1000.0    0.0452
   1000.0    0.0508
   2000.0    0.0365
   3000.0    0.0353
   5000.0    0.0294
   7000.0    0.0251
  10000.0    0.0241
     0.10   3.30E-4
     19.0   9.66E-5
     96.0   2.39E-7
    305.0   1.97E-7
3-0570: mass-based correction    : Drying curve
    1   19   25    3    4    0    1    1    8   30    2
    0.0298    0.1500    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.39E+00
3-0570
100-KR-1    : 60%gr, 33%cs,  7%fs,  0%silt,  0%clay
      3.5    0.1195
      7.3    0.1195
     11.0    0.1195
     21.5    0.1195
     35.5    0.1195
```

```
      49.0    0.1195
      74.5    0.1092
      99.0    0.1017
     200.3    0.0856
     300.0    0.0786
     500.0    0.0700
     700.0    0.0628
     850.0    0.0598
    1000.0    0.0565
    2000.0    0.0429
    3000.0    0.0406
    5000.0    0.0387
    7000.0    0.0327
   10000.0    0.0298
      0.10   3.90E-1
      29.0   6.30E-5
      40.0   1.70E-5
      56.0   1.80E-6
      89.0   4.50E-7
     228.0   1.40E-7
3-0577: mass-based correction    : Drying curve
    1   22   27    3    4    0    1    1    8   30    2
    0.0140    0.1007    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.90E-01
3-0577
100-FR-3    : 66%gr, 35%cs,  4%fs,  0%silt,  0%clay
       0.1    0.1007
       2.5    0.1007
       6.5    0.1007
      10.0    0.1007
      25.0    0.1007
      33.5    0.1007
      51.0    0.1007
      75.0    0.0961
     102.0    0.0880
     201.5    0.0676
     300.0    0.0574
     500.0    0.0496
     700.0    0.0434
     700.0    0.0437
     850.0    0.0409
    1000.0    0.0379
    1000.0    0.0380
    2000.0    0.0292
    3000.0    0.0268
    5000.0    0.0195
    7000.0    0.0165
   10000.0    0.0140
      0.10   9.00E-2
      31.0   8.70E-6
      59.0   3.10E-6
     153.0   8.80E-8
     232.0   2.70E-8
3-0686: mass-based correction    : Drying curve
    1   21   25    3    4    0    1    1    8   30    2
    0.0237    0.1782    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.13E-02
```

```
3-0686
100-FR-1    : 55%gr, 23%cs, 22%fs,  0%silt,  0%clay
       0.1    0.1782
       3.5    0.1782
       6.0    0.1782
       8.0    0.1782
      10.0    0.1782
      25.0    0.1782
      33.5    0.1782
      54.5    0.1775
      71.5    0.1601
     102.0    0.1282
     202.5    0.0872
     300.0    0.0690
     500.0    0.0551
     700.0    0.0473
     850.0    0.0434
    1000.0    0.0387
    2000.0    0.0248
    3000.0    0.0260
    5000.0    0.0215
    6300.0    0.0387
   10000.0    0.0237
      0.10   1.30E-3
      23.0   1.60E-4
      48.0   3.40E-5
     202.0   2.60E-6
3-1702: mass-based correction    : Drying curve
    1   23   30    3    4    0    1    1    8   30    2
    0.0216    0.0976    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.13E-01
3-1702
100-DR-2    :68 %gr,32 %cs,0 0%fs, 0 %silt,   %clay
       0.1    0.0976
       3.0    0.0976
       5.0    0.0976
       8.0    0.0976
      11.5    0.0976
      23.5    0.0944
      37.0    0.0860
      56.0    0.0788
      71.5    0.0721
     102.5    0.0655
     201.0    0.0554
     300.0    0.0498
     500.0    0.0447
     509.9    0.0400
     700.0    0.0417
     713.8    0.0373
     850.0    0.0395
    1000.0    0.0380
    1019.7    0.0316
    3059.1    0.0308
    5098.5    0.0262
    7137.9    0.0225
   10197.0    0.0216
      0.10   1.30E-2
      30.0   2.30E-6
```

```
      44.0   1.70E-6
      65.0   1.10E-6
     111.0   4.40E-7
     153.0   2.30E-7
     258.0   1.00E-7
4-1086: mass-based correction    : Drying curve
    1   23   29    3    4    0    1    1    8   30    2
    0.0173    0.1510    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.11E-01
4-1086
100-K:65 %gr,24 %cs,11 %fs,0 0%silt,   %clay
       0.1    0.1510
       4.0    0.1103
      12.0    0.1078
      20.0    0.1041
      31.0    0.1005
      52.0    0.0967
      70.1    0.0948
     100.9    0.0912
     213.0    0.0759
     300.0    0.0680
     500.0    0.0602
     510.0    0.0571
     690.0    0.0563
     714.0    0.0536
    1000.0    0.0520
    1020.0    0.0520
    2039.0    0.0445
    3059.0    0.0430
    5099.0    0.0398
    7138.0    0.0307
    9993.0    0.0360
   10197.0    0.0334
  136538.0    0.0173
      0.10   1.10E-2
      19.0   1.40E-4
      36.0   1.00E-5
      88.0   1.40E-6
     247.0   4.60E-7
     296.0   1.40E-7
4-1090: mass-based correction    : Drying curve
    1   23   28    3    4    0    1    1    8   30    2
    0.0075    0.1740    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.21E-03
4-1090
100-K:50 %gr,34 %cs,16 %fs,0 0%silt,   %clay
       0.1    0.1740
       4.0    0.1423
      12.0    0.1390
      20.0    0.1379
      31.0    0.1359
      52.0    0.1326
      70.1    0.1166
     100.9    0.1029
     213.0    0.0783
     300.0    0.0653
     500.0    0.0523
```

```
      510.0    0.0467
      690.0    0.0460
      714.0    0.0452
     1000.0    0.0393
     1020.0    0.0429
     2039.0    0.0287
     3059.0    0.0278
     5099.0    0.0230
     7138.0    0.0156
     8565.0    0.0253
    10197.0    0.0446
   228311.0    0.0075
       0.10   2.10E-4
       61.0   1.40E-5
      120.0   3.60E-6
      231.0   7.60E-7
      320.0   2.90E-7
4-1118: mass-based correction    : Drying curve
    1   23   29    3    4    0    1    1    8   30    2
    0.0213    0.1760    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.86E-03
4-1118
100-K:66 %gr,28 %cs,6 0%fs, 0 %silt,   %clay
       0.1    0.1760
       5.0    0.1290
       8.0    0.1293
      11.5    0.1272
      27.0    0.1144
      49.0    0.1080
      70.5    0.1017
     104.0    0.0856
     202.0    0.0820
     300.0    0.0763
     500.0    0.0704
     510.0    0.0621
     700.0    0.0663
     714.0    0.0697
    1000.0    0.0626
    1020.0    0.0618
    2039.0    0.0496
    3059.0    0.0497
    5099.0    0.0479
    7138.0    0.0353
    9993.0    0.0365
   16927.0    0.0306
   55982.0    0.0213
      0.10   8.60E-4
      49.0   2.20E-6
      83.0   6.60E-7
     131.0   1.80E-7
     240.0   8.30E-8
     327.0   6.70E-8
4-1120: mass-based correction    : Drying curve
    1   23   28    3    4    0    1    1    8   30    2
    0.0069    0.1340    0.1000    1.6000    0.3750       0.5        1.       1.0
    1    1    1    1    0    0    1
1 0.33E-03
4-1120
```

100-K:63 %gr,20 %cs,17 %fs,0 0%silt,	%clay
0.1	0.1340
5.0	0.1261
8.0	0.1277
11.5	0.1271
27.0	0.1238
49.0	0.1216
70.5	0.1184
104.0	0.0823
202.0	0.0755
300.0	0.0648
500.0	0.0519
510.0	0.0470
700.0	0.0460
714.0	0.0593
1000.0	0.0383
1020.0	0.0383
2039.0	0.0294
3059.0	0.0291
5099.0	0.0280
7138.0	0.0143
9993.0	0.0184
28450.0	0.0131
223824.0	0.0069
0.10	3.30E-4
27.0	4.10E-5
61.0	1.10E-5
88.0	7.40E-6
118.0	4.80E-6

APPENDIX C

Hydraulic Parameters of the Upper Hanford Formation

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Hanford Low-Activity Tank Waste Performance Assessment Activity:

Determination of In Situ Hydraulic Parameters of the Upper Hanford Formation

AL Ward, RE Clayton and JS Ritter
31 December 1998

Introduction

Under the Hanford Low-Activity Tank Waste Project, the Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of a disposal facility for radioactive wastes currently stored in single and double shell tanks at the Hanford Site. Part of the performance assessment of such a facility involves the use of numerical models to predict the potential migration and fate of contaminants in through the vadose zone.

A general feature of soils is their spatial heterogeneity, i.e., variation of their hydraulic properties in space. The relation between the matric potential, ψ, and the volumetric water content, θ [the soil water characteristic, $\psi(\theta)$], the hydraulic conductivity tensor, $\mathbf{K}(\theta)$, and the diffusivity, $D(\theta)$] are all spatially variable and have been shown to exhibit scale dependence. Thus, vadose flow and transport is a complex, three-dimensional phenomenon, even in soils that appear to be uniform. In addition to the inherent variability, typical field soils may exhibit a number of other structural elements, e.g. lenses, and clastic dikes, that often cause the redirection and concentration of water and solute flux at the local scale. Consequently, a major hindrance to the interpretation and prediction of vadose zone transport is the difficulty in measuring the constitutive properties and the uncertainty over the range of spatial scales required by numerical models. The associated uncertainty in hydraulic properties and its effect of performance of disposal facility is requirement is recognized in the DOE revised interim policy for waste disposal facilities.

The DOE revised interim policy requirement of a reasonable expectation that a disposal facility will comply with the LAW performance objectives implies consideration for uncertainty in model predictions of facility performance. Thus, any model of transport in the vadose zone requires, in the least, knowledge of the average properties of the medium, as well as the magnitude and characteristic length scale of the variations of those properties. Since a major source of uncertainty in model predictions of facility performance will be due to the uncertainty

in hydraulic and transport parameters, there is a need for information on the unsaturated hydrologic properties of the porous media.

The Pacific Northwest National Laboratory (PNNL) is providing geotechnical support to LMHC to assist in the design and performance assessment of the disposal facility. Two related components of the geotechnical support to be provided by PNNL are the determination of *in situ* unsaturated hydraulic parameters for Hanford surface sediments (Task 4b) and the upper Hanford sand sequence (Task 4c) at the proposed location of the disposal facility. In FY 1998, laboratory and field activities for the two tasks were completed and a letter report for Task 4b prepared (Ward et al., 1998). Data analysis and report preparation for Task 4c were deferred until FY-1999. This report represents the completion of Task 4c.

Methods

The experimental site is located approximately 325 m southwest of PUREX plant and about 220 m west of the injection site in the 200E Area used by Sisson and Lu (1984). On completion of the measurements in the surface sediments, a 1.5-m deep trench was excavated and the bottom of the trench instrumented in a manner identical to the surface. Detailed descriptions of the site, experimental design, and instrumentation have presented in the test plan of Ward (1997) and reiterated in the Task 4b letter report (Ward et al., 1998). Briefly, probes were installed along the centerline of the test plot in 25 short rows spaced 0.2 m apart (Figure 1). Each row consisted of 5 TDR probes installed vertically to depths of 0.25, 0.50, 0.75, 1.0, and 1.50 m (Figure 2).

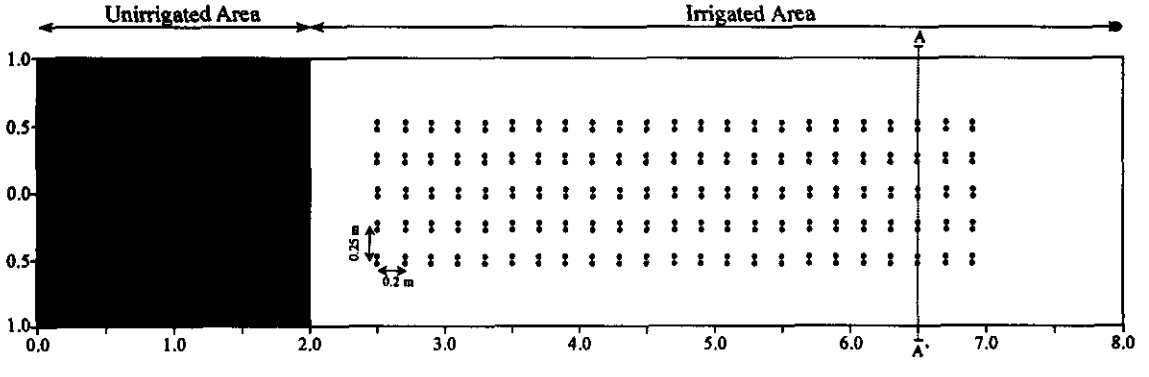

Figure 1. Plan View of Test Plot Showing Instrument Layout. The shaded 2-m section is the unirrigated control.

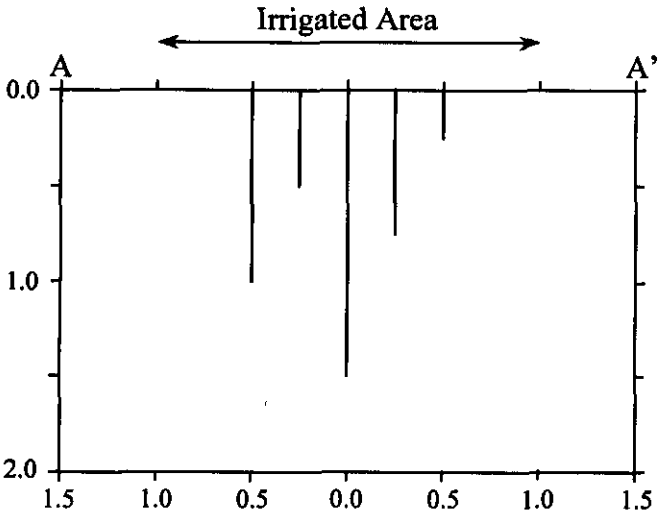

Figure 2. Cross-Sectional View of Test Plot Showing Installation Depths of the Instruments

Six infiltration experiments were conducted over the course of the study. Each experiment was conducted at a different flux density, J_w, to allow determination of $K(\theta_e)$. The values J_w used in the experiment were the same as in the first experiment, i.e., $4.7x10^{-3}$ cm s^{-1}; $2.5x10^{-3}$ cm s^{-1}, $1.292x10^{-3}$ cm s^{-1}, $3.093x10^{-4}$ cm s^{-1}, $3.54x10^{-5}$ cm s^{-1}, and $1.35x10^{-5}$ cm s^{-1}. The maximum application rate during the course of the experiments was determined by the nozzles used on the irrigation system. The lower rates were obtained by increasing the amount of time between each pass by the irrigation system.

Data reduction methods identical to those reported for Task 4b were employed. Briefly, hydraulic parameters for each depth interval were obtained by fitting the van Genuchten (1980) functions to the measured $\psi(\theta)$, and $K(\theta)$ data with the RETC computer program. The RETC program uses non-linear least squares techniques to fit the observed $\theta(\psi)$ and $K(\theta)$ data to closed-form analytical functions (van Genuchten et al., 1991). Unlike in the first experiment, saturated hydraulic conductivity, K_s was measured at fixed intervals along the transect using a tension infiltrometer according to the method of Zhang (1997). The measured K_s provided an additional constraint for the RETC analysis.

Solute breakthrough curves were derived from time domain reflectometry (TDR) measurements of the changes in bulk resistivity, R_L, in response to the application of KCl as a tracer (Ward et al. 1994; Kachanoski and Ward, 1994). The specific mass of tracer applied to the

surface, M_T, was 80 g Cl^- per m^2 of soil surface. At each level of J_w and associated equilibrium water content, θ_e, the specific mass of the tracer present from the surface to depth z=L (L being the length of the TDR probes), as a function of time, $M_L(t)$ [g cm^{-2}], was calculated from R_L at each probe location. The probability density function (pdf) of relative solute mass flux, $f_L(t)$, was calculated from the first derivative of $M_L(t)$ with respect to time. This is equivalent to the measured amount of solute, relative to the amount applied, that fluxes past the end of the TDR probe and represents the solute travel-time pdf.

Three methods were compared for determining transport parameters from measured $f_L(t)$. The first and most common approach fitted the solution to the convection-dispersion equation (CDE) to observed $f_L(t)$ to obtain estimates of the mean transport velocity ($\bar{v}$) and the dispersion coefficient (D). This solution assumes a Dirac delta-function input of solute at the surface and vertical one-dimensional flow. For a semi-infinite soil system, $f_L(t)$ is given by Jury and Roth (1990)

$$f_L(z,t)=\frac{z}{2\sqrt{\pi D t^3}}\exp\left[\frac{-(z-\bar{v}t)^2}{4Dt}\right] \quad (1)$$

where D [L^2 T^{-1}] is the dispersion coefficient, $\bar{v}$ [L T^{-1}] is the mean pore water velocity, z [L] is distance positive downward, and t [T] is time. The dispersion can also be expressed as $\lambda\bar{v}$, where λ [L] is the dispersivity of the soil, controlled by the geometry of the transport volume. It is assumed that the TDR probes measure the total amount of solute in the range $0 \le z \le L$, regardless of the distribution of the solute along the probes. Then $M_L(t)$ represents the mass of solute, relative to the amount applied, that remains in the region $0 \le z \le L$ and is given by

$$M_L(t)=1-\int_0^t f_L(L,\tau)\,d\tau=1-C_F \quad (2)$$

where C_F is the flux-averaged, reduced concentration for a step function input of solute, given by (Parker, 1984)

$$C_F=\frac{1}{2}erfc\left[\frac{L-\bar{v}t}{2\sqrt{Dt}}\right]+\frac{1}{2}\exp\left[\frac{\bar{v}L}{D}\right]erfc\left[\frac{L+\bar{v}t}{2\sqrt{Dt}}\right] \quad (3)$$

A similar development for the convective lognormal transfer function (CLT) model gives the following relationship (Jury, 1983)

$$M_L(t)=\frac{1}{2}erfc\left[\frac{\ln(t)-\mu}{\sqrt{2}}\right] \tag{4}$$

in which μ [ ] is the mean of log transform of the travel time, ln(t), σ is the standard deviation of ln(t). Fitting of Eq. [4] to observed data to obtain μ and σ constitutes the second approach. The third and final approach makes use of time moment analysis to obtain the transport parameters from $M_L(t)$. The mean or expected travel time, E_{LT}, is given by (Kachanoski et al, 1992)

$$E_{LT}=\frac{\int_0^T[-dM_L(t)/dt]t\,dt}{A_{LT}} \tag{5}$$

while the variance of the solute travel time, $Var_{LT}(t)$, is given and by

$$Var_{LT}(t)=\frac{\int_0^T[-dM_L(t)/dt](t-E_{LT})^2\,dt}{A_{LT}} \tag{6}$$

where

$$A_{LT}=\int_0^T[-dM_L(t)/dt]dt \tag{7}$$

and represents the area under the breakthrough curve.

Differences between the three approaches lie in the assumptions made about the transport process. The CDE is essentially the far-field limit for solute transport. It assumes that v is the same at every location and differences in arrival time at an observation plane are due to random diffusion/dispersion processes. Thus, travel time of a solute particle to a depth z = L is assumed to be uncorrelated to its travel time in the next depth increment. In contrast, the CLT does not require any particular assumption about the underlying transport process, except that it is linear and stationary. Information on the transport process is implicit in the measured transfer function. At any particular location, *v* is constant with depth, but it varies in the horizontal plane. Thus, solute spreading at the field scale is attributed to the horizontal spatial variability in vertical transport velocity. Since the vertical solute velocity at any given location is constant with depth,

the horizontal spatial pattern of travel times to an observation plane at z = L is correlated with the spatial pattern of travel time in the next depth increment. The CLT can be used for all transport regimes and is not restricted to near- or far-field limits. However, because of the assumption of linearity and stationarity, this form of the CLT is not applicable to contaminants that exhibit nonlinear interactions with soil components, or to situations of transient water flow. In addition, it provides an integral description of transport from the surface to depth L and there are no provisions for either predicting transport to depths shallower or deeper than the measurement depth. The method of moment is a direct method and makes no assumption about the transport process. Moments can be used to determine parameters of any stable, linear process that can be represented by a transfer function. The nth moment of $f_L(t)$ is given by

$$M_n = \int_0^\infty f_L(t) t^n \, dt \tag{8}$$

The mean travel time of the system is equal to the first moment, M_1; the second moment M_2 is a measure of the dispersion; while the third moment, M_3, is related to the skewness. The main problem with ordinary moments is that higher moments are unreliable due to magnification of small errors in the tail. Nevertheless, for a particular flow model, specific relations exist between the moments and the model parameters.

In each approach, the dispersivity was calculated from the fitted parameters. The dispersivity for the CDE, λ_{CDE}, was calculated as

$$\lambda_{CDE} = \frac{D}{\bar{v}} \tag{9}$$

An equivalent dispersivity for the CLT, λ_{CLT} was calculated as

$$\lambda_{CLT} = \frac{L}{2}[\exp(\sigma^2) - 1] \tag{10}$$

while from moment analysis method, λ_{MOM} was calculated as

$$\lambda_{MOM} = \frac{L}{2} \frac{Var_{LT}}{E_{LT}^{\ 2}} \tag{11}$$

Results

Saturated Hydraulic Conductivity

Figure 3 shows the mean K_s measured at 40-cm intervals along the surface and 1.5-m deep transects. The three high values at the proximal end of the two transects were likely due to poor surface contact and treatment as outliers can be statistically justified (Acton, 1966). Overall, the results show an unexpected similarity in K_s at the two depths. At the surface, measured K_s (minus the outlier at x = 1.6 m) was 0.0013 ± 0.0006 cm s^{-1}, while at z = 1.5 m, K_s was 0.0008 ± 0.0003 cm s^{-1}. An analysis of variance was performed to test the null hypothesis of no difference between K_s measured in the two transects (Snedecor and Cochran, 1980). The value of F was significant at the 1% level (F^{**} = 7.82 < F[0.99;1,24]=8.25). Thus, measured K_s are from two different populations or soil types.

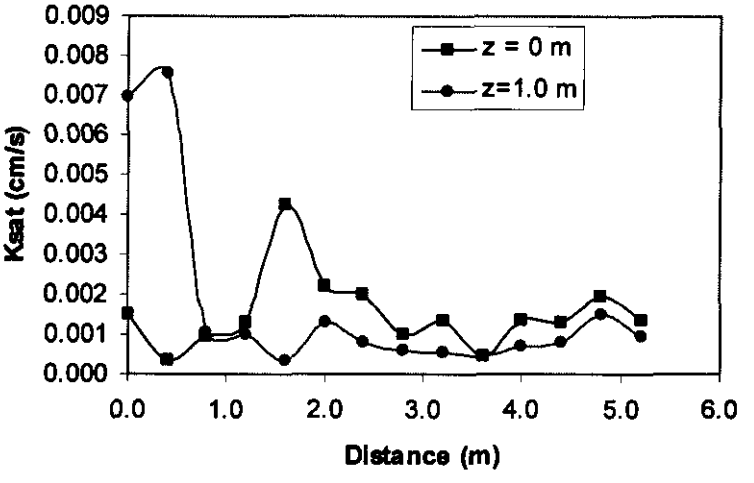

Figure 3. Mean saturated hydraulic conductivity measured along the surface and 1.5-m deep transects. Measurements were made using a tension infiltrometer at a head of -2 cm. Values at x =0 and 0.4 m (z = 0 m) and x=1.6 m(z=1.5 m) were treated as outliers in calculating the mean and variance of K_s.

Spatial Variation in Water Flux Density

An added advantage of using the TDR system for infiltration measurements is its ability to measure soil water storage, *W*, as a function of time, *t*. For a given probe length, *W(t)* is given

simply by $\theta(t) \cong L$, where $\theta(t)$ is the water content averaged over the length of the probe. During the time before the wetting front first reaches a depth L, the derivative of cumulative W with respect to time should be equal to the water flux at the soil surface, assuming no plant water uptake or evaporation (Parkin et al., 1992). Thus, spatial variation in water flux density, from which the variation in infiltration rates can be inferred, can be determined from early time measurements of $W(t)$.

Figure 4 shows the W(t) (L =0 .25 m; x=0 m) and the linear relationship fitted at early time. The rate of application at the soil surface was 2.5×10^{-6} cm s^{-1}. The calculated flux is 3.95×10^{-5} cm s^{-1}, an indication of the variability in the hydraulic conductivity.

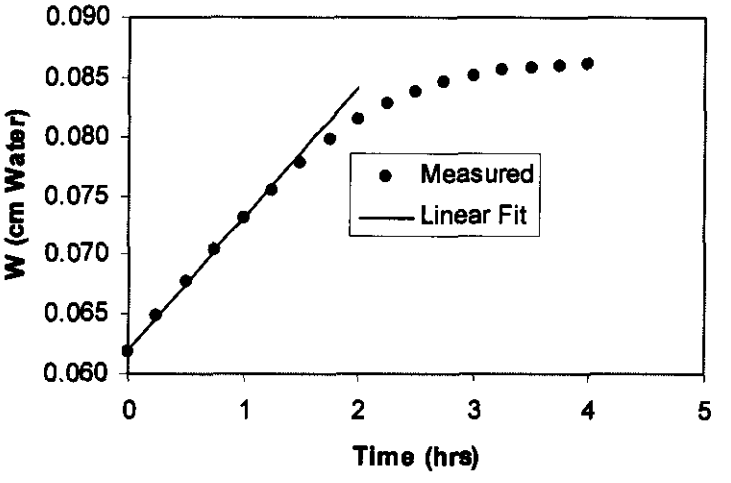

Figure 4. Cumulative storage versus time with a 25-cm probe at x = 0 m. The solid line shows a linear fit used to determine water flux density.

Figure 5 shows the distribution of flux along the transect based on measurements at the 25-cm depth. This result show that even under a constant flux of water at the surface, the actual infiltration rate can be quite variable. The local-scale average (an average of the 24 measurements) is 2.38×10^{-6} cm s^{-1}, while the field-scale average (valued fitted to the average $W(t)$ curve) is 2.61×10^{-6} cm s^{-1}. Similar increases in flow and transport properties from the local scale to the field scale have been made by other researchers (e.g. Kachanoski et al., 1990). The increase from the local scale to field scale is related to the scale dependence of the lateral

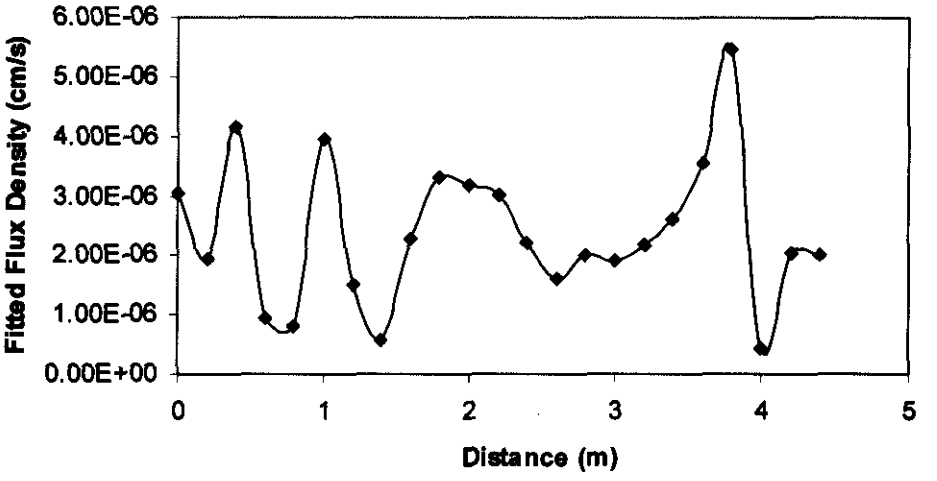

Figure 5. Spatial variation in measured surface flux density. Measurements were made with a 25-cm probe.

variations in water flux density. In this case, most of the variation can probably be explained by the distribution of sagebrush root channels (many of which were present) and micro-topography.

Water Retention Properties

Figure 6 shows the field-averaged moisture characteristic and the fitted van Genuchten relationship for the plot. Figures 7 through 11 show the plots of the individual depths. These data represent mostly imbibition data, collected as the profile was wetted to steady state at each flux of interest. There are some desorption data, mostly obtained between wetting cycles as maintenance was performed on the system. There was generally very little drainage during these periods and the data are not obvious from the plots.

As seen from the data presented, there are not many measurements at matric suctions greater than around 500 cm. The profile remained relatively wet following the first experiment, except very near the surface. In addition, most of the joints between the transducer and tensiometer failed at suctions greater than 400 to 500 cm.

Figure 6 shows that the data can be treated as essentially one population, suggesting some degree of homogeneity. To determine whether there was any advantage to be gained from treating the data otherwise, the measurements were separated out by depth interval and the

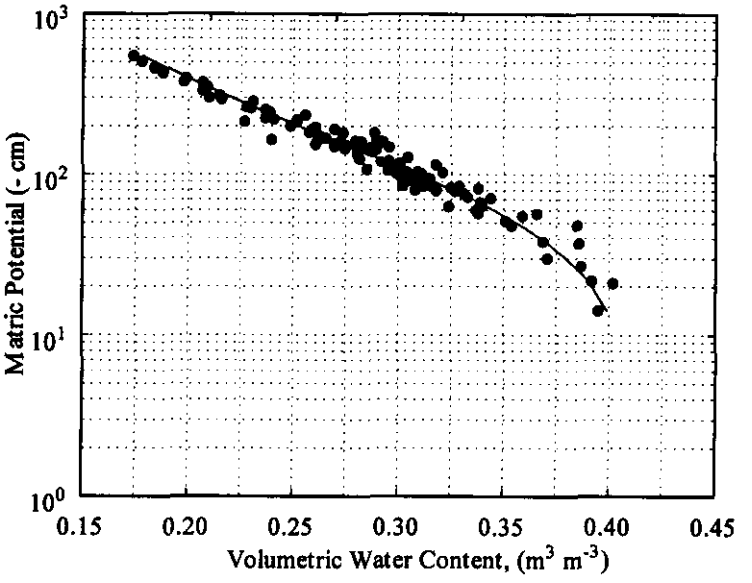

Figure 6. Fitted and observed field-averaged moisture characteristic function. This plot includes measurements from all depth intervals.

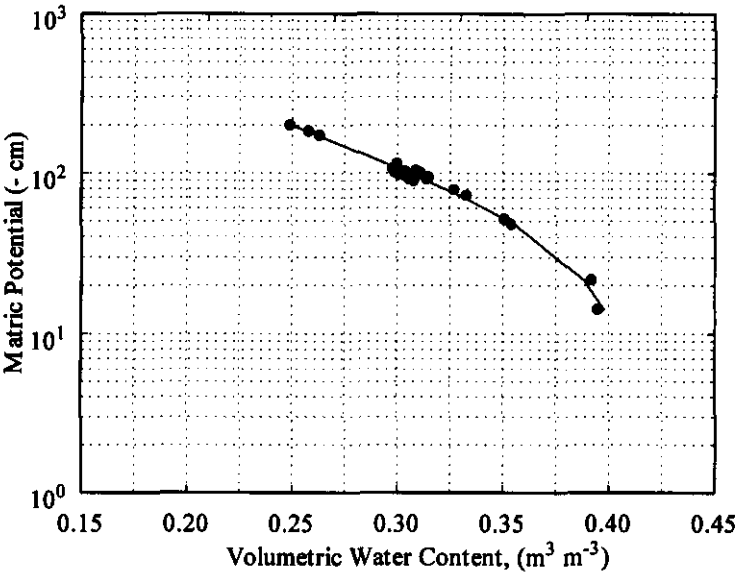

Figure 7. Fitted and observed field-averaged moisture characteristic function for the 0-25 cm depth.

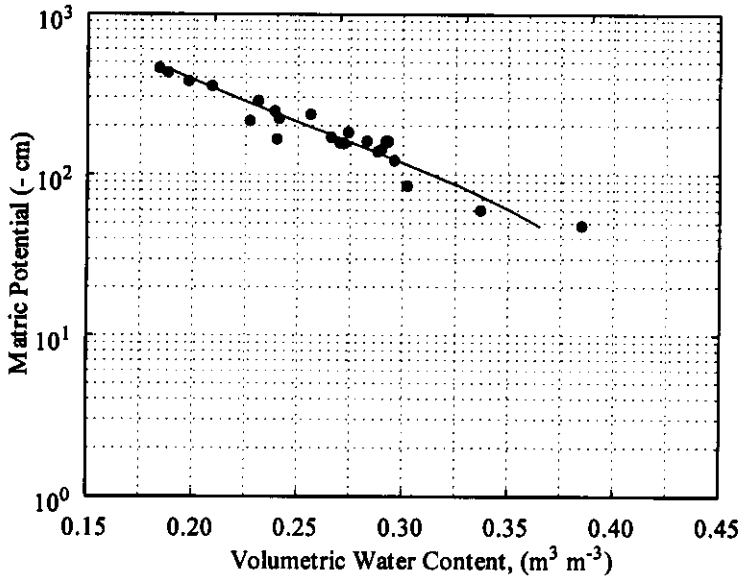

Figure 8. Fitted and observed field-averaged moisture characteristic function for the 25-50 cm depth.

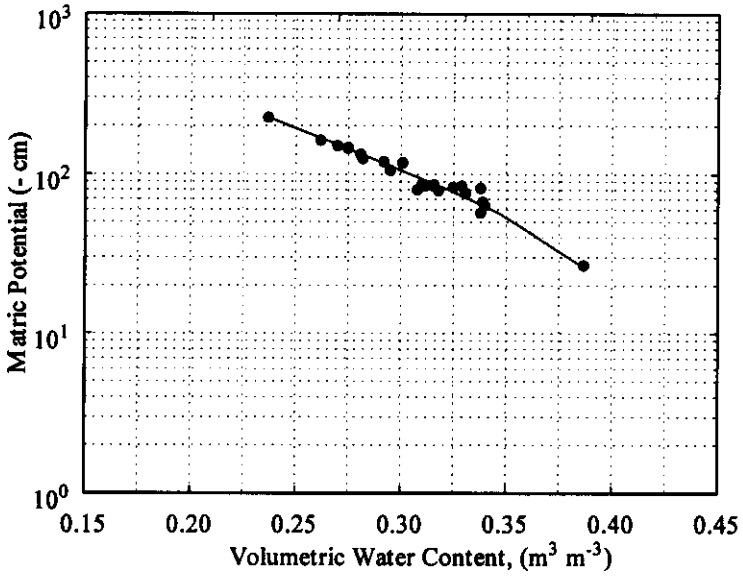

Figure 9. Fitted and observed field-averaged moisture characteristic function for the 50-75 cm depth.

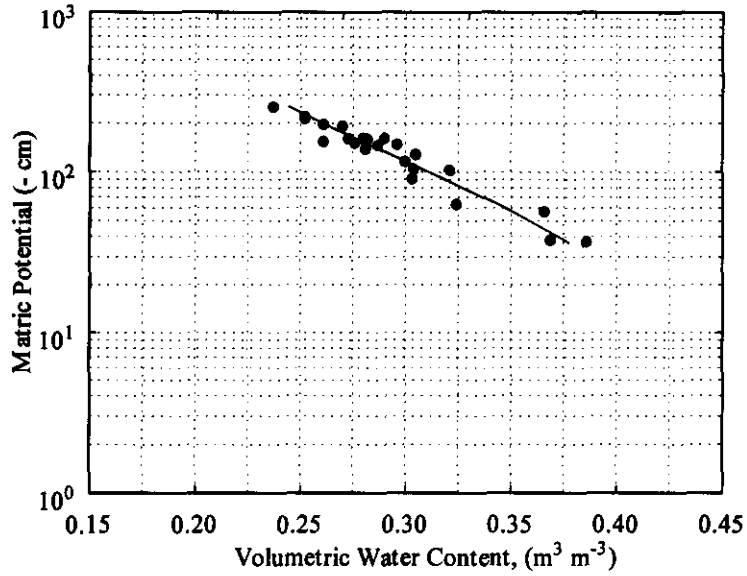

Figure 10. Fitted and observed field-averaged moisture characteristic function for the 75-100 cm depth.

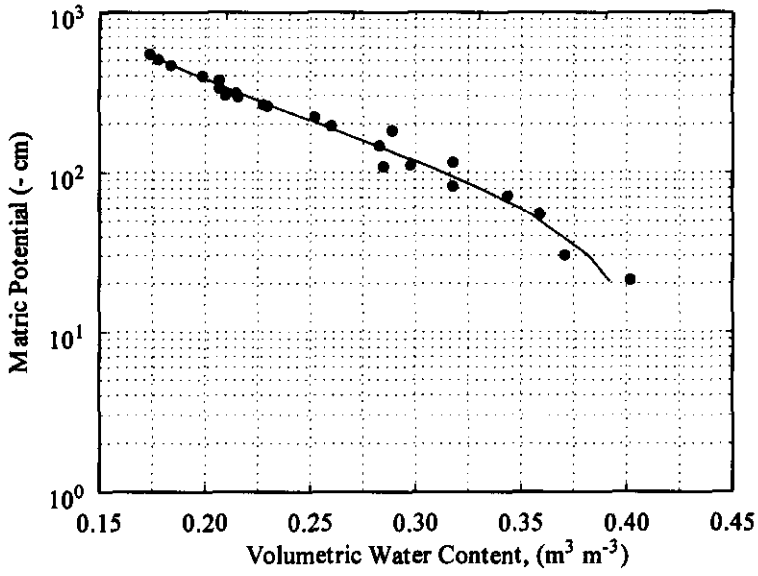

Figure 11. Fitted and observed field-averaged moisture characteristic function for the 100-125 cm depth.

Table 1. A comparison of Fitted Moisture Retention Parameters.

Sample	Depth (m)	Fitted Parameters				Measured K_s (cm s^{-1})
		θ_r	θ_s	α (cm^{-1})	n	
1[a]	1.5	0.0187	0.4131	0.148	1.309	$5.73x10^{-4}$
2	1.5	0.0336	0.3367	0.0211	1.536	$5.73x10^{-4}$
299-E24-95[b]	1.83	0.000	0.3550	0.0061	1.538	$1.40x10^{-4}$
Task 4b[c]	0-0.25	0.007	0.3566	0.1554	1.724	Not measured
	0.25-0.50	0.007	0.3863	0.0741	1.595	Not measured
	0.50-0.75	0.029	0.4215	0.0381	2.468	Not measured
	0.75-1.0	0.035	0.4083	0.0355	2.036	Not measured
	1.0-1.5	0.024	0.3980	0.0290	2.497	Not measured
Task 4c[d]	0-0.25	0.00	0.3172	0.0015	2.024	$8.37x10^{-4}$
	0.25-0.50	0.00	0.4163	0.0162	1.400	Not measured
	0.50-0.75	0.00	0.4164	0.0139	1.419	Not measured
	0.75-1.0	0.00	0.4403	0.0256	1.303	Not measured
	1.0-1.25	0.00	0.4089	0.0127	1.433	Not measured
	Plot Avg.	0.00	0.4117	0.015	1.390	Not measured

(a) Khaleel and Freeman (1995), from the former Grout Site, on the east side of the 200E Area.
(b) Khaleel et al., (1995), one of 15 repacked, 5.1-cm diameter cores.
(c) Surface sediments values are plot averages for each depth interval with 24 samples.
(d) This experiment, values are plot averages for each depth interval with 24 samples.

parameters fitted for each depth. The van Genuchten parameters θ_r, α, n, and θ_s were all fitted and are summarized in Table 1. Table 1 also compares these results with those from the surface sediments and from a set of independent measurements conducted on cores.

The results from this study (Task 4c) compare reasonably well with the previous results, falling within the range of values observed on samples 1 and 2 from the former Grout Site (Khaleel and Freeman, 1995). However, the fitted parameters suggest soil of a somewhat finer texture than expected for this site. As further verification of the field-measured properties, soil samples were taken from the pit on completion of the infiltration experiments and an analysis of particle sizes performed in the laboratory. Results of the analysis show a mean distribution 70.6% sand, 17.7% silt and 11.6% clay. The high silt and clay content may explain the low values of n and α observed in this study.

Solute Transport Parameters

Figure 12 shows the TDR-measured relative mass flux, M(t), at L=0.25 m. The variability in transport, even at such a shallow depth is clear. This behavior is consistent with the variability in water flux density and K_s observed at the surface.

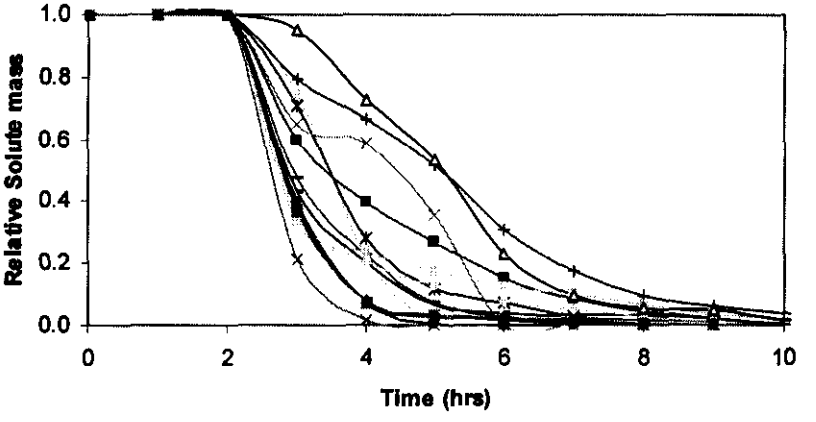

Figure 12. Spatial variability in TDR-measured relative solute mass flux at a depth of 0.25 m. Twenty four measurements were obtained along a 5 m transect at 0.20 m intervals.

Figure 13 shows an example of the observed data, and the fitted results obtained with the CDE and CLT transport models. In both cases, the models diverge from the observed data at late time ($t \geq 5$ hrs), leading to a higher predicted dispersion coefficient and travel-time variance. Although the discrepancy is not large, it suggests that these models may not be the most appropriate for predicting field-scale solute transport.

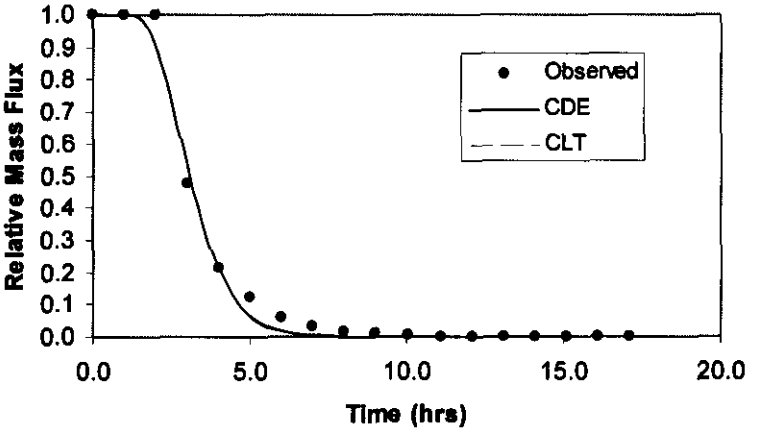

Figure 13. Example of $M_L(t)$ and the least squares fit of the convective dispersion equation (CDE) and convective lognormal transfer function (CLT) models.

Figure 14 shows an example of the solute travel time probability density function obtained by taking the first derivative of an M(t) curve. Theoretically, the area under $f_L(t)$ should equal exactly 1.0, provided all of the solute mass applied can be accounted for. In most cases, the value was less than 1.0, suggesting that either some of the solute may have moved beyond the measurement depth without being detected (preferential flow); moved laterally; or experienced some other delay in vertical transport. The long tails observed in Figure 12 support the hypothesis of delayed vertical movement. The results of the transport analysis are summarized in Table 2.

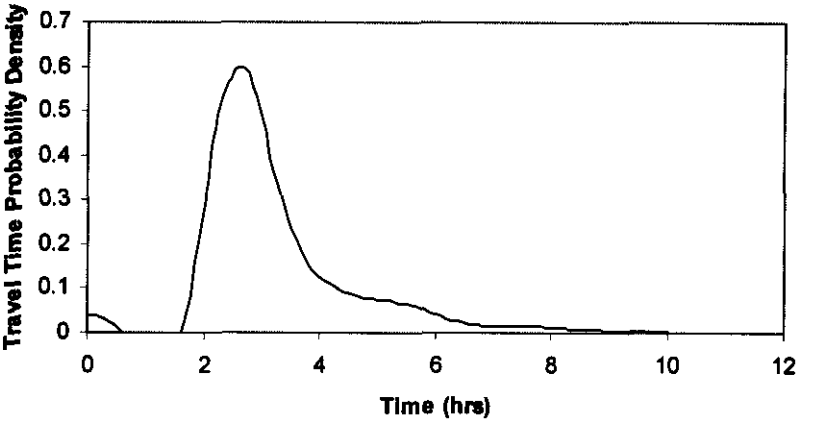

Figure 14. Solute travel time probability density function obtained by taking the first time derivative of the relative mass flux shown on Figure 13.

Table 2. Parameter estimates for the upper Hanford Formation from field transport experiments. D and v are the dispersion coefficient and pore water velocity of the convective dispersion equation (CDE); μ_p and σ_p are the population mean and variance of the convective lognormal transfer function (CLT); M_1 and M_2 are the expected travel time and travel time variance obtained by moment analysis; and λ_{CDE}, λ_{CLT} and λ_{MOM} are the dispersivities obtained by the three techniques.

		CDE				CLT			MOM		
L	θ_e	D	v	λ_{CDE}	t_L	μ_p	σ_p	λ_{CLT}	M_1	M_2	λ_{MOM}
m	m^3/m^3	Cm^2/h	cm	cm	h	h	h^2	cm	h	h^2	cm
0.25	0.331	10.79	8.14	1.32	3.07	3.23	0.106	1.39	3.43	1.98	2.03
0.50	0.312	11.74	8.64	1.36	5.78	5.95	0.056	1.44	6.03	3.88	2.67
0.75	0.294	42.40	9.18	4.62	8.17	8.29	0.12	4.79	8.44	9.59	5.05
1.00	0.283	66.61	9.54	6.98	10.48	10.75	0.137	7.32	10.85	16.88	7.17
1.25	0.283	66.04	9.54	6.92	13.10	13.78	0.112	7.44	13.95	24.32	7.81

Generally the CDE and CLT models predict the same average transport velocity, but differ in their predicted dispersion or degree of solute spread. A useful comparison of the CDE and CLT

has been given in terms of the existence or absence of correlated travel times with depth (Jury, 1982). For uncorrelated flow, the CDE predicts a linear increase in travel time variance with depth. For correlated flow, the CLT predicts an increase in travel time variance as the square of the distance. By comparing the results of the analysis, conclusions can be made on the appropriateness of different transport models.

The CDE, CLT and moment analysis shows reasonably good agreement in the transport parameters. All three methods predict essentially the same mean travel times to the depths of interest. Travel time was linear with depth, except for a small decrease (increase in v) that corresponded to a decrease in θ_e. This is probably due to increasing coarseness of the soil with depth.

The change in travel time variance with depth show that M_2 at the 0.50-m depth was 2 times that at the 25-cm depth, while M_2 at 100 cm was 4 times that at 50 cm. The 2x increase from 25 cm to 50 cm does not meet the criterion for correlated flow required by the CLT model but satisfies the 2x increase required for uncorrelated flow described by the CDE (Jury, 1982). In general, a 4x increase in variance requires constant velocity with depth, which does not exist initially, but becomes more so at greater depth. A CDE approach would be appropriate for modeling transport in this soil.

Table 2 also shows generally good agreement in the dispersivities obtained with the two models. However, λ_{MOM} was almost double the α_{CDE} and α_{CLT}, particularly at the smaller depths. The higher λ_{MOM} values reflect the larger travel time variance used in their derivation. Nevertheless, the range $1.32 \geq \lambda \geq 2.67$ cm observed in the shallow depths is comparable to the $0.01 \geq \lambda \geq 2.0$ cm reported for unconsolidated cores by Freeze and Cherry (1979). Another point worth noting is the increase in λ with depth down to 0.75 m, after which it essentially becomes constant. This result is consistent with the concept of a scale-dependent dispersivity and suggests for vertical transport in this soil, the scale over which λ becomes constant may be smaller than predicted from literature values obtained from horizontal transport in the saturated zone. With respect to upscaling and the extrapolation of data from one site to the next, these observations suggest a need for site-specific transport measurements at a range of scales and concomitant measurements of $\psi(\theta)$ in the same transport volume.

Summary and Conclusions

Field-measured hydraulic properties have been shown to be more representative of natural flow and transport processes but are generally difficult to measure. In this study, it was shown that vertically-installed time domain reflectometry (TDR) probes, when combined with a sprinkler-imposed constant flux system, can be used to measure the spatially variable hydraulic properties. The infiltration rate, when combined with the measured equilibrium water content and matric potential, provide direct measurements of the moisture characteristic function, $\psi(\theta)$, and the unsaturated hydraulic conductivity function, $K(\theta)$ at the field scale.

A series of infiltration tests were conducted at the site of the proposed LLTWDS during the summer of 1998. Measurements of K_s were made using a tension infiltrometer. The spatial distribution of K_s and water flux density determined from water storage measurements appear to be related to micro-topogrpahy and root channels.

Saturated water content and the other van Genuchten parameters, α, n, and θ_r were fitted with the program RETC. The goodness of fit was generally good with coefficients of determination (r^2) all exceeding 0.95.

The fitted mean saturated water content ranged from 0.3172 $m^3\ m^{-3}$ to 0.440 $m^3\ m^{-3}$, increasing slightly with depth. Neither the fitted α nor n showed any dependence on depth. Both parameters were less variable than those observed for the surface sediments.

Solute transport parameters were also obtained field measurements using KCl as a tracer. Analysis of the data using the traditional CDE and the less common CLT models, as well as with moment analysis, showed reasonably good agreement in the transport parameters. The three methods predicted the same mean travel times. Fitted dispersivities also showed good agreement between methods and are within the range observed on unconsolidated cores. Dispersivity also increased with depth down to 0.75 m, after which it essentially became constant. This result suggests a scale-dependent dispersivity, which in this soil appears to be somewhat smaller than predicted from measurements in the saturated zone.

This test has resulted in a data set that can be used the development of a catalogue of hydraulic and transport properties, one that will be amenable to geostatistical analysis and will facilitate the testing of upscaling theories. Comparisons of the data from this study with those from previous studies show remarkable similarity.

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APPENDIX D

Physical and Hydraulic Measurements of FY1998 Clastic Dike Samples

Physical and Hydraulic Measurements of FY 1998 Clastic Dike Samples

MJ Fayer and JS Ritter
19 March 1999

Introduction

Pacific Northwest National Laboratory (PNNL) assists the Lockheed Martin Hanford Company (LMHC) in designing and assessing the performance of disposal facilities for radioactive wastes stored in single and double shell tanks at the Hanford Site. To predict contaminant migration from these facilities requires estimates of the physical and hydraulic properties of sediments within the vadose zone beneath and around the disposal facility. An unusual feature of the Hanford Site is the presence of vertical sediment structures known as clastic dikes in all of the major lithologies of the unsaturated zone. Fecht et al. (1998)[1] discussed dike structure and etiology and summarized some of the measurements that have been made.

Because clastic dikes could impact the performance of the ILAW disposal site, a work plan was prepared that provides details on the measurement and analysis of clastic dikes (Khaleel 1998)[2]. As part of the work plan, a PNNL task was initiated, entitled "Hydraulic Property Lab Tests for ILAW Samples." One objective of this task is to provide the measured data for clastic dike samples. Samples were obtained in fiscal year 1998 for characterization. The objective of this letter report is to document the physical and hydraulic properties of the clastic dike samples.

Properties

Physical and hydraulic properties are required for the clastic dike samples and the samples of the surrounding matrix. Multiple measurements of these properties are required to give some estimate of the degree of variability within each geologic material. The properties are:

Particle Size Distribution. Particle size distribution (PSD) refers to the fractions of the various particle-size classes (e.g., the fraction of particles with diameters between 1 and 2 mm).

Particle Density (ρ_p). Particle density is the mass of the sediment or construction material particles per unit volume of the same sediment or material. This property is used to relate the bulk density to the porosity.

Bulk Density (ρ_b). Bulk density is the mass of oven-dry material per unit bulk volume. The unit bulk volume is the combined volume of material, water, and air prior to oven drying.

Porosity (ϕ). Porosity is the volume of voids per unit bulk volume.

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[1] Fecht, KR, KA Lindsey, BN Bjornstad, DG Horton, GV Last, and SP Reidel. "An atlas of clastic injection dikes of the Pasco Basin and Vicinity," BHI-1103 Draft A, Bechtel Hanford Inc., May 1998.

[2] Khaleel R, January 1998. "Work plan for measurement and analysis of hydraulic properties for clastic dikes and the ILAW Borehole No. 1 sediment samples," Fluor Daniel Northwest, Inc., P.O. Box 1050, Richland, Washington.

Water Retention. Water retention refers to the retention of water by the sediment at various matric potentials. Mathematical functions are fit to the retention data and the resulting parameters are used directly in computer models for predicting water and contaminant movement. Numerous functions are available, but the van Genuchten function is most commonly used:

$$\theta = \theta_r + (\theta_s - \theta_r)\left[(1 + (\alpha h)^n\right]^{-m}$$

where θ_s = saturated water content (cm^3/cm^3)
θ_r = residual water content (cm^3/cm^3)
h = matric potential (-cm)
α, n, m = empirical fitting parameters (α units are 1/cm; n and m are dimensionless)

Typically, m is approximated as $m = 1 - 1/n$

Saturated Hydraulic Conductivity (K_s). Saturated hydraulic conductivity is the proportionality constant in the Darcy equation that relates the flux density to a unit potential gradient.

Unsaturated Hydraulic Conductivity [$K = f(\theta, \psi)$]. Unsaturated hydraulic conductivity is the proportionality factor in the Richards equation that relates the flux density to a unit potential gradient at a specific water content. Because the water content varies in the unsaturated zone, the unsaturated conductivity varies also.

Mathematical functions are used to represent the unsaturated conductivity data; these functions are typically estimated using the water retention functions and saturated conductivity. When measured unsaturated conductivity values are available, the conductivity and retention data can be fit to optimize both the retention and conductivity functions. Several functions are available, but the Mualem conductivity function is most commonly used (in conjunction with the van Genuchten retention function, assuming $m = 1 - 1/n$):

$$K = K_s \frac{\left\{1 - (\alpha h)^{n-1}\left[1 + (\alpha h)^n\right]^{-m}\right\}^2}{\left[1 + (\alpha h)^n\right]^{\ell m}}$$

The K_s value and the pore interaction term (ℓ) are the only requirements for this model. The parameter ℓ is typically assigned a value of 0.5.

Clastic Dike Samples

In March 1998, grab samples were collected from clastic dikes near the towns of Touchet and Lowden, WA (sites identified by Fecht et al. as No. 64 Touchet Road and No. 76 West Lowden). These samples were processed only for particle density and size distribution because of their small size and disturbed nature.

In September 1998, core samples were collected from a clastic dike and surrounding matrix at the Goose Egg site described by Fecht et al. (1998); this site is 6.3 km south-southwest of the ILAW Disposal Site. Two-foot long core liners were constructed from 3.0 in. ID PVC. One end of each liner was sharpened and placed on selected spots, either on a dike or the matrix. A sledge hammer was used to sink the liner into the sediment. The liners did not penetrate very easily and we could see broken, loose material on the top of the sample. The liners were brought back into the laboratory and sectioned into 6-in. lengths, starting with the sharpened end, which was deepest and least affected by the disturbance at the top of the liner. A total of seven undisturbed sections of these lined cores were identified as suitable for testing. All cores were taken from near surface (< 1 m) deposits within 10 m of Army Loop Road. Table 1 lists the sample numbers, depths, and diameters.

Methods

The core samples were tested with the multistep and steady-state methods, then sectioned for the tests of particle size distribution, particle density, and water retention using pressure plates and vapor adsorption. The cores were prepared for the multistep and steady-state tests according to the procedures described by Fayer et al. (1998)[3].

Procedures

Table 2 lists the procedures used to analyze the samples. Additional details for each procedure are discussed below. These additional details are almost exactly the same as those used by Fayer et al.

Particle Density. Two replicates of the particle density test were performed using the pycnometer method (Blake and Hartge 1986a). The Touchet and Lowden sample size was 10 g. For the Goose Egg samples, the entire core was homogenized following the bulk density test. Of this loose material, 8 to 28 g was used for the particle density test. The only deviation was for sample 4A. Because it was so heterogeneous, sample 4A was sub-sampled in three distinctly different regions. Each subsample was tested for particle density.

[3] Fayer MJ, AL Ward, JS Ritter, and RE Clayton, 1998. "Physical and hydraulic measurements of FY 1998 borehole cores," Letter Report to Mr. Fred Mann, Fluor Daniel Northwest, September 10, 1998.

Table 1. Clastic dike samples analyzed in fiscal year 1998.

Sample ID	Description of Sample	Core Internal Diameter in.	Location of Clastic Dike
1h	infill	na	Touchet
2h	infill	na	Touchet
3h	infill	na	Touchet
4h	infill	na	Touchet
5h	silt/clay skin	na	Touchet
6h	silt/clay skin	na	Touchet
7h	infill	na	Lowden
8h	matrix	na	Touchet
1	matrix, some dike/sand bands	3.0	Goose Egg Hill Site
2A	matrix	3.0	Goose Egg Hill Site
2B	matrix	3.0	Goose Egg Hill Site
3A	dike/matrix mix	3.0	Goose Egg Hill Site
3B	dike/matrix mix	3.0	Goose Egg Hill Site
4A	mostly dike	3.0	Goose Egg Hill Site
4B	mostly matrix, some dike	3.0	Goose Egg Hill Site

Table 2. Procedures for measuring physical and hydraulic properties.

Number	Title	Comment
PNL-MA-567, SA-2	Sieve Procedure	For materials > 50 μm effective diameter
PNL-MA-567, SA-3	Particle-Size Analysis	Hydrometer method for materials < 50 μm effective diameter
PNL-MA-567, SA-4	Constant Head Hydraulic Conductivity (HC)	Laboratory measurement for materials with HC> 10^{-6} cm/s
PNL-MA-567, SA-5	Falling Head--Saturated Hydraulic Conductivity (HC)	Laboratory measurement for materials with HC <10^{-6} cm/s
PNL-MA-567, SA-6	Water Retention Procedure	Laboratory method for core or bulk sample (saturation to air dry)
PNL-MA-567, SA-7	Water Content	Necessary for constant head hydraulic conductivity
PNL-MA-567, SA-8	Clod Density/Bulk Density	Necessary for constant head hydraulic Conductivity
PNL-MA-567, SA-9	Determining Particle Density	Necessary for constant head hydraulic conductivity
Klute (1986)	Water Retention: Laboratory Methods	Pressure plate and vapor adsorption methods
Klute and Dirksen (1986)	Hydraulic Conductivity and Diffusivity: Laboratory Methods	Steady-state flux control method for unsaturated conductivity
Eching and Hopmans (1993)	Unsaturated Hydraulic Properties	Multistep outflow method for unsaturated conductivity and water retention estimation

Particle Size Distribution. The PSD test was performed using the methods ASTM 1985 and Gee and Bauder (1986). The Touchet and Lowden sample size was 40 g. For the Goose Egg samples, the entire core was homogenized following the bulk density test. Of this loose material, 80 g was used for the particle size distribution test. The only deviation was for sample 4A. Because it was so heterogeneous, sample 4A was sub-sampled in three distinctly different regions (as mentioned previously). Each subsample was tested for particle density.

Bulk Density. A single measurement of bulk density was made for each intact Goose Egg core. Following the conductivity test, the sediment in the core was oven dried and weighed. Dividing this weight by the volume of the core yielded the bulk density, as per the method of Blake and Hartge (1986b).

Porosity. A single estimate of porosity was made using the bulk density of intact Goose Egg cores and the average particle density. The formula used was $\phi = 1 - \rho_b / \rho_s$ (Freeze and Cherry 1979).

Water Retention. Water retention data for the Goose Egg samples were measured using the pressure-plate extraction and vapor equilibrium methods described by Klute (1986). The tests were conducted on the subsample created after the bulk density core was homogenized. For sample 4A, separate tests were conducted for the three subsamples mentioned previously. Additional retention measurements were obtained during the unsaturated conductivity tests.

Saturated Hydraulic Conductivity. Saturated hydraulic conductivity for the Goose Egg cores was measured on the intact cores prior to the unsaturated conductivity tests using the method of Klute and Dirkson (1986). The measurement of saturated conductivity was conducted several times to verify that a steady value of conductivity was achieved.

Unsaturated Hydraulic Conductivity. The multistep and steady state methods were used to measure unsaturated conductivity of the Goose Egg cores. Both methods were performed on the same core using the same sensor locations. The multistep method, which is an improvement of the one-step method of Kool et al. (1985 a,b), provides θ-ψ pairs and cumulative outflow. These data were used in conjunction with the SFOPT program (a modified version of the MULSTP program of Eching and Hopmans 1993) to determine the optimal set of hydraulic parameters.

Because several tests must be performed on the same core, the following test sequence was established: saturated conductivity, multistep unsaturated conductivity, and steady state unsaturated conductivity. Following the saturated conductivity test, the cores were re-wetted to saturation and analyzed using the multistep method. After equilibrating the cores with zero pressure at the lower plate, three pressure increments were used that were equivalent to head values of 10.9, 71, and 315 cm. Following the multistep test, the cores were rewetted and tested using the steady-state method.

Results

When opened for the bulk density measurements, several cores had noticeable layering. The most dramatic layering occurred in sample 4A, in which it appeared that most of the sample was fine-textured dike material. Three sections of this core were sub-sampled for individual tests of particle density and size distribution, and water retention. These samples are referred to as 4A1, 4A2, and 4A3 in Tables 3, 4, 6, and 7.

Table 3 shows that particle density varies between 2.65 and 2.73 g/cm^3 for the various infill, clay skin, and matrix materials. There appears to be no distinction between infill, skin and matrix in the two locations studied. The particle densities of the three subsamples of 4A are identical.

Table 4 shows the results for both the sieve and hydrometer methods. In all samples, the gravel content was less than 1%. Figure 1 shows all of the data combined to highlight the degree of variability in particle size distribution. Included in Figure 1 are the distributions for dune sand from the southern edge of the ILAW site and sandy gravel from the Grout spoils pile. The clay skins and dike material have the finest particle size distribution. The infill material has a predominance of sand particles between 100 and 200 μm diameter, as does dune sand. Almost all of the infill material particles sizes are less than 500 μm, whereas about 20% of the dune sand particles are greater than 500 μm. The particle size distributions of the subsamples within 4A showed sand contents varying from 42 to 90%. These differences help to explain the water retention differences discussed below.

Table 5 shows that the bulk density ranged from 1.46 to 1.57 g/cm^3. Table 5 also shows the porosity data, which ranged from 0.424 to 0.464. These ranges are smaller than the variations observed by Fayer et al. for the FY 1998 ILAW borehole samples.

Table 6 shows the pressure plate data for four pressures. As expected, samples that had dike material had higher water contents at any given pressure. Within 4A, water content varied between 0.04 and 0.155 cm^3/cm^3 at a matric potential of -530 cm, and 0.024 and 0.089 cm^3/cm^3 at a matric potential of -4080 cm. These differences are large and will make it challenging to represent the properties of the entire core with the properties measured at discrete locations.

Table 7 shows that the vapor adsorption data covered a range of matric potential from -11,600 cm to as dry as -1,460,000 cm. The associated water contents ranged from 0.08 to 0.004 g/g. Most of the measurements are in the very low potential range. There are very few measurements in the range from -10,000 to -100,000 cm.

Table 8 shows the saturated hydraulic conductivity values for the Goose Egg Hill cores range from 1.8×10^{-4} to 5.4×10^{-3} cm/s. The matrix samples generally had the highest values. The results in Table 8 are consistent with other measurements. For the matrix at their dike sites, Fecht et al. measured K_s values that mostly ranged from 1 to 4×10^{-3} cm/s. The one sample that was different had a K_s value of 2×10^{-5} cm/s. This particular sample was measured with a different technique (i.e., the unsaturated flow apparatus, or UFA). For samples with various amounts of dike material and clays skins, Fecht et al. measured K_s values ranging from 5×10^{-5}

to 9 x 10^{-4} cm/s. The values in Table 8 fall within this range. Most of the values also fall within the lower portion of the range of values reported by Fayer et al. for the FY 1998 ILAW borehole samples. The lowest value in Table 8 (1.8 x 10^{-4}) is only slightly lower than the lowest ILAW borehole value (2.6 x 10^{-4}).

Table 9 shows the parameter estimates and fitting statistics determined using the SFOPT program with data from the multistep test. The parameter α varied from 0.0092 to 0.0839, a factor of about 10, and the parameter n ranged from 1.33 to 2.49. These ranges seemed small given the presence of fine-grained zones in some samples, but the statistics indicated reasonable fits to the data.

Some additional fitting tests were performed. To demonstrate the impact of the location of the tensiometer, sample 2A was refitted using the upper rather than lower tensiometer data. Of all the samples, sample 2A had the greatest differences in tension (about 40 cm) between the two tensiometer locations. The refitting reduced α by half (to 0.0342 cm^{-1}) and increased n by 33% (to 2.63). The R^2 was actually improved (from 0.747 to 0.894) and the mass error was reduced (from 1.51 to 0.59%). Outflow data represent the response of the entire sample, whereas the matric potential data are derived from a sample volume that could almost be considered a point. An assumption of the fitting process is that the material is homogeneous. With clastic dikes, the samples are not homogeneous, so point measurements are more likely to deviate from the expected values. The results from refitting sample 2A using the upper tensiometer data illustrate the parameter differences that could be encountered by using tension measurements elsewhere in the column. The matric potential sets from the other samples were much closer in value, so the differences in fitting results (between using the upper versus lower tensiometer data) should not be so large.

An additional fitting exercise was performed to demonstrate the impact of weighting the data. In this exercise, the matric potential and water retention weights were progressively reduced from 1.0 to 0.0 for sample 2A using the upper and lower tensiometer data. Figure 2 shows the sensitivity of the parameter estimates to the weighting used. Because tension is a point measurement, we may want to consider reducing the weight given to such data. One solution may be to weight the tension data according to the fraction of the sample volume that it measures.

The same fitting exercise using variable weighting was also performed for sample 3A using just the lower tensiometer data. The results were similar for most weights. The only exception was a weight of 0.0, which caused the program to terminate without a solution. In this case, the outflow data were not sufficient to allow the program to find an optimal solution.

Table 10 shows the θ-ψ-K triplets that were generated using the steady state method. All of the measurements are at matric potentials above -54 cm. Even so, unsaturated conductivity values were 1 to 2 orders of magnitude less than the saturated values. Because the potentials were so high, the water contents were also relatively high.

Summary

Samples were collected from clastic dike sites in the Columbia Basin in September 1998 and analyzed for physical and hydraulic properties. Eight disturbed samples were obtained from two sites in the towns of Touchet and Lowden, Washington. Seven undisturbed cores were obtained from a site near Goose Egg Hill, which is located 6.3 km SW of the ILAW site. Testing included particle density, particle size distribution, bulk density, water retention, and saturated and unsaturated conductivity. Saturated conductivity values were similar to values reported by Fecht et al. for other clastic dike samples. The samples exhibited some variability but not as much as reported by Fayer et al. for the ILAW borehole samples. The impacts of tensiometer location and data weighting were demonstrated.

Figure 2. Effect of data weighting on prediction of parameters α and n.

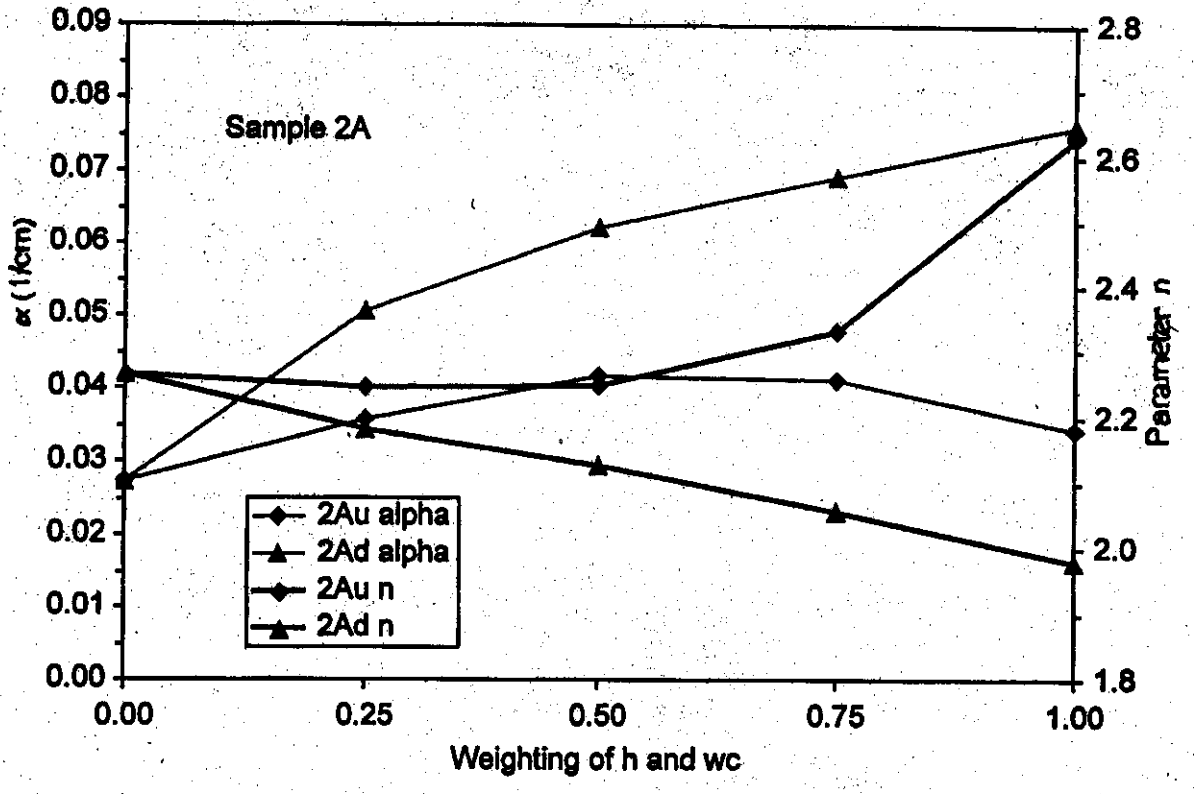

Table 3. Particle density

Sample	Particle Density rep 1 (g/cm^3)	Particle Density rep 2 (g/cm^3)	Average Particle Density, g/cm^3
1h	2.668	na	2.67
2h	2.677	na	2.68
3h	2.708	na	2.71
4h	2.698	na	2.70
5h	2.695	na	2.70
6h	2.651	na	2.65
7h	2.719	na	2.72
8h	2.681	na	2.68
1	2.729	2.734	2.73
2A	2.707	2.709	2.71
2B	2.713	2.709	2.71
3A	2.720	2.720	2.72
3B	2.722	2.722	2.72
4A1	2.717	2.730	2.72
4A2	2.720	2.727	2.72
4A3	2.720	2.727	2.72
4B	2.713	2.733	2.72

Table 4. Particle size distribution

Sample 1h		Sample 2h		Sample 3h		Sample 4h	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	100.0	2000	100.0	2000	100.0	2000	100.0
1000	100.0	1000	100.0	1000	100.0	1000	100.0
500	100.0	500	99.9	500	100.0	500	100.0
250	99.9	250	99.9	250	92.3	250	99.9
106	87.5	106	98.3	106	44.7	106	85.6
75	66.5	75	91.7	75	34.7	75	60.6
53	40.3	53	58.2	53	22.8	53	34.0
52.2	37.5	49.0	60.0	54.1	17.5	52.7	30.0
31.0	25.0	30.8	27.5	31.6	12.5	31.1	20.0
17.3	17.5	17.4	15.0	17.4	10.0	17.3	12.5
10.0	15.0	10.1	12.5	10.1	7.5	10.1	10.0
7.1	12.5	7.2	10.0	7.1	7.5	7.1	10.0
5.8	12.5	5.8	10.0	5.9	5.0	5.8	10.0
5.1	12.5	5.1	10.0	5.1	5.0	5.0	10.0
1.5	7.5	1.5	7.5	1.5	5.0	1.5	7.5

Sample 5h		Sample 6h		Sample 7h		Sample 8h	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.9	2000	100.0	2000	99.8	2000	100.0
1000	99.9	1000	100.0	1000	98.3	1000	99.9
500	99.9	500	100.0	500	90.3	500	99.7
250	99.9	250	100.0	250	42.3	250	99.4
106	98.0	106	99.7	106	18.0	106	93.7
75	94.3	75	99.4	75	15.7	75	81.4
53	84.9	53	97.8	53	13.3	53	48.7
46.6	75.0	44.2	95.0	54.5	12.5	50.6	47.5
27.9	62.5	26.4	85.0	31.5	12.5	31.1	22.5
15.9	47.5	15.3	67.5	17.4	7.5	17.5	10.0
9.6	32.5	9.2	52.5	10.1	7.5	10.2	7.5
6.8	27.5	6.7	42.5	7.1	6.2	7.2	7.5
5.6	25.0	5.5	37.5	5.8	5.0	5.9	7.5
4.9	22.5	4.8	35.0	5.1	5.0	5.1	7.5
1.5	10.0	1.4	17.5	1.5	5.0	1.5	5.0

Table 4. (cont.) Particle size distribution

Sample 1		Sample 2A		Sample 2B		Sample 3A	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.7	2000	100.0	2000	100.0	2000	100.0
1000	98.3	1000	100.0	1000	100.0	1000	100.0
500	93.2	500	99.9	500	99.9	500	99.6
250	83.5	250	95.7	250	96.1	250	89.8
106	38.9	106	17.5	106	12.0	106	35.1
75	30.8	75	7.3	75	5.9	75	18.4
53	25.6	53	4.5	53	4.2	53	10.5
51.3	24.8	56.7	5.6	56.6	6.0	55.1	11.3
30.7	17.9	32.9	4.8	32.8	5.0	32.6	5.6
17.2	13.8	18.0	4.4	18.0	4.0	18.0	4.4
10.1	10.6	10.4	4.0	10.4	3.5	10.4	4.0
7.2	8.8	7.4	3.8	7.4	3.5	7.4	3.5
5.9	8.8	6.0	3.8	6.0	3.5	6.0	3.1
5.1	8.5	5.2	3.5	5.2	2.8	5.2	2.8
1.5	4.8	1.5	3.5	1.5	2.5	1.5	2.5

Sample 3B		Sample 4A1		Sample 4A2		Sample 4A3	
Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter	Particle Diameter (μm)	% Less Than Diameter
2000	99.7	2000	100.0	2000	99.9	2000	99.8
1000	99.4	1000	99.9	1000	99.8	1000	99.6
500	98.6	500	99.8	500	99.7	500	99.4
250	90.4	250	93.6	250	98.2	250	97.1
106	44.4	106	13.9	106	71.5	106	60.3
75	25.6	75	9.6	75	63.0	75	50.6
53	18.8	53	7.4	53	56.1	53	42.8
53.2	18.8	56.0	7.5	45.2	47.0	46.9	41.3
31.8	11.3	32.4	6.9	28.3	34.1	28.7	31.3
17.7	7.5	17.9	5.6	16.2	25.7	16.5	22.5
10.3	6.5	10.3	4.8	9.6	21.3	9.8	16.5
7.3	5.0	7.3	4.0	nd	nd	7.0	15.0
6.0	5.0	6.0	3.8	5.7	13.8	5.8	12.5
5.2	4.8	5.2	3.8	5.0	13.8	5.0	12.3
1.5	3.5	1.5	3.1	1.5	7.5	1.5	7.5

Table 4. (cont.) Particle size distribution

Sample 4B	
Particle Diameter (μm)	% Less Than Diameter
2000	100.0
1000	99.8
500	99.1
250	64.8
106	8.1
75	6.0
53	4.9
56.3	6.3
32.8	4.4
18.0	3.8
10.4	3.1
7.4	3.1
6.0	2.8
5.2	2.8
1.5	2.5

Figure 1. Summary of particle size distributions for all samples, along with dune sand from the ILAW site and sandy gravel taken from the Grout Spoils pile.

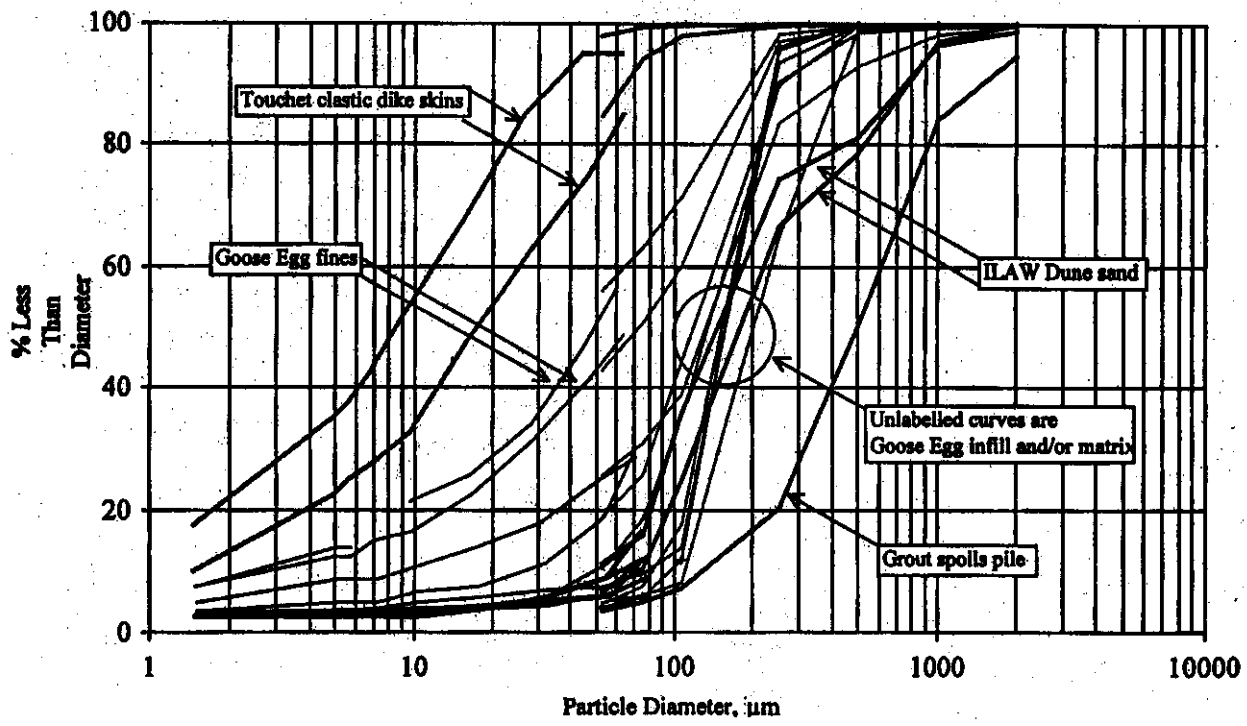

Table 5. Core volume, bulk density, and porosity data for the core samples.

Sample	Core Volume (cm^3)	Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)
1	693	1.57	0.424
2A	684	1.50	0.446
2B	693	1.51	0.443
3A	689	1.46	0.464
3B	698	1.52	0.443
4A	698	1.49	0.454
4B	684	1.57	0.425

Table 6. Water retention data from the pressure plate technique for the core samples.

1		2A		2B		3A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
530	0.1001	530	0.0233	530	0.0339	530	0.0363
1010	0.1088	1010	0.0210	1010	0.0311	1010	0.0322
2040	0.0701	2040	0.0216	2040	0.0243	2040	0.0288
4080	0.0549	4080	0.0099	4080	0.0209	4080	0.0219

3B		4A1		4A2		4A3	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
530	0.0678	530	0.0401	530	0.155	530	0.133
1010	0.0740	1010	0.0363	1010	0.149	1010	0.116
2040	0.0585	2040	0.0302	2040	0.125	2040	0.0901
4080	0.0450	4080	0.0242	4080	0.0887	4080	0.0722

4B	
Matric Potential -cm	Water Content g/g
530	0.0298
1010	0.0258
2040	0.0212
4080	0.0162

Table 7. Water retention data from the vapor adsorption technique for the core samples (measurements at potentials above -10,000 cm are uncertain and should be used with caution).

1		2A		2B		3A	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
28182	0.033	258592	0.018	11648	0.022	121667	0.012
693204	0.012	262464	0.0073	22040	0.017	516971	0.007
1433126	0.009	533191	0.0071	286323	0.008	1018703	0.006
		891172	0.0059	1446643	0.004	1444671	0.005
		1442563	0.0045				

3B		4A1		4A2		4A3	
Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g	Matric Potential -cm	Water Content g/g
98149	0.016	361735	0.010	36699	0.041	19639	0.041
209007	0.011	1233979	0.005	56058	0.036	25367	0.039
326217	0.008	1367281	0.005	992535	0.015	1050295	0.012
1392767	0.005	1459642	0.004	1103810	0.014	1431458	0.010
1450243	0.005			1424506	0.013		

4B	
Matric Potential -cm	Water Content g/g
1395754	0.004
1466263	0.004
1428052	0.004

Table 8. Saturated hydraulic conductivity of the core samples.

Sample	Saturated Hydraulic Conductivity (cm/s)			Average Saturated Hydraulic Conductivity (cm/s)	Method
	Rep 1	Rep 2	Rep 3		
1	5.97E-04	5.97E-04	5.97E-04	5.97E-04	Constant head
2A	4.77E-03	4.97E-03	4.37E-03	4.70E-03	Constant head
2B	3.38E-03	3.06E-03	2.98E-03	3.14E-03	Constant head
3A	3.29E-03	3.58E-03	3.37E-03	3.41E-03	Constant head
3B	1.14E-03	1.14E-03	1.14E-03	1.14E-03	Constant head
4A	1.67E-04	1.96E-04	1.89E-04	1.84E-04	Constant head
4B	5.56E-03	5.40E-03	5.32E-03	5.43E-03	Constant head

Table 9. Parameters and statistics for the van Genuchten function fitted to data from the multistep method using SFOPT (θ_s and K_s were held constant at their measured values; θ_r was estimated for a ψ value of -15,300 cm from the pressure plate and vapor adsorption data; m=1-1/n; l=0.5; matric potential values were from the lower tensiometer; all data were weighted by a factor of 1.0)

Sample	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	R^2	Mass Balance Error, %
1	0.424	0.063	0.0839	1.33	0.878	2.37
2A	0.446	0.019	0.0762	1.98	0.747	1.51
2B	0.443	0.023	0.0741	1.84	0.815	1.47
3A	0.424	0.025	0.0143	2.49	0.985	0.67
3B	0.448	0.050	0.0593	1.54	0.860	1.48
4A	0.454	0.030	0.0092	1.97	0.968	0.79
4B	0.425	0.021	0.0823	2.09	0.836	1.60

Table 10. Water retention and unsaturated conductivity data for each sample during the steady state tests (nd = no data). Matric potential and water content values represent the average of sensors at two depths (approx. 4 and 11 cm) in the sample.

Sample	Matric Potential -cm	Water Content cm^3/cm^3	Unsaturated Hydraulic Conductivity cm/s
1	15.5	0.267	5.4E-5
1	40.2	0.250	2.9E-6
2a	25.6	0.259	2.0E-03
2a	45.3	0.156	1.3E-4
2b	33.9	0.354	1.0E-4
2b	34.2	0.352	1.0E-4
2b	52.6	0.331	3.7E-5
3a	33.3	0.220	2.7E-4
3a	53.9	0.207	8.1E-5
3a	53.3	nd	3.9E-5
3b	13.6	nd	1.5E-5
3b	48.0	0.293	1.4E-5
4a	19.5	0.365	8.9E-6
4a	22.2	nd	9.3E-6
4b	17.5	0.249	4.9E-5
4b	35.6	0.196	2.9E-5

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APPENDIX E

Quality Assurance/Quality Control (QA/QC) Considerations

Quality Assurance/Quality Control (QA/QC) Considerations

This data package is based on data reported in appendices A through D or taken from peer-reviewed, open literature. Data reported in appendices A, C, and D were collected by Pacific Northwest National Laboratories (PNNL), following applicable PNNL QA/QC procedures. Data reported in appendix B were collected by Westinghouse Hanford Company Geotechnical Engineering Laboratory (GEL), following applicable GEL QA/QC procedures.

For analysis of data collected in the laboratory and field and those based on literature, a peer review procedure was established and followed. The peer review members were selected based on their experience and knowledge of specific subject areas. The internal peer review was provided per Fluor Daniel Northwest (FDNW) internal procedures. PNNL provided the Hanford technical review for the data package. A review of the data package was also provided by the Hanford Site Vadose Zone/Groundwater Integration Project. Finally, an external peer reviewer (i.e., Professor L. W. Gelhar, Massachusetts Institute of Technology, Cambridge, MA) has reviewed the data package.

This document was too large to scan as a single document. It has been divided into smaller sections.

Section 5 of 5

Document Information			
Document #	**HNF-5636**	**Revision**	**0**
Title	DATA PACKAGING FOR THE HANFORD IMMOBILIZED LOW ACTIVITY TANK WASTE PERFORMANCE ASSESSMENT: 2001 VERSION		
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Projects			
Other Information			

PNNL-13037

APPENDIX N

Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW-PA)

D. I. Kaplan, WSRC, Aiken, SC
R. J. Serne, PNNL, Richland, WA

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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

Lockheed Martin Hanford Company (LMHC) is designing and assessing the performance of disposal facilities to receive radioactive wastes that are currently stored in single- and double-shell tanks at the Hanford Site. The preferred method of disposing of the portion that is classified as low-activity waste (ILAW) is to vitrify the liquid/slurry and place the solid product in near-surface, shallow-land burial facilities. The LMHC project to assess the performance of these disposal facilities is the Hanford ILAW Performance Assessment (PA) Activity. The goal of this project is to provide a reasonable expectation that the disposal of the waste is protective of the general public, groundwater resources, air resources, surface water resources, and inadvertent intruders. Achieving this goal will require prediction of contaminant migration from the facilities. This migration is expected to occur primarily via the movement of water through the facilities and the consequent transport of dissolved contaminants in the pore water of the vadose zone.

Pacific Northwest National Laboratory (PNNL) assists LMHC in their performance assessment activities. One of the PNNL tasks is to provide estimates of the geochemical properties of the materials comprising the disposal facility, the disturbed region around the facility and the physically undisturbed sediments below the facility (including the vadose zone sediments and the aquifer sediments in the upper unconfined aquifer). The geochemical properties are expressed as parameters that quantify the adsorption of contaminants and the solubility constraints that might apply for those contaminants that may exceed solubility constraints. The common parameters used to quantify adsorption and solubility are the distribution coefficient (K_d) and the thermodynamic solubility product (K_{sp}), respectively. In this data package we approximate the solubility of contaminants using a more simplified construct called the solution concentration limit, a constant value. In future Geochemical Data Packages we will determine whether a more rigorous measure of solubility is necessary or warranted based on the dose predictions emanating from the ILAW 2001 PA and reviewers' comments.

The K_d's and solution concentration limits for each contaminant are direct inputs to subsurface flow and transport codes used to predict the performance of the ILAW system. In addition to the best-estimate K_d's, a reasonable conservative value and a range are provided. We assume that K_d values are log normally distributed over the cited ranges. Presently we do not give estimates for the range in solubility limits or their uncertainty. However we supply different values for both the K_d's and solution concentration limits for different spatial zones in the ILAW system and supply time-varying K_d's for the concrete zone, should the final repository design include concrete vaults or cement amendments to buffer the system pH.

If warranted, more technically rigorous information on uncertainty in the geochemical parameter values and estimates of the changes in parameter values over time will be supplied in future data packages.

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1.0 Introduction

The Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW-PA) examines the long-term environmental and human health effects associated with the planned disposal of the vitrified low-activity fraction of waste presently contained in Hanford Site tanks. Greater than 200,000 m^3 of tank waste has been created as the result of separating nuclear materials from irradiated nuclear fuels. This waste has been stored in 18 underground tank farms. The tank waste is to be retrieved, separated into low-activity and high-level fractions, and then immobilized by private vendors. The high-level fraction, which will be of low volume but contain most of the radionuclides, will be stored at Hanford until a national repository is approved. The low-activity fraction will be disposed as vitrified waste in the Hanford Site 200 East Area.

The design of the ILAW disposal facilities is evolving. Although there are four existing concrete vaults with a total useable volume of about 15,000 m^3 that could be used current design staff are contemplating trench disposal in the 200-E Area of the Hanford Reservation.

The first ILAW performance assessment of the 200 East Area was completed in 1998 and it showed that groundwater transport presents the greatest potential for long-term dose uptake by humans (Mann et al. 1998). Of the numerous radionuclides evaluated in this PA,(included Ac, Am, C, Ce, Cm, Co, Cs, Eu, I, Nb, Ni, Np, Pa, Pb, Pu, Ra, Ru, Se, Sn, Sr, Tc, Th, U, and Zr), the following isotopes were identified as posing the greatest potential health hazard: ^{129}I, ^{237}Np, ^{79}Se, ^{99}Tc, and $^{234/235/238}U$. Kaplan et al. (1995) described the geochemical factors affecting the transport of these radionuclides in the Hanford Site subsurface environment. It was also determined that the outcome of these simulations was very sensitive to the parameter describing the extent to which radionuclides sorbed to the subsurface sediment, the distribution coefficient, K_d. The distribution coefficient is the ratio of the radionuclide concentration associated with the solid phase to that in the liquid phase (described in more detail below). Near the buried vitrified waste, solubility constraints may also control the solution concentrations of contaminants. Thus, this data package contains empirically chosen "solubility limits" for selected contaminants in the regions close to the vitrified waste (see discussions below).

The purpose of this data package is to document the basis for selecting geochemical parameters and input values that will be used in the 2001 version of the ILAW-PA. In addition to the database, the philosophy, approach, and review process are presented.

2.0 Philosophy

2.1. Relation Between Distribution Coefficients and Retardation Factors

The distribution coefficient, or Kd value, is the simplest construct describing contaminant sorption to sediments. It is the ratio of the contaminant concentration sorbed to the solid phase divided by the contaminant concentration in the liquid surrounding the solid phase (Equation 1):

$$Kd = \frac{C_{solid}}{C_{liquid}} \quad (1)$$

where C_{solid} (M kg^{-1}) and C_{liquid} (M L^{-1}) are the concentration in the solid and liquid phases, respectively. It is important to note that sorption, as expressed by Kd values, is normalized by weight. Contaminant transport modelers commonly use Kd values to account for chemical interactions between the contaminant and the sediment. The Kd value is used to define the retardation factor, which is the ratio of the average linear velocity of water (m s^{-1}) divided by the average linear velocity of the contaminant (m s^{-1}). For water saturated systems, the Kd value is related to the retardation factor (Rf, unitless) by the bulk density (ρ_b, kg m^{-1}) and the porosity (η, m^3 m^{-3}) as follows (Valocchi 1984, Bouwer 1991):

$$Rf = \left(1 + \frac{Kd\rho_b}{\eta}\right). \quad (2)$$

The bulk density and porosity terms in Equation 2 convert the weight-normalized Kd value into a volume-normalized value. Note that for partially saturated sediments, the porosity term is replaced by the volumetric water content of the vadose zone sediments.

2.2. "Empirical" Kd Construct

The geochemical behavior of radionuclides in the subsurface will be described for the ILAW-PA using two parameters, the distribution coefficient (Kd value) and the solubility product (K_{sp}) of a specified solid. The distribution coefficient is a thermodynamic construct. It is the ratio of the concentration of a species reversibly adsorbed/exchanged to a geomedia's surface sites divided by the concentration of the species in the surrounding solution. Using uranyl as an example, the definition of a specie-specific Kd as a thermodynamic construct is:

$$K_{d-thermo} = \frac{X{\equiv}UO_2^{2+}}{UO_2^{2+}} \quad (3)$$

where $X{\equiv}UO_2^{2+}$ is the activity of the uranyl species reversibly adsorbed to a specific surface site X, and UO_2^{2+} is the activity of dissolved "free" uranyl species at equilibrium with the surface site

X. Among the many assumptions underpinning $K_{d\text{-}thermo}$ is that adsorption is fully reversible and the presence of adsorbed uranyl species does not influence subsequent adsorption of other dissolved uranyl or other contaminant species. Thus, a single distribution coefficient is used to represent both sorption and desorption of each contaminant species.

However, in order to apply the Kd construct to contaminant transport and performance assessment calculations, the definition of the construct is relaxed. The definition needs to be relaxed for several reasons. In natural systems, a multitude of different types of sorption sites exists. Also, it is very difficult to measure the thermodynamic activity of individual chemical species on the adsorbents' surfaces. Furthermore, the measurement of thermodynamic activities of dissolved species is rarely performed and, as just mentioned for adsorbates on solids, no techniques exist for the measurement of their thermodynamic activity. The parameters that can be readily measured are the total contaminant concentration or radionuclide activity (not to be confused with thermodynamic activity) as opposed to the concentration/radioactivity of each individual species. Thus, the Kd construct, as defined in Equation 3, requires differentiating and quantifying each type of surface site and each solution species. Additionally, spatial variability of the surface sites and groundwater chemistry in natural systems can not practicably be characterized to the degree necessary for the full implementation of species' specific sorption models, such as the triple layer surface complexation model (see Kent et al. 1988 for a good overview and Jenne 1998 for a recent compilation of related articles).

The empirical definition of the Kd value becomes the ratio of the concentration of the complete suite of species [the sum of the total concentration of all species that include the contaminant of interest] sorbed by an assemblage of surface sites, divided by the summed concentration of the suite of species (total concentration) in solution. Again, using uranyl as an example, the definition of the thermodynamic Kd construct would be for a simple system that contained three U(VI) species [UO_2^{2+}, $UO_2(OH)^+$, and $UO_2(OH)_2^0$]:

$$K_{d-therm} = \frac{\sum Adsorbed\ U\ Spieces}{\sum Dissolved\ U\ Spieces} = \frac{X{\equiv}UO_2^{2+} + X{\equiv}UO_2(OH)^+ + X{\equiv}UO_2(OH)_2^0}{UO_2^{2+} + UO_2(OH)^+ + UO_2(OH)_2^0} \quad (4a)$$

where X≡ is an average sorbent site (more than one sorbent site-type is expected in nature). The numerator and denominator in Equation 4a are summed over contaminant species sorbed as well as sorbent sites. The empirical Kd equation would be

$$K_d = \frac{total\ U(VI)\ \ on\ solid}{total\ U(VI)\ in\ solution}. \quad (4b)$$

Among the reasons for selecting the "empirical" Kd construct for the 2001 ILAW-PA, as exemplified by Equation 4b, is

1) the bulk of the existing sorption literature on radionuclide sorption, especially at Hanford can be classified as "empirical" K_d values,

2) under the expected low concentrations of the contaminants in the far field, sorption can be considered to be independent of contaminant concentration and, therefore, K_d is a constant for a given contaminant/geological material combination under identical (geo)chemical conditions,
3) Kd can be used directly in codes used for performance assessments such as the code PORFLO used in past ILAW predictions and the code VAM3DF to be used in future far-field vadose zone transport calculations (see Khaleel 1999), and
4) perhaps most importantly, there is presently no thermodynamically-based conceptual model or numerical code that is robust enough to accurately predict the degree of radionuclide adsorption by natural sediments (see below).

By using site-specific materials in ILAW-funded experiments, it is possible to gather relevant data directly and not to rely on extrapolation from other sediment and aqueous systems. The problem with the rigorous thermodynamic species approach is that, there is presently no numerical or conceptual model developed that is sufficiently robust to predict accurately the degree of radionuclide adsorption by natural sediment (Sposito 1984, Westall 1994, Westall 1986, Wang et al. 1997, Davis et al. 1998). However, mechanistic models provide the necessary paradigms upon which technically defensible "empirical" Kd values must be based. For most of the data used in the ILAW PA geochemical data package, sorption experiments have been conducted with site-specific sediment and site-specific groundwater, which resembles natural vadose-zone porewaters.

Mechanistic models, although impractical for PA purposes, provide the necessary paradigms upon which "empirical" Kd values must be based.

Another aspect of the Kd construct that is typically relaxed when used in contaminant transport calculations is the chemical process that it describes. As pointed out earlier, Equation 3, implies an adsorption or exchange reaction that is reversible. The laboratory Kd measured with complex natural sediments and perhaps complex natural groundwater solutes, often reflect not only adsorption and exchange reactions, but also absorption, specific or somewhat irreversible adsorption, surface complexation, and varying degrees of (co)precipitation reactions. Identifying the processes that govern radionuclide chemical behavior is the single most important task necessary for estimating Kd values for the ILAW PA. Once the dominant geochemical process is identified for a specific geological and chemical environment, the range of "empirical" Kd values can be narrowed. Radionuclide geochemical processes have been ascertained primarily through experiments in which a key parameter is systematically varied, e.g., suspension pH or ionic strength. The trends displayed during these experiments provide key information regarding radionuclide behavior and also shed light on which processes may be controlling the radionuclide interaction between the solid and liquid.

Identifying the processes that govern radionuclide chemical behavior is the single most important task necessary for estimating Kd values. Once the dominant geochemical process is identified for a specific set of environmental conditions, the range of reasonable values for the "empirical" Kd parameter can be narrowed.

The importance of first identifying the dominant geochemical process affecting radionuclide concentrations in the mobile aqueous phase can be illustrated through an

experiment conducted for this project (Kaplan et al. 1998a). In this experiment, as the pH of Hanford sediment-groundwater slurries was increased from pH 8 to 10, U(VI)-K_d values gradually increased from 1.3 to 3.5 mL/g. Above pH 10.5 the amount of U(VI) removed from the aqueous phase increased by >500 fold. The initial increase in K_d between pH 8 and 10 was attributed to increased cation exchange capacity of the sediment. That is, the number of pH-dependent adsorption sites in the natural sediment, which attract cations, increased as the pH increased. The latter more dramatic increase was attributed to (co)precipitation of U(VI) with carbonate phases. These conclusions were supported by independent solubility calculations. What we learn from this particular study is much more than simply the magnitude of the K_d value that should be used as an input parameter to the ILAW PA; we gain a plausible explanation of the processes governing U(VI) removal from solution. As this example illustrates, changes in the dominating chemical processes may account for an appreciable amount of variability in derived K_d values under different geochemical conditions.

2.3. Solubility Constraints

In addition to the K_d construct, solubility products, (both thermodynamically and empirically based), are being used to describe radionuclide geochemical behavior in the ILAW disposal site. The solubility constraints used for conditions where the calculated concentrations of the radionuclides are believed to exceed the solubility of an assumed controlling phase. The selection of controlling solid phases will be based on laboratory experiments and when experimental data are not available, on literature results. If the thermodynamic data for the solid phase is not available from laboratory experiments or the literature, then it will be calculated using chemical speciation and solubility algorithms. Once the solid phase is selected, the upper limit of radionuclide concentration will be calculated with the appropriate background electrolyte composition. If the background electrolyte composition remains essentially constant then the solubility product can be assumed to also be nearly constant. This has lead some PA practitioners to refer to solubility constraints as constants but in reality the solubility constant, K_{sp}, varies with solution chemistry. When radionuclide concentrations exceed the K_{sp}, precipitation can be expected and subsequent radionuclide aqueous concentrations and behavior is controlled by solubility. At concentrations below this limit, the radionuclide concentration will be controlled by the "empirical" K_d construct. When the controlling solid can not be identified but empirical solubility tests clearly indicate that some unidentified phase is controlling solution concentration, then an empirical solubility relationship will be used. This empirical solubility product will include the key solution parameters as independent variables and the empirical solubility product as the dependent variable. In some cases the empirical K_{sp} data may be simplified as a constant concentration limit. This is especially true for the 2001 ILAW PA because little site/waste form/engineered barrier solubility work has been performed that identifies the controlling solids. Recent thermodynamic tabulations by the Nuclear Energy Agency in France may prove to be valuable references. Three books are currently available with data on U, Am, and Tc [see Grenthe et al. 1992, Silva et al.

When the controlling solid could not be identified but empirical solubility tests clearly indicate that some phase is controlling solution concentration, then an empirical solubility relationship will be constructed.

1995, and Amaia Sandino and Osthols 1999, respectively]. Other solubility data for other radionuclides can be found at the NEA web page http://www.nea.fr/html/dbtdb.

2.4. Parametric-K_d Model

When using the constant-K_d model, the retardation factor is a constant for each layer of geologic media (each layer is assumed to have a constant bulk density and water content or saturated effective porosity). The transport equation based on a constant-K_d model does not require knowledge of any other geochemical parameters such as pH or mineralogy, and it is easily solved to determine the solution concentration as a function of time and space. It is the use of the constant-K_d model in retardation factor (Equation 2) that has caused most of the criticism; few natural groundwater pathways are spatially or geochemically homogeneous to the extent that the retardation factor for a species remains constant.

Clearly, the greatest limitation to the constant-K_d approach is that it describes solute partitioning between the aqueous and solid phases for only one set of environmental conditions. Such homogeneity does not exist in nature and therefore greatly compromises the usefulness of the constant. For instance, when the aqueous phase chemistry was varied, Am-K_d values in a Hanford sediment ranged from 0.2 to 53 mL/g, roughly a 200-fold range (Delegard and Barney 1983). Additional variability in the Am-K_d values, albeit less, was observed when slightly different Hanford sediments were used: 4.0 to 28.6 mL/g (Delegard and Barney 1983, Solution 1). Using similar aqueous phases but sediments from around the country, Sheppard et al. (1976) measured Am-K_d values ranging from 125 to 43,500 mL/g. (Interestingly, the lowest K_d in this survey of 12 soils/sediments from DOE-national laboratories was in a Hanford sediment.)

The K_d value in the parametric model varies according to empirically derived relationships with aqueous and solid phase independent parameters. Thus, it has the distinct advantage of being more robust and removes the burden of determining new K_d values for each environmental condition. Because the K_d is a function of a large number of variables, it is common to vary systematically several parameters simultaneously in one experimental study. Factorial design strategies are most often invoked to determine the systematic change resulting from varying the independent variables on the dependent variables, typically the distribution coefficient (Cochran and Cox 1957, Davies 1954, Plackett and Burman 1946, Box and Behnken 1960). Statistical methods commonly used to derive quantitative predictor equations include standard linear or nonlinear regression (Snedecor and Cochran 1967), stepwise regression (Hollander and Wolfe 1973), and adaptive-learning networks (Mucciard et al. 1979, 1980). All these techniques have been used to develop empirical relationships describing K_d values in terms of other variables (Routson and Serne 1972, Serne et al. 1973, Routson et al. 1981, Delegard and Barney 1983).

The empirical predictor equations commonly take the form of a nonlinear multinomial expression. For example, after evaluating solutions consisting of several sodium salts, organic chelates, and acids, Delegard and Barney (1983) came up with the following expression for a americium's K_d value on one particular Hanford sediment:

$$\text{Log } [K_d(Am)] = 2.0 + 0.1[NaOH] - 26.8[HEDTA] + 153.4[HEDTA]^2 \quad (5)$$

The independent parameters and their ranges used to develop Equation 5 were selected to simulate the plume of a HLW emanating from a steel-lined concrete tank into a sediment in the Hanford Site 200 Area Plateau. Numerous salts were found to have no significant effect on americium K_d values and therefore were not included in the expression. Delegard and Barney (1983) also evaluated higher exponential and logarithmic terms and determined that these terms did not improve the predictive capabilities of the expression (i.e., the regression coefficients were not significant at $P<0.05$).

Although the empirical relationships generated from these types of statistical analyses are more powerful than knowledge of individual K_d values, they cannot be used to predict K_d values for conditions beyond the range studied. For example, the parametric-K_d values generated by Delegard and Barney (1983) for the 200 Area Plateau are likely inappropriate for the vitrified LLW plume because the chemistry of the aqueous phase will be appreciably different.

These types of statistical relationships are devoid of causality and therefore provide no certain information on the mechanism by which the radionuclide partitioned to the solid phase, whether it be by adsorption, absorption, precipitation, or coprecipitation. That is, the statistical analyses may suggest a very strong relationship between one variable, for instance pH, and the distribution coefficient, when the actual sorption process may be controlled by iron oxide adsorption. Because pH and iron oxide surface charge are covariant, a statistical relationship could be calculated, suggesting that sorption is solely caused by pH.

The parametric-K_d model can be used in the retardation factor term (Equation 2). When used in a transport equation, the transport code must also keep track of the current value of the independent variables (such as [NaOH] and [HEDTA] for the examples described above; Equation 5) at each point in space and time. Keeping track of other variables is necessary to continually update the concentration of these independent variables that change the K_d value. Thus, the code must track many more parameters, and some numerical solving techniques (such as closed-form analytical solutions) can no longer be used to perform the integration necessary to solve for the contaminant's concentration. Generally, computer codes that can accommodate the parametric-K_d model use a chemical subroutine to update the K_d value used to determine the R_F, when called by the main transport code. The added complexity in solving the transport equation with parametric-K_d sorption models and its empirical nature may be the reasons this technique has been used sparingly for waste disposal safety assessment exercises.

2.5. Overview of Mechanistic Adsorption Models

Mechanistic models explicitly accommodate the dependency of K_d values on contaminant concentration, competing ion concentrations, variable surface charge on the adsorbent, and solute species distribution. Incorporating mechanistic, or semi-mechanistic, concepts into models is attempted because the models become more robust and, perhaps more importantly, for the standpoint of the ILAW PA, scientifically defensible. There are several mechanistic models describing solute adsorption; some are accurate only under limited environmental conditions (Sposito 1984). For

instance, the Stern model is a better model for describing adsorption of inner-sphere complexes, whereas the Gouy-Chapman model is a better model for describing outer-sphere or diffuse swarm adsorption (Sposito 1984, Westall 1986). The complexity of installing these models into existing transport codes that are favored for complete disposal system performance assessment and the diversity of Hanford waste leachate/sediment/contaminant combinations of interest would require a data collection effort more intense and costly than is likely to be available. A brief description of the state of the science is present below. References to excellent review articles have been included in the discussion to provide the interested reader with additional information.

Several mechanistic models have been proposed; however, their application to complex natural sediments is not resolved (Westall and Hohl 1980, Sposito 1984, Westall 1986, Schindler and Sposito 1991). Any complete mechanistic description of chemical reactions at the mineral-electrolyte interface must include a description of the electrical double layer. While this fact has been recognized for years, a satisfactory description of the double layer at the mineral-electrolyte interface still does not exist.

Part of the difficulty of characterizing this interface stems from the fact that natural mineral surfaces are very irregular. They consist of many different micro-crystalline structures that exhibit quite different chemical properties when exposed to solutions. Thus, examination of the surface by virtually any experimental method yields only averaged characteristics of the surface and the interface. Parson (1982) discussed the surface chemistry of single crystals of pure metals and showed that the potential of zero charge of different crystal faces of the same pure metal can differ by over 400 mV. For an oxide surface, this difference was calculated by Westall (1986) to be energetically equivalent to a variation in the zero-point-of-charge of more than six pH units. This example indicated that an observable microscopic property of a polycrystalline surface might be the result of a combination of widely different microscopic properties and that characterizations of these surfaces will remain somewhat operational in nature.

Another fundamental problem encountered in characterizing reactions at the mineral-electrolyte interface is the coupling between electrostatic and chemical interactions, which make it difficult to distinguish their effects between each other. Westall and Hohl (1980) have shown that many models for reactions at the mineral-electrolyte interface are indeterminate in this regard.

Many of the studies from which our current understanding of reactions at the mineral-electrolyte interface have developed were based on titration of colloidal suspensions of minerals. Resolving questions left open by such research requires that the mineral surfaces be better defined (by many different spectroscopic and experimental methods), and that mathematical methods be developed for interpreting the data.

Experimental data on interactions at the mineral-electrolyte interface can be represented mathematically through two different approaches: 1) empirical models and 2) mechanistic models. An empirical model can be defined as a mathematical description of the experimental data without any particular theoretical basis. For example, the K_d, Freundlich isotherm, Langmuir isotherm, Langmuir Two-Surface Isotherm, and Competitive Langmuir are considered empirical models by this definition (Sposito 1984). Mechanistic models refer to models based on thermodynamic concepts such as reactions described by mass action laws and material balance equations. Four of

the most commonly used mechanistic models include the Helmholtz, Gouy-Chapman, Stern, and Triple Layer models (Sposito 1984). The empirical models are often mathematically simpler than mechanistic models and are suitable for characterizing sets of experimental data with a few adjustable parameters, or for interpolating between data points. On the other hand, mechanistic models contribute to an understand of the chemistry at the interface and are often used for describing data from complex multi-component systems for which the mathematical formulation (i.e., functional relations) for an empirical model might not be obvious. Mechanistic models can also be used for interpolation and characterization of data sets in terms of a few adjustable parameters. However, mechanistic models are often mathematically more complicated than empirical relationships. Adjustable parameters are required for both mechanistic and empirical models, but not for the K_d model.

2.6. Gravel-K_d Issue

Essentially all K_d values in the literature and that have been measured at the Hanford site were generated from sediments that do not contain any gravel, particles >2-mm. However, there are regions in the subsurface of the ILAW site that are composed primarily of gravel-sized particles. At issue is that K_d values will likely be lower in sediments containing gravel because of the reduced surface area in the field as compared to the lab tested solids for the radionuclides to interact with. This is referred to as the gravel-K_d issue. Experiments were conducted with Hanford sediments to evaluate a number of methods to address the gravel-K_d issue (Kaplan et al. 1999 and see Appendix A). Three gravel-corrected K_d conceptual models, Kd_{gc}, were evaluated in this study: a correction based on surface area ($Kd_{gc,surf}$), a correction based on the assumption that the gravel simply diluted the $Kd_{<2mm}$ and had no sorption capacity ($Kd_{gc,g=0}$), and a correction based on the assumption that the K_d of the entire sediment (Kd_{tot}) was a composite of the $Kd_{<2mm}$ and the $Kd_{>2mm}$ values ($Kd_{gc,g=x}$). Based on data for the adsorption of trace concentrations of Sr, on average, $Kd_{<2mm}$ tended to overestimate Kd_{tot} by 28%; $Kd_{gc,g=x}$ overestimated Kd_{tot} by only 5%; $Kd_{gc,g=0}$ and $Kd_{gc,surf}$ underestimated Kd_{tot} by 10 and 13%, respectively. Although, $Kd_{gc,g=x}$ provided the best estimate of actual values (Kd_{tot}), the input values for $Kd_{gc,g=0}$ are appreciably easier to acquire. Additional data regarding the gravel-correction can be found in Appendix A.

To account for the presence of gravel in the study area, K_d values will be lowered in a conservative method, whereby the gravel will be assumed to have no sorptive capacity for the radionuclides.

The $Kd_{gc,g=0}$ will be used to correct for the conservative case "empirical" Kd values in the gravel-dominated sequence (described in more detail below) and is defined as:

$$Kd_{gc,g=0} = (1-g)Kd_{<2mm}, \quad (6)$$

where g is the gravel weight fraction of sediment in the field and $Kd_{<2mm}$ is the traditional K_d value measured using the <2-mm fraction. Equation 6 greatly improves the accuracy of the "empirical" K_d construct for Hanford sediments and perhaps more importantly from the stand

point of the ILAW PA, it provides in all cases a more conservative K_d value than the traditional $Kd_{<2mm}$ commonly used in such calculations.

2.7. Moisture Dependency of K_d Values

The moisture dependency of K_d values has been and continues to be evaluated by our group (Lindenmeier et al. 1995, Kaplan et al. 1996, and Gamerdinger et al. 1998). Based on our findings to date, as well as the literature, our present belief on this subject is that there is a slight decrease in U(VI)-K_d values as the moisture content in a system decreases. In support of this contention is that four of the five sediments tested to date showed this trend. The sediment that did not show this trend had only two K_d data points, one from a saturated system and the other from an unsaturated system (Kaplan et al. 1996). This decrease in K_d for U[VI]) as percent saturation decreased may be attributed to the fact that as the degree of saturation decreases, solutes come into contact with fewer exchange sites. But with more contact time between the vadose zone sediments and the porewater, diffusion processes may allow the contaminants to interact with sediment adsorption sites that are "hidden" in dead-end pore spaces. The dead-end pore spaces may be created during the laboratory flow-through column experiments performed at unsaturated moisture contents, although they also occur in nature as determined in some field studies. That is, the slight dependency (decrease in K_d for U[VI]) of K_d as percent saturation decreased may be caused by a physical process, which will become less important in the field, than a chemical process. An alternative explanation is that higher ionic strength fluid exists in the double layer of partially saturated sediments leading to weaker sorption. This latter explanation is less likely since the double-layer around particle surfaces reach only nanometers into the water, whereas the uniform film thickness of pore fluid around unsaturated Hanford sediments is estimated to be several micrometers (see Appendix C for a short discussion). For the 2001 ILAW PA we will ignore the K_d dependency on moisture content and use the K_d values measured in traditional saturated tests. If the flow models used in the future PA's (beyond the 2001 ILAW PA) are capable of modeling the mobile-immobile water concepts presented in van Genuchten (1981), then the effect of moisture content on the retardation factor can be accommodated without altering the K_d value. Consequently, all K_d estimates used in the future PA's for the vadose zone would be slightly lower than values derived from traditional tests conducted in saturated systems. We will also continue studies on the effects of partial saturation on the K_d of U(VI) for one more year in hopes of resolving the issue.

To account for a possible moisture dependency of K_d values, all K_d estimates assigned to the vadose zone will be slightly lower than values derived from traditional tests conducted in saturated systems.

2.8. Colloid-Facilitated Transport of Contaminants

Contaminant transport is traditionally modeled as a two-phase system: a mobile aqueous phase and an immobile solid phase. Over the last 15 years, there has been an increasing awareness of a third, mobile solid phase. This mobile solid phase, mobile colloids, consists of organic and/or inorganic submicron-particles that move with groundwater flow. When radionuclides are associated with colloids, the net effect is that radionuclides can move faster

through the system than would be predicted on the basis of reversible sorption. It is not known whether colloids in the subsurface environment of the Hanford Site enhance contaminant transport. Furthermore, it is not known if mobile colloids in a plume emanating from the ILAW waste site will have significant effects on contaminant transport rates.

Mobile colloid formation is commonly described as a three-step process: genesis, stabilization, and transport. Colloid genesis describes how the submicron particles are formed in groundwater. Stabilization describes how the colloids are brought into suspension, which is a function of the colloid and groundwater composition and water flow forces. Transport describes how the suspended colloids move through the porous media or are retained by physical forces (such as diffusion, straining, or gravitational settling) or physicochemical attraction to the matrix.

Regarding the first step, colloid genesis, there is little doubt that radionuclide-bearing colloids will be generated at the ILAW disposal site. Ramsay (1988) presented strong evidence for the existence of colloid particles in glass and cement leachate and provided an in-depth review of the various types of colloids that can/may exist (e.g., glass fragments, precipitation products, geological materials, secondary phases formed from glass leachate). However, based on experiments using Hanford groundwater and colloids, there is little likelihood that colloids would remain suspended in glass leachate, cement leachate, or Hanford groundwater (McGraw and Kaplan 1997). The ionic strength of these solutions greatly exceed the critical flocculation concentration (the minimum electrolyte concentration to induce colloid flocculation) of most particles. Even in uncontaminated Hanford groundwater, where the ionic strength would be at its lowest, the critical flocculation concentration is likely exceeded by 300 to 600%, depending on the type of colloid in suspension. This would minimize colloid-facilitated transport of radionuclides from the disposal site. Hence, colloid-facilitated transport of contaminants will not be considered as an important transport process in the ILAW PA until there is compelling evidence that our assessment is flawed.

There is little doubt that colloids with radionuclides associated with them will be generated at the disposal site. However, there is little likelihood that colloids would remain in suspension in glass leachate, cement leachate, or even uncontaminated Hanford groundwater because of the high ionic strength of these waters. This would minimize colloid-facilitated transport of radionuclides from the disposal site.

3.0 Geochemistry of Key Radionuclides

This section provides a brief description of the geochemistry of radionuclides identified by preliminary subsurface transport simulations as presenting the greatest health risks. Emphasis is placed on describing the chemical processes relevant to the Hanford unsaturated zone, which is a coarse-sand textured, alkaline, sediment with low natural organic matter concentrations. Geochemical information relevant to other environments, such as reducing environments, is also provided to address possible near-field systems and a possible localized stagnant silt/mud region in the upper unconfined aquifer.

3.1. Iodine

There are 24 known isotopes of I, 18 of these isotopes have half-lives of less than 1 day. The only stable isotope is ^{127}I. Its average natural abundance in geologic materials is 5 mg/kg (Gu and Schulz 1991) and its concentration in uncontaminated surface waters is typically <1 mg/L (Stumm and Morgan 1981). The isotope of concern for long-term disposal at the Hanford Site is ^{129}I, which has a half-life of 1.7×10^7 years.

3.1.1. Aqueous Speciation

Iodine usually exists in fresh water in the minus one oxidation state as iodide (I^-) (Whitehead 1984). In alkaline and marine environments, iodine usually exists in the VII oxidation state as iodate (IO_3^-) (Whitehead 1984). Iodide and IO_3^- were the most commonly detected species in rainwater collected after the Chernobyl accident (Muramatsu et al. 1990). The other oxidation states of iodine, III and V, are much less frequently found in nature. Iodide is likely to be the dominant iodine species in the Hanford upper unconfined aquifer because its domain of predominance extends throughout the pH scale, completely covering a large part of the stability domain of water (Figure 1; Ticknor and Cho 1990). Oxidation of I_2 to produce IO_3^-, the second most abundant form of iodine in aqueous systems, is easily accomplished in basic solution by the reaction:

$$3I_2 + 6OH^- = 5I^- + IO_3^- + 3H_2O \qquad (7)$$

(Cotton and Wilkinson 1972). Thus, the IO_3^- form of iodine is likely dominant in well-oxidized, high-pH systems as may exist in the near field of the ILAW disposal site. Iodide and IO_3^- tend to exist as free ions, but the complexes they do form are generally the most soluble of all halide complexes.

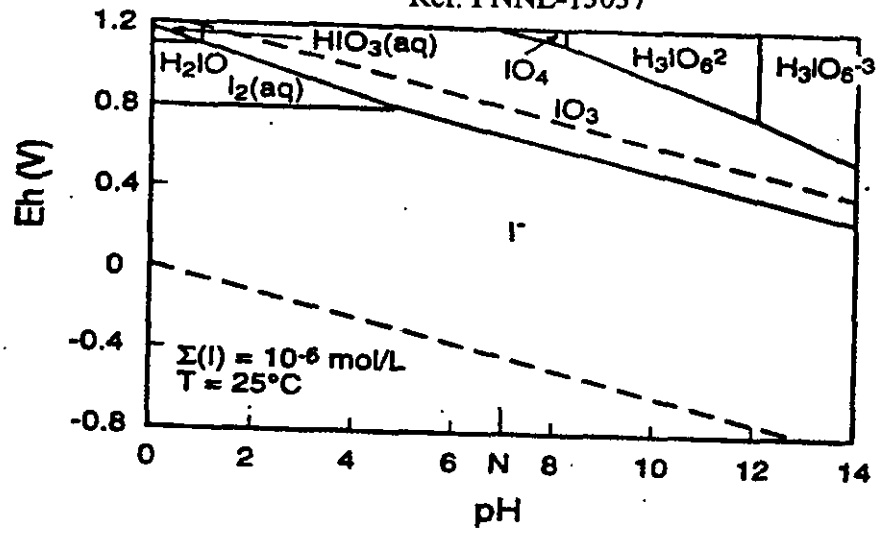

Figure 1. Eh and pH Diagram for Iodine/Water System (Ticknor and Cho 1990)

3.1.2. Precipitation and Coprecipitation

Precipitation of iodide compounds is not likely to be a dominant reaction path for iodide in the glass leachate. Iodide, in comparison with the other halides, forms especially weak complexes with metal ions as a result of its large size (0.22-nm ionic radius, Langmuir 1979). The metals with which I^- and IO^-_3 form sparingly soluble compounds, Ag, Ba, Hg, Pb, and Pd (Pourbaix 1966) exist in nature at very low concentrations. The low concentrations of iodine in the contaminant plume will likely exist as either free species or as highly soluble complex species. However we are finding that the weathering products of glass, zeolites and clays, do seem to incorporate several anionic contaminants, including pertechnetate, Se, and I (it is not clear whether the species is I^- or IO_3^- at this time). Results will be published in a PNNL progress report in early FY00 and past progress that describes preliminary tests are found in Mattigod et al. 1998. At the present time we will not include this apparent co-precipitation or specific adsorption (see below) of iodine leached from the glass into or onto the zeolites and clays that form in transport calculations or the geochemical data package for the 2001 ILAW PA. This will build in a degree of conservatism that will be dealt with (removed) when quantitative data on co-precipitation is available certainly by the time that the 2003 ILAW PA is scheduled.

3.1.3. Sorption

Two types of reactions between anions and inorganic solids are recognized: specific adsorption and nonspecific adsorption. Specific adsorption refers to incorporation of anions as a ligand in the coordination shell of an adsorbent, while nonspecific adsorption refers to adsorption of anions by simple coloumbic (electrostatic) interactions with positive charges. Iodine anions are believed to sorb primarily through nonspecific, anion-exchange reactions on mineral surfaces (Gu and Schulz 1991) and through specific adsorption on organic substances (Walters and Winchester 1971). Nonspecific sorption may occur at the localized positive charges that occur on 1) Fe- and Al- oxide surfaces, 2) edges of aluminosilicate clay surfaces where the oxygen

atoms are not fully coordinated by Al or Si atoms, and 3) on amine and amino groups of organic substances. These positive charges, which increase with decreasing pH, attract anions electrostatically. Whitehead (1973), for example, reported that sorption of I^- by soils was associated with both soil organic matter and Fe and Al oxides, with the oxides increasingly important under more acidic conditions. The maximum amounts sorbed by two surfaces occurred at pH 6.6. At this pH, the amounts of I^- sorbed were found to be closely related to the contents of organic matter but not to Fe- or Al- oxides or clay. At pH<5, the removal of Fe- and Al-oxides resulted in a marked reduction in I^- sorption. Whitehead (1974) further observed that freshly precipitated ferric- and Al-oxides sorbed substantial amounts of I^- from solutions of pH <5.5 but the amount decreased to zero as the pH approached 7. Presumably, this trend reflects the presence of an increasing amount of positive charge (anion-exchange capacity) on the amphoteric oxide surfaces at lower pH levels.

Ticknor and Cho (1990) studied the interaction of I^- and IO^-_3 over a pH range of 7.5 to 8.0 with a number of minerals including calcite, chlorite, epidote, goethite, gypsum, hematite, kaolinite, bentonite, muscovite, and quartz. No I^- sorption was detected from any of the solutions on any of the minerals. Iodate was removed from solution to a somewhat greater extent then I^-. Bentonite, calcite, gypsum, and muscovite adsorbed no IO_3^-. Muramatsu et al. (1990) reported that neither I^- nor IO_3^- sorbed to quartz sand. The authors concluded that the low I^- and IO^-_3 sorption was the result of the low anion-exchange capacities of the minerals at the high pH of the systems investigated. Recently, Kaplan et al. (1999) showed that some naturally occurring 2:1 phyllosilicate minerals have the ability to sorb large amounts of iodide. Kd values >60 mL/g were measured for illites. Illite generally accounts for about 20% of the clay fraction of Hanford sediments. Even at pH >9, iodide Kd values for these illites were >20 mL/g. Subsurface Hanford sediment with a pH of 8 had Kd values that average 3 mL/g and ranged from 0.1 to 10 mL/g.

3.2. Neptunium

There are 16 known isotopes of Np from ^{228}Np to ^{241}Np (Keller, 1971). Only ^{237}Np, a neutron reactor product of ^{238}Np (n, 2n), and ^{235}Np (n, γ), with a half-life of 2.14×10^6 years, are of interest to the ILAW PA.

3.2.1. Aqueous Speciation

Neptunium exists in aqueous solutions in five oxidation states, Np(III), Np(IV), Np(V), Np(VI), and Np(VII). In the absence of complexing agents, the first four oxidation states exist as hydrated ions Np^{+3}-H_2O, Np^{+4}-H_2O, NpO_2^+-H_2O, NpO_2^{+2}-H_2O (Ames and Rai 1978). Np(VII) is a strong oxidizing agent that is stable in strong alkaline solution as NpO_5^{-3}. Between pH 0 to 9, NpO_2^+ is the common Np species formed in aqueous environments (Ames and Rai 1978). Above pH 9 (and >100 mg/L carbonate) an uncharged bicarbonate complex is formed. According to Keller (1971), Np(V) does not form hydroxide complexes below pH of 7. Np(V) exists as the singly-charged neptunyl ion, NpO_2^+, with symmetrical linear bonding $(O\text{-}Np\text{-}O)^+$. It hydrolyses only at a pH of greater than 7, disproportionates only at high-acid concentrations, and

forms no poly-nuclear complexes (Keller 1971). NpO_2^+ ion complexes only weakly with inorganic ligands.

3.2.2. Precipitation and Coprecipitation

In an oxidizing environment, Np solids in an increasing order of stability are $Np(OH)_4$, NpO_2, $NpO_2(OH)_2$. Because NpO_2 can maintain a very high concentration of Np in solution, it is unlikely that NpO_2 would be found as a discrete solid in terrestrial environments. It may exist in very reducing conditions as a solid.

3.2.3. Sorption

A singly charged neptunyl ion, NpO_2^+, is likely the dominant species of Np in the oxidizing environment of the Hanford vadose zone (Ames and Rai 1978). NpO_2^+ does not compete favorably with Ca^{2+} and other common divalent ions for adsorption sites on sediments; consequently, Np-K_d values are usually relatively low (Routson et at. 1976, Sheppard et al. 1976). Benson (1961) examined Np sorption to 25 common sulfide, silicate, and carbonate minerals using trace amounts of Np in Columbia River water at 80°C. Neptunium was adsorbed poorly or not at all by the minerals tested. Robertson (1974) determined the speciation of Np in the cooling water effluent from the Hanford N Reactor. Through the use of ultrafiltration and cation and anion exchange resins, the following distribution was observed: 25% particulate, 70% cationic, <3% anionic, and <1% non-ionic. The fact that Np may become associated with a particulate phase may have significant ramifications regarding the potential role of subsurface mobile colloids in enhancing contaminant transport. A few studies have been conducted to evaluate the propensity of Np to adsorb to Hanford sediments (Rouston et al. 1976, Serne et al. 1993). Their results suggest low-to-moderate adsorption and are included in this data package.

A singly charged neptunyl ion, NpO_2^+, is likely the dominant species in the oxidizing environment of the Hanford vadose zone. Neptunyl sorbs poorly to most minerals.

3.3. Selenium

^{79}Se is a long-lived fission product whose half-life is not well established. One estimate is 6.5×10^4 years but the value may be as much as ten times larger. ILAW is monitoring current efforts to resolve the half-life issue. ^{79}Se is commonly found as a fission product in spent fuel elements. The stable, nonradioactive form of Se is ubiquitous, especially in the western U.S. sediments. After nonradioactive Se was found to be the cause of reduced fecundity of migrating birds in the mid-1980s, much research was directed at understanding the environmental fate of Se.

3.3.1. Aqueous Speciation

Selenium exists in natural aqueous environments in –2, +4, and +6 valence states. Most of the Se species in natural waters exist as anions: selenate [Se(VI)] or selenite [Se(IV)]. Under reducing conditions, H_2Se^0 would dominate below pH 3.8 and HSe^- would dominate above pH 3.8 (Rai and Zachara 1984). The selenite species would predominate under intermediate to slightly oxidizing conditions. Highly oxidizing conditions (pe + pH >15) are necessary for SeO_4^{2-} to form to a significant extent. Selenate and selenite may form ion-pair species with Ca^{2+}. Solid phases in order of increasing solubility are $FeSe_2$, FeSe, and CuSe (Rai and Zachara 1984). However, the solubility product K_{sp}, for $FeSe_2$ or the other compounds are not well-defined.

3.3.2. Precipitation and Coprecipitation

Although several solid phases (such as $FeSe_2$) are predicted to be stable under relatively reducing conditions, and some studies indicate precipitation may be occurring, no definitive information on solubility-controlling solids is available. $Fe(OH)_4SeO_3$ was proposed (Geering et al. 1968) to help explain the insolubility of Se in soils as well as the strong association of Se with Fe in precipitates. Benjamin and Bloom (1981) observed that metal ion adsorption onto amorphous iron oxyhydroxides was enhanced in the presence of an Fe-Se solid phase adsorbed on the oxyhydroxide surface. Benjamin and Bloom (1981) observed that selenite was irreversibly adsorbed on crystalline iron oxide surfaces (goethite, hematite). As mentioned in the Iodide section, recent laboratory tests where glass doped with anionic forms of Se, I, and Tc were weathered in water show that significant masses of these elements are incorporated into secondary minerals (clays and zeolites) that form. Thus ignoring co-precipitation and/or specific adsorption of these elements in the vault region may significantly over-estimate the transport and dose calculations in the 2001 ILAW PA. However, until we gain a better understanding of the glass weathering products, their long-term stability, and the incorporation process(es), we will not take credit for these retention processes until the 2003 ILAW PA.

3.3.3. Sorption

Laboratory studies indicate that, in spite of their anionic nature, selenite and selenate may be adsorbed significantly by some soils. The experimental evidence suggests that crypto-crystalline and amorphous forms of SiO_2, Al_2O_3, and Fe_2O_3 control Se adsorption (John et al. 1976, Singh et al. 1981). Studies with pure mineral phases demonstrate that hydrous oxides of Fe and Al and amorphous aluminosilicates have a high affinity for Se(IV, VI) (Leckie et al. 1980, Hingston et al. 1968), which significantly exceeds that of layer lattice silicates (Frost and Griffin 1977, Hamdy and Gissel-Nelson 1977). (Singh et al. 1981). Selenate may be adsorbed more strongly by clay minerals than selenite (Frost and Griffin 1977), while the inverse applies to hydrous oxides of Fe (Leckie et al. 1980, Benjamin and Bloom 1981).

Though selenite (pK_2:7.9) and selenate (pK_2:1.7) differ appreciably in their acidity, little difference is seen in their adsorption by soil.

The adsorption of Se(IV) and Se(VI) on goethite, amorphous iron oxyhydroxide, and gibbsite is strongly pH dependent (Hingston et al. 1968, Leckie et al. 1980, Hingston et al. 1972). The anions are strongly sorbed under acidic conditions, but sorption decreases with increasing pH. Limited experimental evidence suggests that, at a given pH, Se adsorbs to neutral and positively charged amphoteric oxide surfaces displacing water, hydroxyls, and other adsorbed ligands (e.g., sulfate, silicate) until the surface is neutral in charge (Rajan 1979).

The presence of competing anions may reduce Se(IV) and Se(VI) adsorption by using limited ligand exchange sites and reducing surface net positive charge. Phosphate reduces Se adsorption on goethite, though some sites are specific to Se (Hingston et al. 1971). Sulfate reduces SeO_4^{2-} adsorption on amorphous iron oxyhydroxides in a manner consistent with the competitive Langmuir equation (Leckie et al. 1980). The Se adsorption tests using Hanford-specific sediments and groundwater/alkaline leachates are described in this data package.

3.4. Technetium

All isotopes of Tc are radioactive. Several Tc isotopes are obtained by the fissioning of nuclear fuels of U in the reactor. The Tc isotopes and their yields resulting from U fission include: ^{99}Tc, 6.06%; ^{101}Tc, 5.6%; ^{102}Tc, 4.3%; ^{103}Tc, 3.0%; ^{104}Tc, 1.8%; ^{105}Tc, 0.9%; and ^{106}Tc, 0.19%. Of these fission products, only ^{99}Tc is a potential hazard from long-term burial of ILAW, because this isotope has a long half-life (2.12×10^5 years).

3.4.1. Aqueous Speciation

Technetium exists in valence states from (VII) to (-I). The most stable and characteristic oxidation state of Tc in slightly acid, neutral, or basic aqueous solutions in equilibrium with the atmosphere is pertechnetate ion (TcO_4^-) in which Tc is in the heptavalent state (Coughtrey et al. 1983, Hanke et al. 1986). Various Tc(V), Tc(IV), or Tc(III) species may be formed under reduced conditions (Pilkington 1990). However, the most stable of these reduced oxidation states is generally Tc(IV) (Bondietti and Francis 1979). The nature of the Tc(IV) species is uncertain: the most common species is TcO_2(s) (Bondietti and Francis 1979, Gu and Schulz 1991). The reduced Tc species are rapidly oxidized to Tc(VII) by atmospheric oxygen (Coughtrey et al. 1983), and therefore, regardless of the oxidation state of the Tc emanating from the near field, it is likely to be in the (VII) oxidation state once it reaches the far field.

Pertechnetate ion is highly soluble (Baes and Mesmer 1976, Pilkington 1990). In alkaline solutions and a low redox potential, the Tc(IV) species are more prevalent and its complexes are typically much less soluble, on the order of 10^{-7} to 10^{-8} mol L^{-1} over a range from pH 4 to 10 (Pilkington 1990). The solubility of Tc in contact with hydrated TcO_2 was investigated by Pilkington (1990). He found that pH had little effect on measured solubility of Tc over the pH range of 1 to 12.5. However, the presence of organic materials increased the measured solubility of Tc by a factor of 10, indicating that complexation between the dissolved organic materials and the Tc is important. Wildung et al. (1986) suggested that low molecular

weight organic ligands may increase the solubility of reduced forms of Tc, whereas complexation with the high molecular weight organic ligands, particularly insoluble organic ligands, may lead to precipitation. Schulte and Scoppa (1987) showed that Tc(IV) had a strong tendency to coordinate with ligands containing highly polar groups and negatively charged ligands.

3.4.2. Precipitation and Coprecipitation

Precipitation of TcO_4^- - containing solids is not likely to be an important geochemical process affecting ^{99}Tc transport through the Hanford vadose zone. Technetium(VII) forms very soluble oxides and halide complexes (Baes and Mesmer 1976). However, if Tc(VII) is reduced to Tc(IV) in the near field, it may form a number of sparingly insoluble complexes such as TcO_2 or Tc-sulfide solids. As mentioned above, the glass weathering products formed in the short-term lab tests sequester significant amounts of Tc present in the glass as the pertechnetate species. Thus ignoring this removal process in the 2001 ILAW PA would appear to be adding a level of conservatism to the final predictions.

3.4.3. Sorption

A number of studies have shown that retention of Tc by solid phases is related to the physicochemical properties of the solid phase (reviewed by Ames and Rai 1978, Gu and Schulz 1991). These studies indicate that systems containing low amounts of clay, organic carbon, and Al/Fe oxides show very little adsorption. Bowen (1966) reported that in oxic conditions, 90% of added TcO_4^- was readily extractable from soils and assumed to remain in solution either as the free ion or weakly adsorbed to ion-exchange sites. Similarly, Wildung et al. (1977) reported that under oxic conditions, 78 to 88% of the TcO_4^- added to the soil could be extracted easily 30 days after application. Under anaerobic conditions, Cataldo et al. (1978) reported that Tc removal from solution by soils could exceed 97% in 2 to 5 weeks.

In a study of 7 mineral soils and 27 organic soils, Sheppard et al. (1990) reported that in addition to the redox status, the organic matter content of soils plays an important role in Tc sorption. Evidence of the complexation between organic materials and Tc has also been presented by Van Loon et al. (1986). They indicated that such complexes can be readily synthesized by chemical reduction of pertechnetate in the presence of organic matter.

Reduced Tc precipitates or organic matter-Tc complexes are not resolubilized by the chelating agents, EDTA and DTPA, which are known to form stable Tc complexes (Stalmans et al. 1986). This would indicate that EDTA and DTPA complexes are not as strong as the Tc-organic matter complexes, suggesting that naturally occurring organic matter may play a significant role in Tc transport by forming relatively stable Tc complexes. Whether these complexes are soluble or insoluble, depends on the size of the organic ligand. It is not known whether the

Retention of Tc is largely determined by the oxidation states of the system, due to the vast difference in the solubility between Tc(VII) and Tc(IV) containing compounds; Tc(VII) is retained appreciably less than Tc(IV).

organic matter – Tc(IV) complexation reaction can favorably compete with Tc(IV) hydrolysis reactions.

Many Hanford-specific adsorption studies with Hanford sediments and waters under oxidizing conditions have been performed and they generally show no adsorption of the pertechnetate anion. Specifics are found in this data package mainly in the tables found in Section 5.

3.5. Uranium

The natural abundance of U in geologic matter is about 3 mg/kg (Ames and Rai 1978). Naturally occurring U typically contains 99.283% ^{238}U, 0.711% ^{235}U, and 0.0054% ^{234}U by weight. Geologically, U occurs as U(IV) in minerals such as pitchblende, uraninite, carnotite, autunite, and as U(VI) in uranophane. It is also found in phosphate rock, lignite, and monazite sands at levels that can be commercially recovered. In the presence of lignite and other sedimentary carbonaceous substances, U enrichment in nature is believed to be the result of U reduction to form insoluble precipitates, such as uraninite. The U isotopes of interest in waste disposal and their respective half-lives include: ^{233}U, 162,000 years; ^{234}U, 247,000 years; ^{235}U, 7.13×10^8 years; ^{236}U, 2.39×10^7 years; and ^{238}U, 4.51×10^9 years.

3.5.1. Aqueous Speciation

Uranium can exist in the (III), (IV), (V), and (VI) oxidation states. The aqueous U(VI) uranyl cation (UO_2^{2+}) is the most stable ion in oxidizing solutions. The U(III) species easily oxidizes to U(IV) under most reducing environmental conditions, while the U(V) aqueous species (UO_2^{+}) readily disproportionates to U(IV) and U(VI). In aqueous systems, U(IV) species will not be present to any great extent as a result of the low solubilities of U(IV) species, such as uraninite (UO_2) or some other solids with O/U ratios between 2.3 and 2.7 (Bruno et al. 1988, Bruno et al. 1991). Average U concentrations in natural waters under reducing conditions are between 3 and 30 ppb (Bruno et al. 1991); this is consistent with equilibrium concentrations controlled by UO_2(s) (Bruno et al. 1988). In the absence of complexing agents, U(IV) is expected to hydrolyze to form mononuclear hydroxo complexes, $U(OH)_n^{4-n}$ (Langmuir 1978). Complexation of (IV) actinides with natural organic humic and fulvic acids has been suggested as an important process (log K = 12 to 16; Birch and Bachofen 1990). Hence, U(IV) could form stable organic complexes, increasing the solubility of the U(IV). In general, (IV) actinides species form stronger organic complexes than do the (VI) actinides species (Birch and Bachofen 1990).

Aqueous U(VI) or uranyl, UO_2^{2+}, tends to form strong complexes with inorganic oxygen-containing ligands such as hydroxide, carbonate, and phosphate. Aqueous UO_2^{2+}, hydrolyses to form a number of aqueous hydroxo complexes including UO_2OH^{+}, $(UO_2)_2(OH)_2^{2+}$, $(UO_2)_3(OH)_5^{+}$, and $UO_2(OH)_3^{-}$. In aqueous systems equilibrated with air or higher pCO_2 waters at near neutral to high pH, the carbonate complexes [$UO_2CO_3^0$, $UO_2(CO_3)_2^{2-}$, $UO_2(CO_3)_3^{4-}$] will dominate, but at lower pH the hydrolysis species will dominate as CO_2 solubility decreases.

Phosphate-UO_2^{2+} complexes ($UO_2HPO_4^0$, $UO_2PO_4^-$) could be important in aqueous systems with a pH between 6 and 9 when the total concentration ratio $(PO_4^{3-}{}_{Total}/CO_3^{2-})_{Total}$ is greater than 10^{-1} (Sandino and Bruno 1991, Langmuir 1978). Complexes with SO_4^{2-}, F^-, and possibly Cl^- are potentially important U(VI) species where concentrations of these anions are high. However, their stability is considerably less than that of the carbonate and phosphate complexes (Grenthe 1991). Because of the high hydroxide, high carbonate, and low organic matter concentrations expected in both the near and the far field of the Hanford ILAW disposal sites, U(VI) is likely to exist as a complexed carbonate and/or to a lesser extent, as a hydroxide-complexed species.

3.5.2. Precipitation and Coprecipitation

Precipitation or coprecipitation of a solid phase will likely not control the mobility of U(VI) in the far field vadose zone. However, reduced conditions may be created in the near field that may maintain the waste U as a uraninite precipitate, $UO_2(s)$, (Rai et al. 1990). Uranium is also sequestered in the glass weathering products formed in short-term laboratory experiments such that coprecipitation reactions in the glass vault should be considered in the 2003 ILAW PA after more quantitative data are available. Besides determining the "loading" capacity of the weathering products for U and other contaminants, the long-term stability of the weathering products needs to be established. U(VI) insoluble compounds also appear to control solution concentrations of U in cementitious environments (see Brady and Kozak 1995, Krupka and Serne 1998, and Serne et al. 1996).

3.5.3. Sorption

Uranium is most mobile in oxidizing, carbonate-rich solutions. Therefore, under these conditions, one would anticipate that U would be most soluble. However, other secondary factors may affect the mobility as well. For example, in low ionic strength solutions, the uranyl ion concentrations will probably be regulated, in part, by cation-exchange adsorption process. The uranyl ion will adsorb onto clays, organics, and oxides, and this will limit its mobility. As the ionic strength of an oxidized solution increases, other ions, notably Ca^{2+}, Mg^{2+}, and K^+ will displace the uranyl ion, forcing it into solution. Not only will other cations out compete the uranyl ion for exchange sites, but carbonate ions will form strong soluble complexes with the uranyl ion, further lowering its affinity for positively charged solids while increasing the total amount of U in solution (Yeh and Tripathi 1991). The anionic uranyl-carbonate complexes do not adsorb to the naturally negatively-charged Hanford sediments at neutral to alkaline pH conditions.

The uranyl ion is particularly mobile in high-ionic-strength solutions such is expected to exist in the plume emanating from the Hanford LLW burial site.

Some of the sorption processes in which uranyl ion participates are not completely reversible. Sorption onto iron and manganese oxides can be a major process for extraction of U from solution. These oxide phases act as a short-term irreversible sink for U in soils. Uranium bound in these phases is not generally in isotopic equilibrium with dissolved U in the same

system, suggesting that the reaction mediating the transfer of the metal between the two phases is slow.

Solid phase organics are another possible sink for uranyl ions in soils, and to smaller extents, in sediments. The mechanisms for U sequestration onto organic-rich sediments are numerous and complex. One mechanism may involve sorption of the uranyl cation onto exchange sites such as carboxylic acid groups. These groups can coordinate with the uranyl ion, displacing water of hydration and form stable complexes. A process such as this probably accounts for a significant fraction of the organically bound U in soils, and perhaps, in sediments. Alternatively, sedimentary organics may reduce dissolved UO_2^{2+} species to U(IV) species. These reduced species are generally low in solubility and may remain associated with the organic phase after precipitation as a reduced oxide. Little seems to be known about the nature of organic-U associations in soils or sediments on a molecular level, although several different types of interactions may be taking place. The amount of naturally-occurring organic substances, such as fulvic and humic acids, is quite low in the subsurface of the Hanford Site. However, there is a possibility that the contaminant plume leaving the near-field may contain some organic substances (sulfur polymer cement contains 5% organic binder and asphalt also may be used in covers). Both of these engineered materials possess some of chemical properties of the naturally-occurring organic substances found in natural systems.

Uranium sorption to iron oxides and smectite clay has been shown to be extensive in the absence of CO_3^{2-} (Kent et al. 1988, Hsi and Langmuir 1985, Ames et al. 1982). In the presence of CO_3^{2-} and organic complexants, however, sorption was shown to be substantially reduced or severely inhibited (Hsi and Langmuir 1985, Kent al. 1988, Ames et al. 1982). The importance of U(VI) sorption to inorganic solid phases, such as clays and iron oxides, may be minor in many natural environments because of the limited quantity of these materials and because of the presence of particulate or dissolved organic matter and dissolved carbonate.

Rancon (1973) studied the adsorption of U using four soils and three pure phase minerals. Quartz was characterized as inert (K_d = 0 mL/g), calcite was a poor U adsorber (K_d = 7 mL/g), and illite and other 2:1 clays (K_d = 139 to 270 mL/g) were the best adsorbers of U from solution. Acid, organic-rich soils showed higher U sorption (K_d = 33 mL/g) than soils containing carbonate minerals (K_d = 16 mL/g).

Formation of complexes between U(VI) and organic ligands such as humic and fulvic particulates has been studied most frequently because of interest in ore-forming environments. At ambient temperatures (~25 ^{0}C), U is adsorbed to humic substances through rapid ion-exchange and complexation processes with carboxylic and other acidic functional groups (Idiz et al. 1986, Boggs et al. 1985, Shanbhag and Choppin 1981, Nash et al. 1981, Borovec et al. 1979, Szalay 1964). The adsorption is often followed by reduction to the U(IV) species followed by precipitation of UO_2 (Andreyev and Chumachenko 1964). In studies with lignite, however, the uranyl species formed a stable complex with the lignite without subsequent reduction; reduction only occurred at elevated temperatures (Nakashima et al. 1984). However, organic matter does have the capacity to act as a reductant, most notably because of the presence of quinone, sulfone, and reduced metal porphyrin (tetrapyroles) moieties (Macalady et al. 1986).

4.0 Approach

The geochemical data for both the far field and the near field were organized into five look-up tables, one for each environmental zone that was chosen to represent the ILAW pathway from the glass repository to the Columbia River. The concept and features of these five geochemical zones are presented in Table 1. A schematic representation of the five zones is presented in Figure 2. Each look-up table contains "empirical" K_d values and/or solubility data. For each contaminant in each environmental zone, a most-probable estimate, a reasonable lower-bounding estimate, and a likely range of estimates are provided. The distribution for all contaminant specific K_d and solubility parameters is assumed to be log normal for stochastic modeling. For each data entry, comments and references are provided to support the values.

Geochemical data will be organized into a number of look-up tables containing K_d values and/or solubility data for five environmental zones.

Whenever possible, the estimates provided in these tables were based on Hanford site-specific experiments. Generic literature or off-site data was used when site-specific data were not available. Careful selection of generic literature K_d values was required to ensure that the experimental conditions used to generate the K_d values were appropriate for the Hanford-specific zones. Consequently, expert opinion and geochemistry experience was utilized where non-site specific data was used; rationale and experimental evidence to support the expert opinion is provided. In some cases there was no generic data available and we were forced to use "expert judgement" to estimate values. The estimated values that have no actual measurements to defend the choices are marked.

Based on borehole 299-E17-21, the stratigraphy below the ILAW disposal site has two sequences, a sand-dominated sequence that exists from about 0- to 75-m depth and a gravel-dominated sequence that exists from about 75- to >475-m depth (Reidel et al. 1998). The sand-dominated sequence has essentially no gravel, except for a few gravel lenses (Reidel et al. 1998). The gravel-dominated sequence consists of about 90% gravel. Gravel-corrected K_d values (g in Equation 6 = 0.9) were used for radionuclides in the gravel-dominated layers (Zones 4 and 5 in Table 1). Little information is available about the properties and distribution of a mud layer that may exist within the gravel-dominated sequence at about 13- to 30-m below the water table (125- to 142-m below surface). Unique K_d values will not be assigned to this potential layer. This is a conservative simplification because reducing (sulfide odor is associated with core samples) clays in this zone, likely have a large sorption capacity as a result of a large cation-exchange-capacity (CEC) and surface area, and large potential for reductive precipitation. If this reducing mud layer was found to be present in a large area underneath the ILAW sites it would warrant more attention, especially for the fate of the high-dose redox-sensitive contaminants, such as Tc, U, Np, and Se discussed in Section 3.

Table 1. Conceptual features of the five geochemical zones

Zone (Data Table)	Solid Phases	Aqueous Phase	Geo-chemical Parameters Used in Zone
Zone 1 – Near Field (Table 2)	Glass, secondary phases formed from glass degradation, and backfill and engineered barrier materials	Glass leachate: high pH, high ionic strength, high radionuclide concentrations	Kd, solubility constraints
Zone 2 – Degraded Concrete Vault (Table 3) As of 12/01/99 this Zone may not be relevant in future repository design.	Three assemblages of minerals will exist, based on concrete age; fresh concrete with pH = 12.5, moderately aged concrete with pH ~10.5, and completely aged concrete with pH ~ 8.5.	Three types of concrete leachate chemistries controlled by different aged solid phases: young concrete leachate pH 12.5, then pH 10.5, final pH 8.5; generally high in ionic strength and high radionuclide concentration	Kd, solubility constraints
Zone 3 – Chemically Impacted Far Field in Sand Sequence (Table 4)	Sand-dominated sequence, slightly altered due to contact with moderately caustic aqueous phase	pH 8 (background) to 11, ionic strength 0.01 (background) to 0.1, low radionuclide concentration	Kd
Zone 4 – Chemically Impacted Far Field in Gravel Sequence (Table 5)	Same as Zone 3 except in gravel-dominated sequence	Same as Zone 3 except in gravel-dominated sequence	Kd_{gc}
Zone 5 – Far Field in Gravel Sequence (Table 6)	Unaltered Hanford gravel sequence (90% gravel, 10% <2-mm)	Unaltered Hanford groundwater except for trace levels of radionuclides	Kd_{gc}

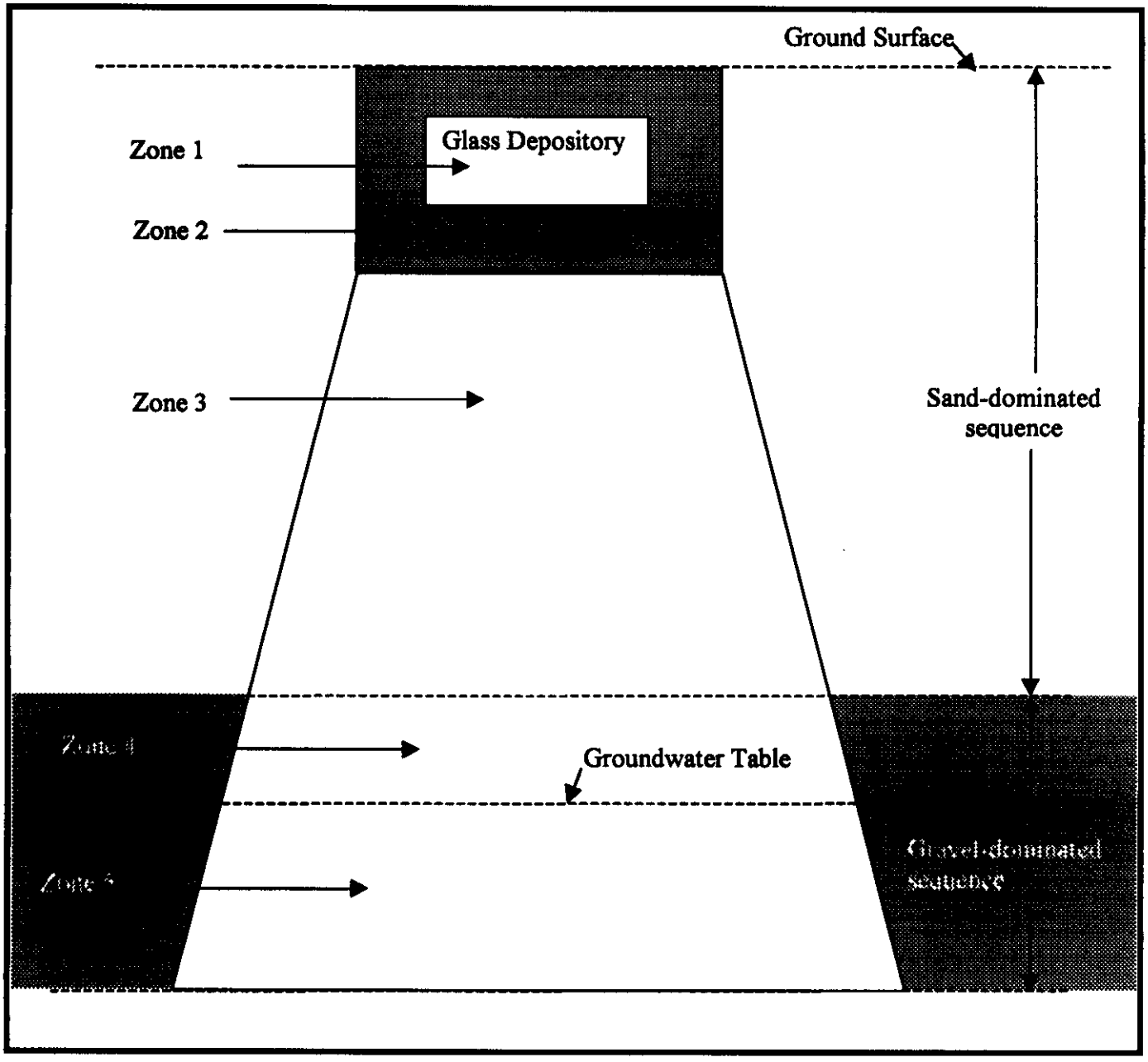

Figure 2. Schematic representation of the five geochemical zones.

The conceptual details of each of the five geochemical zones is described below.

1. Near Field: The chemistry in this zone is dominated by the presence of glass leachate until all the glass has dissolved. Glass leachate has high pH, ionic strength [especially soluble Na], and radionuclide activity. Radionuclide behavior in this zone is affected by unique solid phases dominated by glass, its weathering products, and backfill/engineered barrier materials. Initially, little or no contaminant adsorption will be considered on the glass. As reaction time

increases, radionuclides will be incorporated, coprecipitated, into secondary phases formed from glass-dissolution. Accounting for these processes will be closely linked with the glass waste-form leaching data package [see McGrail et al. 1999]. For the 2001 ILAW PA no credit will be taken for the coprecipitation of contaminants into the weathered glass secondary phases because we have not obtained adequate quantitative data for secondary minerals formed on the new BNFL glass formulations. We have also not determined the long-term stability of the weathering products found in the short-term hydrothermal [90 °C] tests. However, it seems clear from past [see Mattigod et al., 1998] and on-going studies on secondary phases formed from weathering other glass recipes that the coprecipitation process for trace contaminants into the zeolites and clays that form is significant. We have not presently finished determining how to take the empirical observations and generate mathematical algorithms for inclusion in the near-field transport code. Laboratory studies on determining the nature of the weathering products and trace contaminant sequestration amounts have been underway since early FY99 (Mattigod et al. 1998). Adequate data should be available for the 2003 ILAW PA.

2. Degraded Concrete Vault: Note that as of 12/01.99 the ILAW repository may not include concrete vaults; however crushed cement may still be used in the near field for pH control. The chemistry in this zone is dominated by the presence of cement leachate and weathered cement minerals/compounds, which have high pH, moderate ionic strength, and high to moderate radionuclide activity. The cement leachate chemistry will change with time as the concrete degrades and weathers. The assemblage of secondary minerals that form is different from that formed from glass degradation; thus, the radionuclide behavior is expected to differ from Zone 1. Zone 2 will also contain backfill materials. The cement weathering time evolution discussed in Krupka and Serne (1998) and Bradbury and Sarott (1995) were used to develop lookup tables for both K_d's (onto degraded concrete/aggregate) and solubilities (in concrete porewaters and porewaters from concrete) as a function of time. Three temporal environments are being considered at present; fresh concrete with pH 12.5, moderately aged concrete with pH ~10.5, and completely aged concrete with pH ~ 8.5. It is possible that the glass leachate will maintain a basic pH condition for tens of thousands of years such that only the first two time-dependent chemistries will be experienced in the ILAW PA system conceptual model. We will rely on the 2001 ILAW PA results to refine the conceptual model for this zone.

The convention of Bradbury and Sarott (1995) for the three types of physicochemical environments that all cements and concretes progress through was used for the development of a preferred database of K_d and solubility constraints. The following text describing the three temporal environments was taken from Krupka and Serne (1998).

Temporal Environment I: This environment occurs immediately after the cement hardens and is wetted by infiltrating water. The cement pore water is characterized as having a high pH [>12.5], high ionic strength, and high concentrations of potassium and sodium resulting from the dissolution of alkali impurities in the clinker phases. The high concentration of sodium is sometimes augmented by the dissolution of inorganic salts that have been solidified and buried in the disposal facility. Hydration is still continuing during Environment I with the formation of C-S-H gel [short hand for the $CaO\text{-}SiO_2\text{-}H_2O$ amorphous material that hardens

and constitutes "cement"] and portlandite [$Ca(OH)_2$]. The composition of the cement pore fluid is at equilibrium with portlandite during this time. The duration of Environment I is relatively short when compared to the later "environments." Based on the modeling estimates discussed in Berner (1992), this environment may last for the first 100 to 10,000 years.

Temporal Environment II: During this period, the soluble salts of the alkali metals are all dissolved. The pH of the cement pore water is controlled at a value of 12.5 by the solubility of portlandite. The C-S-H and portlandite are the major solid phases present. Environment II may last for a long time. Its duration depends on how much water percolates through the system and the mass of cement present in the concrete structure. The flux of water must dissolve all the slightly soluble portlandite before this environment changes. Using the estimates from Berner (1992), this environment may last from 100-10,000 years to 1,000-100,000 years.

Temporal Environment III: The concentration of portlandite has been reduced to such an extent by this period that the solubility of C-S-H now controls the pH of the cement pore fluid. The C-S-H starts to dissolve incongruently with a continual decrease in pH. At the end of this evolution, Environment III can be conceptualized as leaving only silica (SiO_2) as the solubility control for the pore fluid pH. The ionic strength of the cement pore fluid during this period is low, and its pH is ~10 or less. For the sake of simplicity, the final end point of Environment III can be considered somewhat analogous to the geochemical conditions of the "normal" ambient soil environment. Of the three "environment" types, the duration of Environment II is thus the longest in which the pore fluid composition is influenced by the hydration and dissolution reactions of the cement components.

3. Chemically Impacted Far Field in Sand Sequence: The chemistry in this zone has been impacted by the glass and concrete leachates, such that the porewater has a moderate pH between 8 (background) and 11, a moderate ionic strength between 0.01 (background) to 0.1, and low radionuclide activity (below solubility limits). This zone contains moderately altered Hanford formation sediment. This zone starts at the outside edge of the cement vault/engineered barriers and ends at the start of the gravel-dominated sequence (Figure 2). Contaminants will be controlled primarily by adsorption and not solubility constraints. However, we will consider [for the 2003 ILAW PA] the use of solubility controls in this zone should additional information become available that supports doing so. If the glass leachate and cement/engineered barrier leachates do evolve to less basic and lower ionic strength chemical solutions at long times, then the K_d values in Zone 3 will approach those in Appendix B, K_d values for the Far field in the Sand Sequence. Appendix B shows K_d values for <2 mm sized sediments for natural Hanford groundwater.

4. Chemically Impacted Far Field in Gravel Sequence: The chemistry in this zone has been impacted by the glass and concrete leachate, such that its pore water has a moderate pH between 8 (background) and 11, a moderate ionic strength between 0.01 (background) to 0.1, and low radionuclide activity (below solubility limits). This zone exists in the gravel-dominated sequence. The K_d values in this zone will be identical to those for Zone 3, except that the K_d values are gravel corrected. If the glass leachate and cement/engineered barrier leachates do evolve to less basic and lower ionic strength chemical solutions at long times,

then the K_d values in Zone 4 will approach those for Zone 5 at some time during the PA calculation.

5. Far Field in Gravel Sequence: This zone is located below the water table and is in the gravel-dominated sequence. The groundwater is assumed to dilute the major solutes down to natural background levels. The water in this zone is assumed to be "significantly tainted" only by contaminants and not by major common constituents of the glass and/or cement/backfill leachate. Hanford groundwater is dominated by calcium and bicarbonate, and has a pH of 8 and an ionic strength of 0.005 to 0.01 M. The K_d values in the look-up table for this zone will remain constant with time. This is equivalent to assuming that the salts emanating from Zones 1 and 2 have been completely removed by the geomedia or diluted to insignificant levels when compared to natural groundwater by the time the solution reaches Zone 5. This is equivalent to assuming that the groundwater flow is sufficiently large that it will dilute the leachate to the point that no competitive effects exist from the waste form and barrier's leachates. The K_d values in zone 5 can be considered to be time invariant in our conceptual model.

5.0 Summary Tables

Geochemical input values for the five zones identified in Table 1 and Figure 2 are presented in Tables 2 through 6. For Zones 1 and 2, solubility constraints are provided for some contaminants where appropriate. If the near-field solution concentration of a contaminant is above the "Solubility Limit," the solubility value will be used to control the solution concentration; if the solution concentration is below this value, then the K_d values will be used in the retardation factor equation to calculate solution concentrations. Four K_d values are provided in each table cell: a Reasonable Conservative K_d, a "Best" estimate (or most probable) K_d, and Upper and Lower K_d Limits. The Reasonable Conservative K_d is a reasonable lower-bounding value that takes into consideration potential conditions that may enhance radionuclide migration. This estimate was usually identical to the lower value of the range. For a few situations, the lower limit was not selected as the Reasonable Conservative K_d value because the lower limit value originated from a questionable experiment or the experimental conditions used to generate the value would yield a lower value than the conditions of the zone of interest merit. The "best" estimates are presented to provide guidance on what the most likely K_d value is for a given condition. This was based primarily on some central value of the literature or laboratory K_d values and on expert judgement. The concept of using a central value, the statistics, and the raw data involved in identifying this central value were presented by Kaplan and Serne (1995) for I, Np, Se, Tc, and U. The range is provided to help in uncertainty estimates and sensitivity analyses. The distribution of K_d values within this range is assumed to be log-normal.

For the empirical solubility estimates only Reasonable Conservative and "Best" estimate (or most probable) values are given. No ranges or solubility distributions are given at this time. If the 2001 ILAW PA shows that solubility constraints are important then some effort will be undertaken to improve the uncertainty/sensitivity calculations during the 2003 ILAW PA. Finally, supporting references for the selection of the various K_d and solubility values or estimates is provided.

Table 2a. K_d values for Zone 1 – Near Field[a]

Radio-nuclide	Reasonable Conservative K_d (mL/g)	"Best" K_d (mL/g)	K_d Range (mL/g)	Justification/References [b]
^3H, Cl, I, Se, Ru, C	0	0	0 to 1.1	C, Se, Cl, and I are anionic. ^3H will move with H_2O. Ru has often been suggested as being water coincident in tank leak scenarios based on gamma borehole logging. C as carbonate in high pH tank environments is insoluble and combines with alkaline earths. To account for insolubility a K_d value > 0 is appropriate but to keep C from getting stuck permanently in this source (high impact) zone the value was set at 0 (1, 2, 3).
Tc	0.1	1	0.1 to 1.2	Non-zero Tc K_d values exist for this condition, 1.04 ± 0.02 and 1.07 ± 0.03 mL/g, were measured in Hanford sediments in high pH, high ionic strength conditions (8).
Ac, Am, Ce, Cm, Eu	2	5	2 to 10	Estimated (2, 4)
Cs	1	1.5	1 to 25	Based on observations at T-106, cesium-137 seemed to peak at about 10 ft below the base (elevation) of the tank and nitrate at about 80ft. This implies an in situ Rf of about 8 or a K_d value of about 1 or 2 mL/g during the initial tank leak. The lack of cesium in groundwater beneath tanks suggests it has not broken through. Serne and Burke (7) measured a K_d of 26 ml/g for simulated REDOX tank liquor. But the results are not consistent with inferred Cs migration using gamma borehole logging at SX tank farm (6).
Co, Ni, Nb, Np, Pa, Sn	0.1	0.2	0.1 to 4	Estimated (4).
Sr, Ra	4	10	4 to 20	Sr is known to be rather insoluble in tank liquors and does not migrate through soils in tank liquor as rapidly as other cations (4).
Th, Zr, Pb, Pu	5	10	5 to 100	Estimated (2, 4).
U	5	20	10 to 800	Kaplan et al. (5) reported U- K_d values increased from ~2 to >500 mL/g when the pH of a Hanford sediment/groundwater slurry increased from 8.3 to > 10.5. The extremely high K_d was

Table 2a. K_d values for Zone 1 – Near Field[a]

				attributed to U (co)precipitation either as uranium phases or as calcite phases. Over a 1000-year period, it is anticipated that the solutions pH of any near field would eventually decrease. Thus, over time, the K_d values would be expected to decrease as the pH increased above ~10.5 and the uranium dissolved from the solid phase.

[a] The aqueous phase has a high pH, high radionuclide concentrations, and high ionic strength; the solid phase is dominated by backfill, glass, and glass secondary phases (Table 1 and Figure 1). No gravel correction to K_d values.
[b] References: 1 = Ames and Rai 1978; 2 = Thibault et al. 1990; 3 = Martin 1996; 4 = Ames and Serne 1991; 5 = Kaplan et al. 1998a; 6 = Hartman and Dresel 1997; 7 = Serne et al. 1998; 8 = Kaplan et al. 1998b.

Table 2b. Solubility Values for Designated Solids in Zone 1 – Near Field[a]			
Radio-nuclide	Reasonable Conservative Solubility Limit (M)	"Best" Solubility Limit (M)	Justification/References [b]
^{3}H, Cl, Tc, I, Se, Ru, C	—	—	At present, none of these contaminants have solubility constraints in glass leachate. Tc, C, Se, Cl, and I are anionic. ^{3}H is considered to be present as water. Ru may be present as the RuO_4^-.
Ac, Am, Ce, Cm, Eu,	1×10^{-7}	1×10^{-9}	Assume that glass leachate has high pH and is similar to concrete leachates. Concrete leachate solubility values can be realistically applied for hydrous oxide/metal hydroxides being the controlling solid. Solubility of these types solids are dependent almost solely on pH and nothing else in the pore fluids (1, 2, 3)
Cs	—	—	No solubility constraint is expected. But Cs could be incorporated into the glass weathering products. Ignoring this should be conservative but not overly so, seeing as adsorption will prevent Cs from reaching the water table.
Co, Ni	5×10^{-4}	5×10^{-7}	Assume that metal hydroxide is controlling solid and thus pH is the only sensitive variable. There is data for alkaline cement conditions and we will assume they hold for alkaline glass leachates (1, 2, and 3).
Nb, Np, Pa, Sn	5×10^{-4}	5×10^{-6}	Assume that metal hydroxide is the controlling solid. There is empirical data in Ewart et. al.(3) that predicts much lower than thermodynamic predictions (1, 2, 3).
Ra	1×10^{-5}	3×10^{-6}	Ra sulfate is the controlling solid. Bayless et al. (4) found no precipitation for Ra at 10^{-7} M in concrete leachate.
Sr	2×10^{-5}	1×10^{-7}	Sr carbonate forms in cements (1, 2, and 3) but for glass leachates we are not sure. These values may need to be revised or not used in order to be conservative.
Th, Zr, Pb, Pu	5×10^{-7}	1×10^{-8}	Assume solubility controlling phase of hydroxide/hydrous oxides for Th, Zr, Pu and hydroxycarbonates for Pb. There is data for Th and Pu in cement leachates under oxidizing and reducing conditions. We chose the oxidizing conditions (Ewart et al. (3)). Other assessments of these values are presented in (1,2).

Table 2b. Solubility Values for Designated Solids in Zone 1 – Near Field[a]

U	1×10^{-6}	1×10^{-7}	Two reports (1,2) discuss solubility in cements using U(VI) hydrous oxide [schoepite] and uranophane [calcium U(VI) silicate] as solubility control. Ewart et. al. (3) shows some empirical data for solubility in cement waters. Kaplan et al. (5) reported U- K_d values increased from ~2 to >500 mL/g when the pH of a Hanford sediment/groundwater slurry increased from 8.3 to > 10.5. The extremely high K_d was attributed to U (co)precipitation either as uranium phases or as calcite phases.

[a] The aqueous phase has a high pH, high radionuclide concentrations, and high ionic strength; the solid phase is dominated by backfill, glass, and glass secondary phases (Table 1 and Figure 2). No gravel correction to Kd values.
[b] References; 1 = Krupka and Serne (1998); 2 = Brady and Kozak (1995); 3 = Ewart et al. (1992); 4 = Bayliss et al. (1989); 5 = Kaplan et al. 1998a.

Table 3a. K_d Values for Zone 2 – Degraded Concrete[a]

Rad	Young Concrete (pH~12.5)			Moderately Aged Concrete (pH~10.5)			Aged Concrete (pH~8.5)			Justification/References [b]
	Conservative K_d (mL/g)	"Best" K_d (mL/g)	K_d Range (mL/g)	Conservative K_d (mL/g)	"Best" K_d (mL/g)	K_d Range (mL/g)	Conservative K_d (mL/g)	"Best" K_d (mL/g)	K_d Range (mL/g)	
^3H, Tc	0	0	0 to 2	0	0	0 to 2	0	0	0 to 1	Tc may be slightly sorbed to concrete, albeit, very little (1, 2, 3, 4, 5, and 6).
Cl	0.8	8	0.8 to 25	1	2	1 to 5	0	0	0 to 1	Estimated. French sulfate-resistant cement had a Cl K_d of 25 mL/g (7). Cl diffused through cement disks slower than ^3H (8). Cl K_d to cement powder after 24-hr contact time = 0.8 mL/g (9)
I	10	20	10 to 150	5	8	5 to 15	1	2	1 to 5	Iodide K_d values of 7 types of concrete samples increased gradually over 3 months, than leveled off to between 25 and 130 mL/g (10, 11). After 300 days contact with various cements, 77 to 98% iodide sorbed; even more iodate sorbed. I^- sorption to cement is very concentration dependent: at 10^{-8} I^- K_d = 1000 mL/g at 10^{-2} M I^- K_d = 1.4 mL/g (12). I^- sorption to cement is highly reversible (12). Iodine K_d in 7 day contact = 2.5 mL/g; after 30 days 7.7 mL/g (13).
C	10	20	10 to 1000	5	10	5 to 1000	0	0	0	Carbon-14 chemistry is complicated in cement; C (co)precipitation more important process in concrete than adsorption. See solubility discussion in Table 3b and (18).
Ac, Am, Ce Cm, Eu	2000	5000	2000 to 40000	1000	5000	1000 to 30000	400	500	400 to 1000	Trivalent metal K_d values to concrete exceed those to sediments (1). Am K_d >10,000 mL/g (14). Am K_d ~12,000 mL/g based on diffusion

Table 3a. K_d Values for Zone 2 – Degraded Concrete[a]										
										tests of cement (15). Am K_d values ranged from 2,500 to 35,000 mL/g for 7 different fresh (unaged)-concrete blends (10, 11). Am K_d for 65-yr old concrete sample = 10,000 (10, 11). Fresh cement Am-K_d = 2000 for 24-hr contact time (9). Eu-K_d = 2,400 mL/g for 24 hr contact time (9).
Co, Ni, Ra, Sn	70	100	70 to 250	70	100	70 to 250	7	10	7 to 25	Co-K_d = 4,300 mL/g (9). Ni-K_d for 3 cement types: 500 to 3000 mL/g (16), 1500 mL/g (9), and 500 to 3000 mL/g (17.
Nb, U	700	1000	700 to 2500	700	1000	700 to 2500	70	100	70 to 250	U(VI)-K_d's for 7 types of cement = 350 to 13,000, average = ~1000 and median = 1400 mL/g (10, 11)
Cs	2	3	2 to 5	20	30	20 to 50	20	30	20 to 50	Cs K_d's in hardened HTS cement discs, pH ~13.3, were 3 mL/g (7). Cs Kd's of 0.2 mL/g were measured in hardened sulfate resisting cement (12). Many authors have reported increase sorption at pH ~12.5 (13, reviewed by 23).
Np, Pa	1400	2000	1400 to 10000	1400	2000	1400 to 10000	140	200	140 to 500	The dominant protactinium species is assumed to be Pa O_2^+. NpO_2^+ is assumed to be a reasonable analog (19). Np sorption test to 7 different 65-yr old cements using cement pore water reached steady state after 30 days, Kd's ranged 1500 to 9500 mL/g (10, 11).
Ru, Se	1	2	1 to 800	1	2	1 to 100	0	1	0 to 300	Estimated. Dominant species for Se and Ru were assumed to SeO_4^{2-} and RuO_4^{2-} respectively (19). Ru K_d's in Hanford sediment (not concrete) did not change systematically with pH; at pH 8.5 the K_d was 274 mL/g; at pH 10.4, 44 mL/g; and at pH 14, 752 mL/g (21). Using a

Table 3a. K_d Values for Zone 2 – Degraded Concrete[a]

										pH 12 simulated tank waste solutions and Hanford sediment, K_d values for Ru ranged from 2.14 to 0 mL/g, averaging about 0.8 mL/g (20). Sulfate may be used as an analog for selenate chemical behavior in concrete. Sulfate (or sulfite) is often included in concrete mixes and therefore it would be expected to be retained strongly by concrete, primarily by (co)precipitation constraints. Selenate adsorption, independent of precipitation processes would be expected to be rather large.
Pb, Pu, Th	1000	5000	1000 to 10000	1000	5000	1000 to 10000	100	500	100 to 1000	Estimated. Using 3, 65 yr-old, crushed concrete samples, and 7 different fresh concrete samples, Th-K_d were 2500 to 5500 mL/g (10, 11). Th-K_d values were: consistently less than Am-K_d's, greater than U-K_d's, and very similar to Np Pu K_d's (10, 11). Pu-K_d's ranged from 1000 to 12,000 mL/g (10, 11). Concrete containing reducing agents (BFS) did not have greater Pu K_d's than those that did not contain reducing agents. The high K_d values are attributed to high solubility of Pu in high pH solutions, not to adsorption/absorption processes (22)

[a] The aqueous and solid phases in this zone are greatly influenced by the presence of concrete. The concrete is assumed to age and form three distinct environment (Krupka and Serne 1998).

[b] References: 1 = Angus and Glasser 1985; 2 = Gilliam et al. 1989; 3 = Tallent et al. 1988; 4 = Brodda 1988; 5 = Serne 1990; 6 = Serne et al. 1992; 7 = Sarott et al. 1992; 8 = Johnston and Wilmot 1992; 9 = Kato and Yanase 1993; 10 = Allard et al 1984; 11 = Hoglund et al. 1985; 12 = Atkinson and Nickerson 1988; 13 = Hietanen et al. 1985; 14 = Ewart et al 1988; 15 = Bayliss et al. 1991; 16 = Hietanen et al. 1984; 17 = Pilkington and Stone 1990; 18 = Allard et al. 1981; 19 = Pourbaix 1966; 20 = Ames and Rai 1978; 21 = Rhodes 1957a,b; 22 = Krupka and Serne 1998; 23 = Bradbury and Sarott 1992.

Table 3b. Solubility Limits for Designated Solids for Zone 2 – Degraded Concrete[a]

Rad	Young Concrete (pH~12.5)		Moderately Aged Concrete (pH~10.5)		Aged Concrete (pH~8.5)		Justification/References [b]
	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	
^{3}H, ^{36}Cl, Tc, I, Ru, Se	—	—	—	—	—	—	We will assume no solubility constraint for these species although there could be some isotope exchange into cement and secondary minerals.
C	10^{-5}	10^{-6}	10^{-3}	10^{-4}	10^{-2}	10^{-3}	Estimated. Carbon-14 chemistry is complicated in cement; C (co)precipitation more important process in concrete than adsorption. Calcite will be a good controlling solid and the carbon-14 will be isotopically exchanged with stable C For young concrete assume that portlandite controls Ca to 6×10^{-3} M. For moderately aged cement and aged cement that the Ca is controlled at 10^{-2} M by some undefined reactions.
Ac, Am, Ce, Cm, Eu	1×10^{-7}	1×10^{-9}	3×10^{-7}	3×10^{-8}	1×10^{-5}	1×10^{-7}	Known cement values can be realistically applied for hydrous oxide/metal hydroxides being the controlling solid. These solids are dependent almost solely on pH, and nothing else in the pore fluids (1, 2, and 3).
Co, Ni	5×10^{-4}	5×10^{-7}	5×10^{-4}	1×10^{-6}	1×10^{-3}	2×10^{-5}	Assume that metal hydroxide is controlling solid and thus pH is the only sensitive variable. There is data for alkaline cement conditions and predictions for groundwater (aged cement end member) (1, 2, 3).

Table 3b. Solubility Limits for Designated Solids for Zone 2 – Degraded Concrete[a]

Rad	Young Concrete (pH~12.5)		Moderately Aged Concrete (pH~10.5)		Aged Concrete (pH~8.5)		Justification/References [b]
	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	
Nb, Np, Pa, Sn	5×10^{-4}	5×10^{-6}	1×10^{-3}	5×10^{-4}	1×10^{-3}	5×10^{-4}	Assume that metal hydroxide is the controlling solid. There is empirical data in Ewart et. al.[3] that predicts much lower than thermodynamic predictions (1, 2, 3).
Cs	—	—	—	—	—	—	No solubility constraint is expected.
Ra	1×10^{-5}	3×10^{-6}	1×10^{-5}	3×10^{-6}	1×10^{-5}	3×10^{-6}	Ra sulfate is the controlling solid. Bayless et al. (4) found no precipitation for Ra at 10^{-7} M in concrete leachate.
Sr	2×10^{-3}	1×10^{-7}	2×10^{-4}	1×10^{-6}	5×10^{-3}	1×10^{-3}	Sr carbonate forms in cements (1,2,3) and could be a plausible control in sediments also.
Pb, Pu, Th, Zr	5×10^{-7}	1×10^{-8}	5×10^{-7}	1×10^{-8}	5×10^{-6}	1×10^{-7}	Assume hydroxide/hydrous oxides for Th, Zr, Pu and hydroxycarbonates for Pb. There is data for Th and Pu in cement leachates under oxidizing and reducing conditions. We chose the oxidizing conditions (3). Other assessments of Pb, Pu, Th, and/or Zr solubility under these conditions have been conducted (1, 2).

Table 3b. Solubility Limits for Designated Solids for Zone 2 – Degraded Concrete[a]

Rad	Young Concrete (pH~12.5)		Moderately Aged Concrete (pH~10.5)		Aged Concrete (pH~8.5)		Justification/References [b]
	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	Conser-vative (M)	"Best" Solubility (M)	
U	1×10^{-6}	1×10^{-7}	1×10^{-6}	1×10^{-7}	1×10^{-6}	1×10^{-7}	Two reports (1,2) discuss solubility in cements using U(VI) hydrous oxide [schoepite] and uranophane [calcium U(VI) silicate] as solubility control. Ewart et. al. (3) shows some empirical data for solubility in cement waters. Kaplan et al. (5) reported U-Kd values increased from ~2 to >500 mL/g when the pH of a Hanford sediment/groundwater slurry increased from 8.3 to > 10.5. The extremely high Kd was attributed to U (co)precipitation either as uranium phases or as calcite phases. Serne et al. (6) discusses solubility of U in presence of groundwater.

[a] The aqueous and solid phases in this zone are greatly influenced by the presence of concrete. The concrete is assumed to age and form three distinct environment (Krupka and Serne 1998).

[b] References; 1 = Krupka and Serne (1998); 2 = Brady and Kozak (1995); 3 = Ewart et al. (1992); 4 = Bayliss et al. (1989); 5 = Kaplan et al. (1998a); 6 = Serne et al. (1999).

Table 4. Kd Values for Zone 3 – Chemically Impacted Far Field in Sand Sequence[a]

Radio-nuclide	Reasonable Conservative K_d (mL/g)	"Best" K_d (mL/g)	K_d Range (mL/g)	Justification/References[b]
^3H, Cl, Tc	0	0	0 to 0.1	Tc and Cl are anionic. ^3H will move with H_2O.
Ac, Am, Ce, Cm, Eu	100	350	100 to 1500	Am-K_d's: In low ionic strength Ca system, >1200 mL/g; In low ionic strength Na system, 280 mL/g (1)
C	5	20	5 to 50	Estimated. ^{14}C geochemistry complex and poorly described by K_d construct. ^{14}C is expected to enter liquid, solid and gas phase through volatilization (CO_2-gas), precipitation with calcite, isotopic exchange, and adsorption. Based on Martin (9), who measured ^{14}C-K_d values in Hanford sediments using uncontaminated Hanford groundwater (relatively low ionic strength). ^{14}C as $H^{14}CO_3K_d$ values increased during a 70 day contact time from 0 (1-hr contact time) to 400 mL/g in sediment and 20 (1-hr contact time) to 360 mL/g in calcrete. ^{14}C removed by solid phases never stabilized during 70 days, suggesting (co)precipitation reaction.
Co	150	300	150 to 2000	In 0.01 to 1 M Na system, K_d is 1060 to 4760 mL/g (2) In 0.01 to 1 M Ca system, K_d is 222 to 640 mL/g (2) Forms complexes, especially with organics.
Cs	40	80	40 to 2000	Estimated. In low ionic strength Na system, K_d is 64 to 1170 mL/g (2). No complexes. In low ionic strength Ca system, K_d is 790 to 1360 mL/g (2). Unpublished recent results from Zachara (PNNL, EMSP project) using Hanford sediments and simulated tank waste indicate that Cs sorption decreases markedly compared to when ionic strength is appreciably lower.
I	0	0	0 to 2	Anion. Estimated.
Ni, Sn, Nb	40	80	40 to 400	Ni is similar to Co but adsorbs slightly less possibly because of moderate complexing. Estimated (3, 4)
Np, Pa	0.2	0.8	0.2 to 5	Np K_d's in low ionic strength solutions = 0.4 to 4 mL/g (1). The dominant protactinium species is assumed to be PaO_2^+. NpO_2^+ is assumed to be a reasonable analog (10). Based on studies conducted at the Whiteshell Laboratories (personnel communications with Tjalle T

Table 4. Kd Values for Zone 3 – Chemically Impacted Far Field in Sand Sequence[a]

				(Chuck) Vandergraaf, Atomic Energy of Canada Limited, Pinawa, Manitoba, Canada), Pa sorbs appreciably more than Np. Thus, Pa-K_d estimates based on measured Np- K_d values will be conservative.
Pb	20	100	20-1000	Good absorber, insoluble. Estimated (4).
Pu	80	200	80 to 1000	K_d is >98 mL/g (5)
Ra, Sr	0.2	10	0.2 to 50	Na system, 1.7 to 42 mL/g for Sr-K_d (2). Ca system, 0.3 to 1.6 mL/g for Sr-K_d (2). In 4 M $NaNO_3$, Sr-K_d in Hanford sediment was 5 mL/g (pH 8), and 10 mL/g (pH 10) (12). Near identical K_d values using Savannah River Site Sediments and 30% $NaNO_3$ (13). Based on periodicity considerations, Ra would be expected to sorb more strongly to sediments than Sr. However, no Hanford Ra-K_d values are available. Thus, basing Ra-K_d estimates on measured Sr-K_d values will likely provide a conservative Ra-K_d estimate.
Ru	0	1	0 to 500	May form RuO_4^{2-} and/or anionic complexes with nitrates and nitrites. Estimate (3, 6, and 7).
Se	2	4	2 to 10	Anionic. Se K_d measured at the ILAW disposal site had K_d values of 6.7 ± 0.4 mL/g (14). Unpublished results of a Se sorption experiment to Hanford sediments in high ionic strength (NaOH and $NaOCl_4$) indicate Se Kd values of ~4 mL/g.
Th, Zr	40	300	40 to 500	Sandy soil data, K_d is 40 to 470 mL/g for Th (8).
U	2	10	2 to 500	Anionic and neutral carbonate and hydroxide species. Kaplan et al. (11) reported U-K_d values increased from ~2 to >500 mL/g when the pH of a Hanford sediment/groundwater slurry increased from 8.3 to > 10.5. The extremely high K_d was attributed to U (co)precipitation either as uranium phases or as calcite phases.

[a] The aqueous phase is moderately altered from the cement and glass leachate emanating from Zones 1 and 2; pH is between 8 (background) and 11, and the ionic strength is between 0.01 (background) and 0.1. The solid phase is in the sand-dominated sequence and is slightly altered due to contact with the moderately caustic aqueous phase (Table 1 and Figure 2).

[b] References: 1 = Routson et al. 1976; 2 = Routson et al. 1978; 3 = Ames and Serne 1991; 4 = Kaplan et al. 1995; 5 = Rhodes 1957a, b; 6 = Ames and Rai 1978; 7 = Barney 1978; 8 = Sheppard et al. 1976; 9 = Martin 1996; 10 = Pourbaix 1966; 11 = Kaplan et al. 1998a; 12 = Rhodes and Nelson 1957; 13 = Prout 1959; 14 = Kaplan et al. 1998c.

Table 5. Gravel-corrected Kd Values (Kd_{gc}) for Zone 4 – Chemically Impacted Far Field in Gravel Sequence[a]

Radio-nuclide	Reasonable Conservative Kd_{gc} (mL/g)	"Best" Kd_{gc} (mL/g)	Kd_{gc} Range (mL/g)	Justification/References [b]
^3H, Cl, Tc	0	0	0 to 0.01	No gravel-corrected K_d data available. Tc and Cl are anionic. ^3H will move with H_2O.
Ac, Am, Ce, Cm, Eu	10	35	10 to 150	No gravel-corrected K_d data available. Am-K_d's: In low ionic strength Ca system, >1200 mL/g; In low ionic strength Na system, 280 mL/g (1)
C	0.5	2	0.5 to 5	Estimated. No gravel-corrected K_d data available. ^{14}C geochemistry complex and poorly described by K_d construct. ^{14}C is expect to enter liquid, solid and gas phase through volatilization (CO_2-gas), precipitation with calcite, isotopic exchange, and adsorption. Based on Martin (9), who measured ^{14}C-K_d values in Hanford sediments using uncontaminated Hanford groundwater (relatively low ionic strength). K_d values increased during a 70 day contact time from 0 (1-hr contact time) to 400 mL/g in sediment and 20 (1-hr contact time) to 360 mL/g in calcrete. ^{14}C removed by solid phases never stabilized during 70 days, suggesting (co)precipitation reaction.
Co	15	30	15 to 200	No gravel-corrected K_d data available. In low ionic strength Na system, 1060 to 4760 mL/g (2) In low ionic strength Ca system, 222 to 640 mL/g (2) Forms complexes, especially with organics.
Cs	4	8	4 to 200	No gravel-corrected K_d data available. No complexes. Estimated. In 0.01 to 0.1 M Na system, 64 to 1170 mL/g (2). In 0.01 to 0.1 M Ca system, 790 to 1360 mL/g (2). Unpublished recent results from Zachara (PNNL, EMSP project) using Hanford sediments and simulated tank waste indicate that Cs sorption decreases markedly compared to when ionic strength is appreciably lower.
I	0	0	0 to 0.2	No gravel-corrected K_d data available. Anion. Estimated.
Ni, Sn, Nb	4	8	4 to 40	Ni is similar to Co but adsorbs slightly less possibly because of moderate complexing. Estimated (3, 4)

Table 5. Gravel-corrected Kd Values (Kd_{gc}) for Zone 4 – Chemically Impacted Far Field in Gravel Sequence[a]

Np, Pa	0.02	0.08	0.04 to 0.5	No gravel-corrected K_d data available. Np K_d's in low ionic strength solutions = 0.4 to 4 mL/g (1). The dominant protactinium species is assumed to be PaO_2^+. NpO_2^+ is assumed to be a reasonable analog (10). Based on studies conducted at the Whiteshell Laboratories (personnel communications with Tjalle T (Chuck) Vandergraaf, Atomic Energy of Canada Limited, Pinawa, Manitoba, Canada), Pa sorbs appreciably more than Np. Thus, Pa-K_d estimates based on measured Np- K_d values will be conservative.
Pb	2	10	2 to 100	No gravel-corrected K_d data available. Good absorber, insoluble. Estimated (4).
Pu	8	20	8 to 100	No gravel-corrected K_d data available. >98 mL/g (5)
Ra, Sr	0.02	1	0.02 to 5	Na system, 1.7 to 42 mL/g for Sr-K_d (2). Ca system, 0.3 to 1.6 mL/g for Sr-K_d (2). In 4 M $NaNO_3$, Sr-K_d in Hanford sediment was 5 mL/g (pH 8), and 10 mL/g (pH 10) (12). Near identical K_d values using Savannah River Site Sediments and 30% $NaNO_3$ (13). Sr-K_d values measured in low ionic strength conditions and with Hanford sediments containing sediments are presented in Appendix A. Based on periodicity considerations, Ra would be expected to sorb more strongly to sediments than Sr. However, no Hanford Ra-K_d values are available. Thus, basing Ra-K_d estimates on measured Sr-K_d values will likely provide a conservative Ra-K_d estimate.
Ru	0	0.1	0 to 50	No gravel-corrected K_d data available. May form RuO_4^{2-} and/or anionic complexes with nitrates and nitrites. Estimate (3, 6, and 7).
Se	0.2	0.4	0.2 to 1	No gravel-corrected K_d data available. Anionic. Se Kd measured at the ILAW disposal site had K_d values of 6.7 ± 0.4 mL/g (14). Unpublished results of a Se sorption experiment to Hanford sediments in high ionic strength (NaOH and $NaOCl_4$) indicate Se K_d values of ~4 mL/g.
Th, Zr	4	30	4 to 50	No gravel-corrected K_d data available. Sandy soil data, 40 to 470 mL/g for Th (8).
U	0.2	1	0.2 to 50	No gravel-corrected K_d data available. Anionic and neutral carbonate and hydroxide species. Kaplan et al. (11) reported U-Kd values increased from ~2 to >500 mL/g when the pH of a Hanford sediment/groundwater slurry increased from 8.3 to > 10.5. The extremely high Kd was attributed to U (co)precipitation either as uranium phases or as calcite phases.

[a] The aqueous phase is moderately altered from the cement and glass leachate emanating from Zones 1 and 2; pH is between 8 (background)

Table 5. Gravel-corrected Kd Values (Kd_{gc}) for Zone 4 – Chemically Impacted Far Field in Gravel Sequence[a]

and 11, and the ionic strength is between 0.01 (background) and 0.1. The solid phase is in the sand-dominated sequence and is slightly altered due to contact with the moderately caustic aqueous phase (Table 1 and Figure 2).

[b] References: 1 = Routson et al. 1976; 2 = Routson et al. 1978; 3 = Ames and Serne 1991; 4 = Kaplan et al. 1995; 5 = Rhodes 1957a, b; 6 = Ames and Rai 1978; 7 = Barney 1978; 8 = Sheppard et al. 1976; 9 = Martin 1996; 10 = Pourbaix 1966; 11 = Kaplan et al. 1998a; 12 = Rhodes and Nelson 1957; 13 = Prout 1959; 14 = Kaplan et al. 1998c.

Table 6. Gravel-corrected Kd Values (Kd_{gc}) for Zone 5 – Far Field in Gravel Sequence[a]

Radio-nuclide	Reasonable Conservative Kd_{gc} (mL/g)	"Probable" Kd_{gc} (mL/g)	Kd_{gc} Range (mL/g)	Justification/References[b]
^3H, Cl, Tc	0	0	0 to 0.06	No laboratory results of gravel-K_d values available. Tc exists predominantly as TcO_4^-. A review of Hanford sediment Tc-K_d values showed a range of -2.8 to 0.6 mL/g for 15 observations; median was 0.1-mL/g (1). Later studies did not change this range but did decrease the median slightly to -0.1 mL/g (2). Negative K_d values are possible and may not be an experimental artifact (2). ^3H is expected to move along with water. Cl is expected to behave as a dissolved anionic species. Most recent results using ILAW specific borehole sediments [299-E17-21] yielded Tc-K_d of 0 mL/g (18). Gravel correction of negative K_d values in Estimated K_d Range was assumed to make Kd less negative by a factor of 0.9 because of reduced surface area that would create the anion exclusion.
Ac, Am, Ce, Cm, Eu	6	30	6 to 130	No laboratory results of gravel-K_d values available. Am-K_d: 67 to >1200 mL/g (3). Am-K_d: 125 to 833 mL/g (4)
C	0.05	0.5	0.05 to 100	No laboratory results of gravel-K_d values available. Assumed dominant species: HCO_3^-. Three processes will be acting on the ^{14}C to take it out of solution: adsorption onto the calcite surface, volatilization as CO_2 gas, and precipitation into the calcite structure. The latter process is largely irreversible, therefore it is not well represented by the K_d construct (K_d assumes that adsorption occurs as readily as desorption). Volatilization is entirely removed from the definition of the K_d construct. In systems that contain higher concentrations of carbonate minerals, such as the calcrete layer in the 200 West Area, an appreciably higher K_d should be used to account for the isotopic dilution/precipitation reaction that may occur, a K_d of 100 mL/g would be appropriate for such a system. Since most of the 100 and 200 plateau areas contain <1% carbonate, lower K_d values are warranted for these areas, such as 0.5 mL/g. K_d values of ^{14}C of >250 mL/g have been measured in calcite ([5]). At 100K Area, the C-14 is widely distributed down gradient from a major source (crib). Additional references: 6, 7, 8, 9, and 10. Estimated range.

Table 6. Gravel-corrected Kd Values (Kd_{gc}) for Zone 5 – Far Field in Gravel Sequence[a]				
Co	100	200	100 to 1250	No laboratory results of gravel-K_d values available. Na system, 1290 to 2120 mL/g (11); Ca system, 2000 to 3870 mL/g (11); Hanford sediment/groundwater system 11600 to 12500 mL/g (12)
Cs	50	200	50 to 400	No laboratory results of gravel-K_d values available. Na system, 1410 to 1590 mL/g (11) Hanford sediment/groundwater system, 540 to 3180 mL/g (12).). Most recent results using ILAW specific borehole sediments [299-E17-21] yielded K_d of 2,030 ± 597(18).
I	0	0.01	0 to 1.5	No laboratory results of gravel-K_d values available. A review of Hanford sediment I-K_d values showed a range of 0.7 to 15 mL/g for 9 observations; median was 0.7-mL/g (1). Later studies increased this range to 0.2 to 15 mL/g; the median was decreased to 0.3 mL/g (2). Most recent results using ILAW specific borehole sediments [299-E17-21] yielded K_d of 0 mL/g. See Kaplan et al. (18) for details.
Ni, Sn, Nb	5	30	5 to 250	No laboratory results of gravel-K_d values available. Ni: Hanford sediment/groundwater system, 440 to 2350 mL/g (12) Ni: A study of a broad range of sediments, including those from Hanford had Ni-Kd's of 50 to 340 mL/g (13).
Np, Pa	0.2	1.5	0.2 to 2.5	No laboratory results of gravel-K_d values available. A review of Hanford sediment Np-K_d values showed range of 2.4 to 21.7 mL/g for 4 observations; median was 17.8 mL/g (1). Later studies increased the K_d's to 2.2 to 21.7 mL/g; the median of these later studies was 15 mL/g (2). The dominant protactinium species is assumed to be PaO_2^+ and NpO_2^+ is assumed to be a reasonable analog (19). Based on studies conducted at the Whiteshell Laboratories (personnel communications with Tjalle T (Chuck) Vandergraaf, Atomic Energy of Canada Limited, Pinawa, Manitoba, Canada), Pa sorbs appreciably more than Np. Thus, Pa-K_d estimates based on measured Np- K_d values will be conservative.
Pb	800	1000	800 to 8000	No laboratory results of gravel-K_d values available. pH 6 and no competing ions: 13,000 to 79,000 mL/g (14)
Pu	5	15	5 to 200	No laboratory results of gravel-K_d values available. Pu(V, VI): pH 4 to 12: 80 to >1980 mL/g (17)
Ra, Sr	0.5	1.4	0.5 to 20	Sr K_d values: Na system, 173 mL/g, 49 to 50 mL/g (11), Ca system, 8 to 13 mL/g, 5 to 19 mL/g (11), 5 to 120 mL/g (15), 19.1 to 21.5 mL/g (12), Na system, pH 7 to 11, 14.9 to 25.1 mL/g (16). Recent data using ILAW borehole sediment [299-E17-21] yielded Sr-K_d values

Table 6. Gravel-corrected Kd Values (Kd_{gc}) for Zone 5 – Far Field in Gravel Sequence[a]

				of 14.3 ± 1.6 mL/g (18). See Appendix A for Sr K_d values measured with sediments containing gravel. Based on periodicity considerations, Ra would be expected to sorb more strongly to sediments than Sr. However, no Hanford Ra-K_d values are available. Thus, basing Ra-K_d estimates on measured Sr-K_d values will likely provide a conservative Ra-K_d estimate.
Ru	1	2	1 to 100	No laboratory results of gravel-K_d values available. Estimated (17 as cited in 11)
Se	0.3	0.7	0.3 to 1.5	No laboratory results of gravel-K_d values available. Hanford groundwater/sediment system: -3.44 to 0.78 mL/g (12). Most recent data using ILAW borehole sediment [299-E17-21], which did not contain measurable amounts of gravel, yielded K_d values ranging from 3.75 to 10.85 mL/g and had an average of 6.7 ± 1.9 mL/g (18).
Th, Zr	4	100	4 to 250	Estimated. No laboratory results of gravel-K_d values available. Zr: pH 6 to 12 : 90 to >2000 mL/g (15)
U	0.05	0.06	0.01 to 8	No laboratory results of gravel-K_d values available. A review of Hanford sediment U-K_d values showed range of 0.1 to 79.3 mL/g for 13 observations; median was 0.6-mL/g (1). Results from later studies support the range (2). In all reported data, some U was adsorbed by Hanford sediments and >90% of the values were between 0.6 and 4 mL/g. Most recent work with the ILAW Borehole sediment [299-E17-21] yielded K_d of 0.6 ± 0.1. See (18).

[a] The aqueous phase is untainted Hanford groundwater except for trace levels of radionuclides; the solid phase is composed of the unaltered gravel-dominated sequence material (Table 1 and Figure 2). Kd_{gc} is the gravel-corrected Kd value as defined in Equation 6. Kd values for the far field, without a gravel correction, are presented in Appendix B.

[b] References: 1 = Kaplan and Serne 1995b; 2 = Kaplan et al. 1998b; 3 = Routson et al. 1976; 4 =Sheppard et al. 1976; 5 = Martin 1996; 6 = Striegl and Armstrong 1990; 7 = Garnier 1985; 8 = Allard et al. 1981; 9 = Mozeto et al. 1984; 10 = Zhang et al. 1995; 11 = Routson et al. 1978; 12 = Serne et al. 1993; 13 = Serne and Relyea 1983; 14 = Rhoads et al. 1994; 15 = Rhodes 1957a; 16 = Nelson 1959; 17 = Rhodes 1957a, b; 18= Kaplan et al. 1998c; 19 = Pourbaix 1966.

6.0 Review Process

6.1. Internal PNNL Review

Scientists from the Applied Geology and Geochemistry group that are not contributors to the ILAW project performed an internal peer review concurrent with the Hanford Review and to cover the required PNNL/DOE document clearance process. The Data Package was created in the format of a typical PNNL topical report.

6.2. Hanford Review

The Hanford Personnel who reviewed this data package are:

- Fred Mann, Fluor-Daniel Northwest
- Harry Babad, WHC retired (private consultant)
- Tom E. Jones, MacTec-Meier

We have received and addressed the comments of the Internal Hanford Review Team in the September 10, 1999 version of the document. The comments were not contentious enough to warrant a comment resolution meeting prior to submittal for review by the other Hanford organizations [DOE/BHI/LMHC].

The September 10, 1999 version of the Geochemical Data Package was then sent concurrently to DOE-RL/ORP [Richland Operations Office of River Protection], BHI, and LHMC project management for review. Their comments were minor. The Data Package was revised a second time on September 20, 1999. This revision was sent to the external review team.

6.3. External Review

We solicited review comments from external reviewers. The members of the External Review were:

- Patrick V. Brady, Sandia National Laboratory
- Steve Serkiz, Westinghouse Savannah River Company
- Tjalle T. (Chuck) Vandergraaf, Atomic Energy of Canada, Limited at Pinawa, Manitoba, Canada.

Resumes for these three reviewers are available from R. J. Serne at PNNL. The reviewers were given the Data Package and instructions on what is expected of them. After they reviewed the instructions and had all questions answered, the review process started in FY00. The three sets

of review comments were considered and our responses to the individual questions were shared among all external reviewers. This occurred in mid-December 1999. A final review was performed by Fred Mann prior to submittal to Lockheed and DOE-RL on December 20, 1999. Each reviewer prepared comments on the electronic September 20, 1999 draft and in emails. Our responses to the main comments were prepared and an electronic file [Respon~2.doc] was circulated. The final draft of the data package December 20, 1999 and the response file will be used by the reviewers to finalize any comments. These final comments, the Respon~2.doc electronic file and the data package will become part of the public record associated with this data package.

6.4. Scope of the Work Reviewed

The reviewers (both internal and external) were given the data tables of Kd and solubility controls for each of the six geochemical zones for each contaminant, the reference to the publicly available documents that were used , and the rationale for the choice of each value. The rationale, for those values that were chosen by relying on expert judgment and generic literature, were especially clearly documented. We also prepared a general description of our overarching philosophy on approaching the selection of geochemical parameters for the ILAW PA in chapter 2. In the final version of the data package public record we will include an assessment of how satisfied we are with the technical defensibility of each selected value and a priority listing on which parameters deserve the attention of future funding. The prioritization will also include a brief discussion of the types of test that would best be performed to improve technical defensibility and what key parameters should be controlled, varied or monitored in the experimental test program.

6.5. Review Criteria

The reviewers were given all the above material and were asked to review/comment on several levels including:

- understandability of the overall geochemical approach from a "layman's " and "systems PA" approach
- technical defensibility of the overall geochemical approach (peer to peer technical comments)
- technical opinion on the particular Kd and solubility constraints provided for each geochemical zone and contaminant
- request for missing/overlooked data that the reviewers think would improve selected values
- opinion on our assessment of satisfaction of the "defensibility" for each value or contaminant's overall geochemical data base
- assessment of our choice and prioritization for future work regarding contaminants that need more study and on the type of tests to perform and what are the key parameters to vary, monitor, or control.

6.6. Schedule

TABLE 7. SCHEDULE FOR GEOCHEMICAL DATA PACKAGE APPROVAL

	Item	Date
1	Send Data Package Plan to Technical Representative for Review	March 30, 1999
2	Final Plan, Incorporating Comments Issued By The Tech. Rep.	April 30, 1999
3	Inform technical representative by electronic message that Kd selection of Zones 3, 4, 5 and 6 have been completed	June 30, 1999
4	Send out Draft Data Package for Internal Hanford Review	July 1, 1999
5	Get comments back from Hanford Technical Review	July 12, 1999
6	Send out Draft Data Package to DOE/BHI/LHMC	September 30, 1999
7	Get comments back from other Hanford Organizations	October 15, 1999
8	Respond to Hanford Reviewers' comments	October 31, 1999
9	Send final Hanford Reviewed Draft to Outside Reviewers	October 8, 1999
10	Respond to Outside Reviewers First Round of Comments	November 15, 1999
11	Respond to Outside Reviewers 2nd Round of Comments	December 10, 1999
12	Get final/formal letter comments back from Reviewers and Complete Data Package	December 31, 1999

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7.0 References

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8.0 Appendices

Appendix A - A Less Conservative Approach to Correcting Kd Values for the Presence of Gravel

Appendix B - Kd Values For Far-Field Sediment Conditions

Appendix C - Discussion on Double Layer and Film Thickness

Appendix D - Information Requested For Near Field Geochemical Transport Modeling

Appendix A - A Less Conservative Approach to Correcting Kd Values for the Presence of Gravel

An alternative approach to correcting Kd values that is less conservative than the approach used in the data package is provided. This approach was developed from a project conducted in conjunction with the ILAW PA. A manuscript of this research has been submitted for publication and is included in this appendix.

The equation used for gravel-corrected Kd values was:

$$Kd_{gc,g=0} = (1-f)Kd_{<2mm} \quad \text{(A-1)}$$

where f equaled 0.9. Thus, all the Kd values in the gravel-dominated sequence was reduced by an order of magnitude (1 – f = 1 – 0.9 = 0.1). An alternative correction would be:

$$Kd_{gc,g=x} = (1-f)Kd_{<2mm} + (f)Kd_{>2mm}. \quad \text{(A-2)}$$

Equation A-1 underestimated actual Kd_{total} by 28 to 47%, whereas Equation A-2 slightly overestimated Kd_{total} by 3 to 5%. Equation A-1 is conservative and Equation 2 is not, although the difference between Kd_{total} and $Kd_{gc,g=x}$ is not significant ($P < 0.05$). Equation A-1 becomes less and less accurate, i.e., the degree to which it underestimates Kd_{total} increases, as the percent of gravel (f) increases. At $f = 0.9$, $Kd_{gc,g=0}$ will greatly underestimate the actual Kd_{total}.

An attempt was made to apply Equation A-2 to the gravel corrections. We have laboratory data on Sr and Cs for $Kd_{>2mm}$, i.e., for 2 of the 26 radionuclides for which Kd data is needed for the data package. The ratio of $Kd_{>2mm}/Kd_{<2mm}$ for Sr and Cs were 0.23 and 0.42, respectively.

Assuming all radionuclides have a $Kd_{>2mm}/Kd_{<2mm}$ of 0.23, we can rewrite Equation A-2 as:

$$Kd_{gc,g=x} = (1-f)Kd_{<2mm} + (f)0.23Kd_{<2mm}. \quad \text{(A-3)}$$

and then by setting $f = 0.9$, this simplifies to:

$$Kd_{gc,g=x} = 0.31Kd_{<2mm}. \quad \text{(A-4)}$$

Thus, gravel corrected Kd values based on Equation A-4 will be 210% greater than those based on Equation A-1. Equation A-4 is likely to provide a more accurate estimate than Equation A-1, especially at the high gravel concentrations needed for the PA. However, and perhaps more importantly, more uncertainty is associated with the approach presented in A-4, due to the lack of $Kd_{<2mm}$ for each radionuclide.

DRAFT

Gravel-Corrected Kd Values

Daniel I. Kaplan [a], Igor V. Kutnyakov [b], Amy P. Gamerdinger [c], R. Jeff Serne [b], Kent E. Parker [b]

[a] Westinghouse Savannah River Company, Aiken, SC 29808. (803) 725-2363.
[b] Pacific Northwest National Laboratory, Mailstop K6-81, Richland, WA 99352. (803) 376-5952.
[c] Washington State University, Department of Chemistry, Richland, WA 99352. (803) 373-3077.

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Gravel-Corrected Kd Values

Abstract

Standard measurements of solute sorption to sediments are typically made on the <2-mm sediment fraction. This fraction is used by researchers to standardize the method, and to ease experimental protocol, whereby large labware is not required to accommodate the large gravel fraction (>2-mm particles). Since sorption is a phenomenon directly related to surface area, sorption measurements based on the <2-mm fraction would be expected to underestimate actual whole-sediment values for sediments containing gravel. This inaccuracy, referred to as the Gravel-Kd Issue, is a problem for ground water contaminant transport modelers who use laboratory-derived sorption values, typically expressed as a distribution coefficients (Kd), to calculate the retardation factor (Rf), a parameter that accounts for solute-sediment chemical interactions. The objectives of this laboratory study were to quantify the effect of gravel on Kd and Rf values and to develop an empirical method to calculate gravel-corrected Kd values. Three gravel corrections, Kd_{gc} values, were evaluated: 1) a correction based on the assumption that the gravel simply diluted the $Kd_{<2mm}$ and had no sorption capacity ($Kd_{gc,g=0}$), 2) a correction based on the assumption that the Kd of the intact sediment (Kd_{tot}) was a composite of the $Kd_{<2mm}$ and the $Kd_{>2mm}$ ($Kd_{gc-g=x}$), and 3) a correction based on surface area ($Kd_{gc,surf}$). On average, $Kd_{<2mm}$ tended to overestimate Kd_{tot} by 28 to 47%; $Kd_{gc,g=x}$ overestimated Kd_{tot} by only 3 to 5%; $Kd_{gc,g=0}$ and $Kd_{gc,surf}$ underestimated Kd_{tot} by 10 to 39%. Although, $Kd_{gc-g=x}$ provided the best estimate of actual values (Kd_{tot}), $Kd_{gc-g=0}$ was appreciably easier to acquire. These results have important implications regarding the traditional approach to modeling contaminant transport which uses $Kd_{<2mm}$ values. Such calculations may overestimate the ability of gravel-containing sediments to retard contaminant migration, thereby overestimating lower-bounding limits of contaminant migration. Use of gravel-corrected Kd values will improve such lower-bounding estimates.

Introduction

The extent that contaminants sorb to sediments is typically measured in the laboratory using a batch test in which the <2-mm particle size fraction of the sediment is placed into contact with an aqueous phase containing the contaminant of interest. The <2-mm fraction is used to standardize the method and to ease the experimental protocol, whereby large labware is not required to accommodate the gravel (>2-mm particles). The distribution coefficient, or Kd value, is the simplest construct describing contaminant sorption to sediments. It is the ratio of the contaminant concentration sorbed to the solid phase divided by the contaminant concentration in the liquid surrounding the solid phase (Equation 1):

$$Kd = \frac{C_{solid}}{C_{liquid}} \tag{1}$$

where C_{solid} (M kg^{-1}) and C_{liquid} (M L^{-1}) are the concentration in the solid and liquid phases, respectively. Since sorption is typically a surface reaction phenomenon (Sposito 1984), the extent of sorption based on the <2-mm fraction will overestimate the true extent of sorption for the entire sediment, especially in sediments dominated by gravel.

The discrepancy between the laboratory Kd value and the true field value due to excluding the gravel from the laboratory samples is referred to as the "gravel-Kd issue." Contaminant transport modelers commonly use Kd values to account for chemical interactions between the contaminant and the sediment. The Kd value is used to define the retardation factor, which is the ratio of the average linear velocity of water (m s^{-1}) divided by the average linear velocity of the contaminant (m s^{-1}). The Kd value is related to the retardation factor (Rf, unitless) by the bulk density (ρ_b, kg m^{-1}) and the porosity (η, m^3 m^{-3}) as follows (Valocchi 1984, Bouwer 1991):

$$Rf = \left(1 + \frac{Kd\rho_b}{\eta}\right). \tag{2}$$

As gravel concentrations in a sediment increase, the Kd value would be expected to decrease because the specific surface area of the sediment decreases; the bulk density would be expected to increase. These changes in sediment properties have opposite effects on the magnitude of the retardation factor (Equation 2). Bulk density values in the subsurface typically vary between 2650 kg m^{-3} (the density of a solid quartz crystal) to 1180 kg m^{-3} (the density of closely packed clay-size particles). Kd values of many metals and cationic radionuclides often vary by several orders of magnitude as a function of particle size (reviewed by Ames and Rai 1978 and Thibault et al. 1990). Thus, it is likely that the introduction of gravel to a system will cause the actual retardation factor to decrease because the Kd values will decrease to a greater extent than bulk density values will increase. An important implication of this conclusion is that transport modelers using traditional Kd values measured with the <2-mm sediment fraction will likely overestimate the ability of a gravel-containing sediment to retard contaminant movement, thereby overestimating lower-bounding limits of contaminant migration.

The objectives of this study were to: 1) quantify the effect of gravel on Kd and Rf values, and 2) develop a method to calculate gravel-corrected Kd values (Kd_{gc}). The intent of this research was to conduct batch-sorption experiments to develop a Kd_{gc} that would be beneficial to contaminant transport modelers. Thus, we wanted the corrections to be based on the traditional Kd value, $Kd_{<2mm}$, for which there is an extensive literature base. Also, any additional parameters needed for the correction had to be easily obtainable, which would rule out extensive solid phase characterization.

Materials and Methods

Two laboratory experiments were conducted using similar experimental protocols. In the Natural Sediment Experiments, Sr sorption to various size fractions of eight natural, gravel-containing sediments was measured. In the Gravel-Amended Experiment, Sr sorption to sediments amended with varying amounts of gravel was measured. Three gravel corrections were evaluated: 1) a correction based on the assumption that the gravel simply diluted the $Kd_{<2mm}$ and had no sorption capacity ($Kd_{gc,g=0}$), 2) a correction based on the assumption that the Kd of the intact sediment (Kd_{tot}) was a composite of the $Kd_{<2mm}$ and the $Kd_{>2mm}$ ($Kd_{gc-g=x}$), and 3) a correction based on surface area ($Kd_{gc,surf}$). Strontium was selected as a trace solute because its geochemistry is relatively simple. It exists almost exclusively as the Sr^{2+} species between pH 3 to 9.5 and it sorbs to sediments almost exclusively by cation exchange (Ames and Rai 1978, Kaplan et al. 1998). It was anticipated that the relative simplicity of Sr geochemistry would ease data interpretation.

General Sorption Procedure

The general procedure used in the two experiments was identical. The solid phases (natural sediment or gravel-amended sediment) was first pre-equilibrated with an uncontaminated ground water collected from the Hanford Site located in Richland, Washington (Well 600-S3-25, Table 1). This was accomplished by adding the ground water to the solid phases (typically in a 40:1 solution to solid ratio), shaking the suspensions overnight, centrifuging, decanting the supernatant, and then measuring the supernatant pH. This was repeated until the pH of the wash solution did not change by more than ± 0.05 units before and after contact with the solid phase. Equilibration by this method typically required three washings. The purpose of the pre-equilibration step was to isolate the Sr-adsorption reaction from other reactions that may occur while sediments and solutions came to chemical equilibrium.

A portion of the equilibrated ground water solution was amended with 25-μCi L^{-1} ^{85}Sr, as carrier-free Sr^{2+}, and then mixed overnight on a platform shaker. The ^{85}Sr-amended solution was then placed in contact with the solids. The solid-to-solution ratio was 1:30 (wt:wt). This relatively low solid-to-solution ratio provided optimal sensitivity for measuring K_d values in the range of 10 to 30 L kg^{-1}. The aqueous ^{85}Sr/sediment suspensions were placed on a slow-moving platform shaker to equilibrate for 14 days. After equilibration, the suspensions were centrifuged and then passed through 0.45-μm filters. The ^{85}Sr activity and pH of the filtrates were measured. The ^{85}Sr activity was measured with a germanium detector. All radiological counting was performed to a 3% total error.

Distribution coefficients (K_d, L kg^{-1}) were calculated using Equation 3. This equation accounts for the dilution of the initial ^{85}Sr-amended solution by the interstitial ground water remaining in the sediment after the final pre-equilibrating wash (i.e., the ^{85}Sr-free ground water left in the tube after pre-equilibration):

$$Kd = \frac{(C_{initial} \times V_{initial}) - C_{final}(V_{initial} + V_{interstitial})}{C_{final} \times M_{sediment}} \quad (3)$$

where $V_{interstitial}$ is the volume of the interstitial solution left after the final pre-equilibration wash (L), $M_{sediment}$ is the sediment mass (kg), $V_{initial}$ is the volume of the ^{85}Sr-amended solution added to the sediment (L), C_{final} is the ^{85}Sr concentration in the effluent solution after contact with the sediment (Ci L^{-1}), and $C_{initial}$ is the ^{85}Sr concentration in the ^{85}Sr-amended solution added to the solids (Ci L^{-1}).

Two types of control treatments were included in these experiments: a negative and a positive control. The positive control consisted of the ^{85}Sr-amended aqueous phase, $C_{initial}$, and no solid phase. This control monitored Sr sorption to labware and filters. The negative control consisted of the solid and aqueous phases without added ^{85}Sr. This control quantified the amount of ^{85}Sr in the uncontaminated aqueous and solid phases or introduced into the experiment through laboratory activities. Four replicates of controls and of each treatment were included in the experimental design.

The ground water used in this study was characterized by standard methods. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) was used to determine dissolved cation concentrations. It had an analytical precision of $\leq \pm 4\%$ at 5 mg L^{-1} cation concentrations. Ion chromatography (IC) was used to determine dissolved anion concentrations. It had an analytical precision of $\leq \pm 4\%$ at 5 mg L^{-1} anion concentrations. A carbon analyzer was used to determine total and inorganic carbon (Nelson 1987).

Sediment characterization was conducted using standard methods. Cation exchange capacity (CEC) was determined by the Na^+ - ion exchange method that is specifically designed for arid sediments (Rhodes 1987). Particle size distribution was determined by the sieve and pipette method (Gee and Bauder 1987). Bulk density and porosity were determined gravimetrically by repacking dry sediments in a column assembly (Klute and Dirksen 1986). pH was determined by the 1:1 solid:solution method (McLean 1987).

Three gravel corrections, Kd_{gc} values, were evaluated: a correction based on the assumption that the gravel simply diluted the $Kd_{<2mm}$ and had no sorption capacity ($Kd_{gc,g=0}$), a correction based on surface area ($Kd_{gc,surf}$), and a correction based on the assumption that the Kd of the entire sediment (Kd_{tot}) was a composite of the $Kd_{<2mm}$ and the $Kd_{>2mm}$ values ($Kd_{gc,g=x}$). $Kd_{gc,g=0}$ was defined as:

$$Kd_{gc,g=0} = (1-f)Kd_{<2mm} \quad (4)$$

where f if the weight fraction of gravel in the total sediment.

$Kd_{gc,g=x}$ was defined as:

$$Kd_{gc,g=x} = (1-f)Kd_{<2mm} + (f)Kd_{>2mm}. \quad (5)$$

One important disadvantage of $Kd_{gc,g=x}$ compared to $Kd_{gc,g=0}$ is that it requires $Kd_{>2mm}$, a parameter that may be difficult to measure. The additive approach would be expected to overestimate the extent of actual sorption because it does not account for masking of sorption sites by particles contacting each other.

The definition of $Kd_{gc,surf}$ is:

$$Kd_{gc,surf} = (1-f)\left(Kd_{<2mm}\right) + (f)\left[\left(Kd_{<2mm}\right)\left(\frac{SA_{>2mm}}{SA_{<2mm}}\right)\right] \quad (6)$$

where $SA_{>2mm}$ and $SA_{<2mm}$ is a specific surface-area estimate ($m^2\ kg^{-1}$) of the greater-than and less-than 2-mm fractions of the sediment, respectively (further defined below). The first term on the right side of Equation 6 is the weight-averaged Kd value of the <2-mm fraction. The second component on the right side of the equation accounts for the Sr sorption to the >2-mm fraction. Such a correction to the $Kd_{<2mm}$ assumes that the sorptive surfaces and sorption site density of the <2-mm and >2-mm fractions are similar. Furthermore, it assumes that the cause for differences between $Kd_{<2mm}$ and $Kd_{>2mm}$ values is due to the differences in the surface areas of the >2-mm and <2-mm fractions. These may be reasonable simplifying approximations in systems where the surfaces are coated with Fe-oxyhydroxides, organic matter, or carbonates.

In the absence of direct measurement, specific surface area can be approximated by assuming spherical particles, and from the particle surface area, volume, and particle density,

$$SA_i = (4\pi r_i^2)\left[\left(\frac{1}{4/(3\pi r_i^3)}\right)\left(\frac{1}{\rho_{p-i}}\right)\right], \quad (7)$$

where r is the average particle radius, ρ_p is the particle density, and the subscript i refers to either the <2-mm or >2-mm fraction. The term within the square brackets in Equation 7 converts the surface area of one particle (m^2 particle^{-1}) to the specific surface area of a particle ($m^2\ kg^{-1}$). By assuming that $\rho_{p-<2mm}$ is equal to the $\rho_{p->2mm}$, the ratio of $SA_{>2mm}/SA_{<2mm}$ in Equation 6, simplifies to $r_{<2mm}/r_{>2mm}$. For this study, $r_{<2mm}$ was estimated by multiplying the percent clay, silt, and sand in each sediment by 1.025, 0.026 and 0.001 mm, respectively, and then averaging these three numbers. $r_{>2mm}$ were assumed to be 3 mm.

Natural Sediment Experiment

Eight subsurface sediment samples were collected from the walls of a 20-m deep trench located in the 200 East Area of the Hanford Site, Richland, Washington. Samples were collected from sediment layers exposed by the trench to provide a wide range of gravel concentrations. At each sampling location, the surface 0.2-m of sediment was discarded prior to collecting approximate 1-kg sample. Samples were collected within 200 m of each other, in the same geologic formation and appeared to be composed of similar mineral assemblages. The samples were air-dried and then characterized for CEC, pH, bulk density, and porosity. Strontium-sorption tests were conducted on total, <2-mm, and >2-mm fractions following the General Sorption Procedure described above. There were four replicates for each gravel-amendment and both controls. Gravel-corrected Kd values were calculated using Equations 4 through 7.

Gravel-Amended Experiment

The solids used in these Sr-sorption experiment were composites created by combining varying amounts of gravel with the <2-mm sediment fraction from Sediment F of the Natural Sediment Experiment. The composite samples contained 0, 20, 40, 60, 80, and 100% (wt) gravel. The gravel used to make these samples was itself a composite of the gravel-fractions isolated from the sediments used in the Natural Sediment Experiment. The air-dried samples were characterized for CEC, pH, bulk density, and porosity. Strontium-sorption tests were conducted on the entire composite sample following the General Sorption Procedure described above. There were four replicates of each gravel-amendment and both controls. Gravel-corrected Kd values were calculated using Equations 4 through 7.

RESULTS AND DISCUSSION

Natural Sediment Experiment

Selected physical and chemical properties of the sediments used in the Natural Sediment Experiment are presented in Table 2. The gravel, sand, and silt-plus-clay (<50 μm fraction) fractions varied greatly between the sediments, ranging from 11.5 to 64.8 %(wt) gravel, 35.1 to 88% sand, and 0.1 to 25 %(wt) silt-plus-clay. Sediment pH, porosity, and bulk density did not vary greatly; pH ranged by <1 pH unit, porosity by <0.12-m^3 m^{-3}, and bulk density by 280 kg m^{-3}. There was no significant correlation ($P \leq 0.05$ at 7 degrees of freedom) between gravel concentrations and CEC, porosity or bulk density. One would expect that as the gravel concentrations increased that bulk density would increase, and CEC and porosity would decrease. There was also no significant correlation between pH and CEC. There were significant differences between the bulk density and porosity values of the <2-mm and >2-mm fractions. The bulk density for the <2-mm fraction was always less than the bulk density for the whole sediment (except Sediment H). The porosity for the <2-mm fraction was always greater than the porosity for the whole sediment (again, except for Sediment H).

The various measured Kd values and gravel-corrected Kd values are presented in Table 3. Means and standard deviations for four replicates of the measured Kd values, Kd_{tot}, $Kd_{<2mm}$, and $Kd_{>2mm}$, are presented. No estimate of the variance associated with the gravel-corrected values is

available because they had to be calculated from averaged $Kd_{<2mm}$ and gravel concentration (f) values. All the gravel corrected Kd values were significantly correlated to Kd_{tot}, with $Kd_{gc,g=x}$ and $Kd_{<2mm}$ having the largest correlation coefficients (Table 3). However, based on the percent difference with Kd_{tot} (Equation 8), the accuracy of the various gravel-corrected Kd values for estimating Kd_{tot} varied appreciably.

$$\%\Delta Kd_x = \left(\frac{Kd_x - Kd_{tot}}{Kd_{tot}} \right) \times 100 \qquad (8)$$

where Kd_{tot} is the Kd value measured using the entire sediment sample, Kd_x is a measured or gravel-corrected Kd value (Equations 4 – 7), and $\%\Delta Kd_x$ is the percent difference between Kd_x and Kd_{tot}. On average, $Kd_{<2mm}$ was 28% greater than Kd_{tot}, indicating that the $Kd_{<2mm}$ overestimated the Kd of the entire sediment sample by 28% (Table 3). Conversely, $Kd_{>2mm}$ was on average 45% smaller than Kd_{tot}. On average, $Kd_{gc,g=0}$ underestimated Kd_{tot} by 10%, indicating that the >2-mm fraction had some sorptive capacity. This is not surprising in light of the fact that Hanford subsurface sediments typically contain iron-oxyhydroxide and carbonate coatings. Kaplan and Serne (1998) reported that three subsurface Hanford Site sediments contained about 0.3% (wt) Fe_2O_3 and 1.8% $CaCO_3$. These coatings may enhance the sorptive capacity of the feldspar, and quartz particles that typically comprise the larger particles of Hanford Site sediments. On average, $Kd_{gc,g=x}$ overestimated Kd_{tot} by only 5%. On average, $Kd_{gc,surf}$ values underestimated Kd_{tot} by 13%.

The average ratio of $Kd_{>2mm}$ to $Kd_{<2mm}$ for these sediments was 0.42 ± 0.08 (Table 3). Stated differently, the Kd value of the gravel was 42% of the Kd value of the <2-mm fraction. By using Equation 9, which assigns the $Kd_{>2mm}$ a value 0.42 times $Kd_{<2mm}$, it was possible to calculate precisely the average Kd_{tot} (Table 3).

$$Kd_{gc,g=0.42} = (1 - f)Kd_{<2mm} + (f)0.42Kd_{<2mm}. \qquad (9)$$

Equation 9 provides the most accurate average gravel correction. Although Equation 8 requires only the knowledge of f and $Kd_{<2mm}$, it is limited insofar that the robustness of the 0.42 factor is not known. The 0.42 factor is likely not applicable to other contaminants or even to Sr in other sediment systems, since other sorption processes will often be involved.

Retardation factors were calculated (Equation 2) using the various measured and calculated Kd values (Table 3). For these calculations, the porosity and bulk density values of the total sediment (Table 2) were used because these parameters are essentially always measured on the entire sediment sample, as opposed to the <2-mm sieved fraction used for the Kd measurement. The Rf value for the sediments, Rf_{tot}, averaged 231 ± 64, meaning that Sr would be expected to move through these sediments at an average rate that was 231 times slower than water. The various Rf values varied proportionally to their respective Kd values, since the difference between the two constructs is a scalar (i.e., the ratio of ρ_b/η was constant for a given sediment). Thus, the % differences and correlation coefficients between the various Rf values and Rf_{tot} are identical to those listed in Table 3 for their respective Kd values.

The relation between sediment properties and the various Kd values were evaluated through linear regression analyses and correlation coefficients (Table 4). As expected, gravel fraction (*f*) and bulk density were generally inversely related to the various Kd and $\%\Delta\text{-}Kd_x$ values, whereas porosity and CEC were generally directly related to these parameters. Increases in gravel concentrations could decrease Sr Kd values by a number of processes, including reducing the sediment surface area. Increases in bulk density would be expected to result in decreased Sr Kd values because bulk density tends to increase in coarse sediments (Hillel 1980) and coarse sediments tend to have low specific surface areas (or low binding site concentrations) for Sr sorption. Conversely, increases in porosity would be expected to result in increased Sr Kd values because porosity tends to decrease in coarse sediments (Hillel 1980). The positive correlation coefficients with CEC may be attributed to the greater number of sorption sites available for Sr sorption.

Gravel-Amended Experiment

This experiment provided an estimate of the effect of gravel on sediment Sr-Kd values under more controlled conditions than in the Natural Sediment Experiment. In this experiment, the gravel fractions and the <2-mm fractions of each of the composite sediments had identical mineralogy, particle-size distributions, and surface chemistry. The only thing that changed between the samples was the proportion of the two size fractions.

The sediment properties used in the Gravel-Amended Experiment varied in an expected manner consistent with the amount of gravel added to the sediments (Table 4). As more gravel was added, the cation exchange capacity decreased ($r = -0.999$, $P \leq 0.001$), porosity decreased ($r = -0.990$, $P \leq 0.001$), and the bulk density increased ($r = 0.66$, $P \leq 0.05$). Unexplainably, pH also increased with increasing gravel additions ($r = -0.991$, $P \leq 0.001$).

$Kd_{gc,g=x}$ estimates most closely reflected the measured Kd_{tot} values; overestimating the Kd_{tot} values on average by $3 \pm 3\%$ (Equation 8 and Figure 1). $Kd_{gc\text{-}surf}$ underestimated Kd_{tot} values on average by $-33\% \pm 32\%$, the degree of underestimation increased as the amount of gravel added increased. Similarly, $Kd_{gc,g=0}$ underestimated Kd_{tot} values on average by $-39 \pm 37\%$, the degree of underestimation also increased as the amount of gravel added increased. A ranking of the Kd values by percent difference with Kd_{tot}, i.e., by their overall accuracy in estimate Kd_{tot}, is consistent with the ranking for the Natural Sediment Experiment (Figure 2): $Kd_{<2mm} > Kd_{gc,g=x} > Kd_{tot} > Kd_{gc,g=0} \geq Kd_{gc,surf} > Kd_{>2mm}$. For this experiment, $Kd_{>2mm}$ was 15.2 L kg^{-1} and $Kd_{<2mm}$ was 29.5 L kg^{-1} (Figure 1). The $Kd_{>2mm}/Kd_{<2mm}$ was 0.52, compared to the average ratio in the Natural Sediment Experiment of 0.42 (Table 3).

Strontium retardation factors calculated with Kd_{tot} values (Equation 2) varied from 235 for the <2-mm fraction treatment (0% gravel-added sediments in Figure 2) to 166 for the gravel amended (100% gravel-added sediments in Figure 2). $Rf(Kd_{gc,g=x})$ values estimated actual Rf values, $Rf(Kd_{tot})$, very closely. $Rf(Kd_{<2mm})$ overestimated and $Rf(Kd_{gc,surf})$ and $Rf(Kd_{gc,g=0})$ underestimated $Rf(Kd_{tot})$. All of these trends are consistent with those observed for the respective Kd values (Figure 1). Unlike the other Rf values, $Rf(Kd_{<2mm})$ values increased as the percent of added gravel increased. Since the value of $Kd_{<2mm}$ used to calculated $Rf(_{Kd<}2mm)$ remained constant for the various added-gravel treatments, the increase in Rf values reflects

changes in the ratio of bulk density to porosity (Equation 2). The bulk density to porosity ratio varied from 7.84 to 11.37 as the percent of added gravel increased from 0 to 100% (Table 5). This is an increase of 45% with respect to the ratio of the 0% added-gravel treatment. Since an increase in Rf is not expected as more gravel is added to a system, this illustrates an intrinsic error with keeping the Kd constant while varying the bulk density and porosity values. Since bulk density and porosity are more easily measured or estimated by empirical relations, it is not improbable that a modeled system would make this error.

Conclusions

Two experiments were conducted to quantify the gravel-Kd issue. Additionally, these experiments sought to evaluate methods an empirical method or formula to permit the conversion of the $Kd_{<2mm}$ value traditionally collected from laboratory experiments to gravel-corrected Kd values. The worse estimate of the actual Kd and Rf values for gravel-containing sediments was the traditional $Kd_{<2mm}$. On average, $Kd_{<2mm}$ over estimated actual Kd values by 28% in the Natural Sediment Experiment and 47% in the Gravel-Added Experiment. In one experiment, $Rf(Kd_{<2mm})$ values actually increased as the actual Rf values decreased. Of the various gravel-corrected Kd values, $Kd_{gc,g=x}$ provided the best estimate of the actual Kd value, Kd_{tot}, slightly overestimating Kd_{tot} values on average by between 3 and 5%. In both experiments, $Kd_{gc-x=0}$ and $Kd_{gc,surf}$ underestimated actual Kd values, the disparity systematically increased as the amount of gravel in the sample increased. This suggests that the gravel corrections for both constructs are less than perfect and therefore become systematically worse as the amount of gravel in the sample increases.

Although $Kd_{gc,g=x}$ clearly provided the best estimate of the actual Kd value, it has the important disadvantage in that it requires knowledge of the Kd value for the >2mm fraction. This is experimentally difficult to measure and requires additional resources to acquire. When this information can not be acquired, the $Kd_{gc,g=0}$ or $Kd_{gc,surf}$ constructs may be a reasonable alternative. $Kd_{gc,g=0}$ has the advantage over $Kd_{gc,surf}$ in that the former requires knowledge of the percent gravel, whereas the latter requires knowledge of percent gravel and mean particle sizes in the <2-mm and >2-mm fractions. Percent gravel in a sediment may be inexpensively acquired by sieve analysis or if need be, estimated from common stratigraphic descriptions of well boreholes.

The findings in this study have important implications regarding the traditional approach to modeling contaminant transport using $Kd_{<2mm}$ values because such modeling may overestimate the ability of gravel-containing sediments to retard contaminant migration. This is a problem insofar that lower-bounding estimates, that is, conservative estimates, of contaminant migration may not be in fact truly lower-bounding and therefore worse-case scenarios may be improperly estimated. Use of gravel-corrected Kd values will improve such lower-bounding estimates.

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Table 1. Ground water (<0.45-μm Filter) Chemical Composition

Constituent	*Concentration (mg L^{-1})*
pH	8.3 (unitless)
Cl^-	22
NO_3^-	1.7
SO_4^{-2}	108
Total Organic C	0.73
Total Alkalinity (as CO_3^{2-})	67.5
Al	0.14
B	0.05
Ba	0.069
Ca	67.5
Fe	0.14
K	3
Mg	16.4
Mn	0.046
Na	27.6
Si	16.2
Sr	0.28
Sum of Cations [a]	0.0065 M
Sum of Anions [a]	0.0054 M
Equilibrium Ionic Strength [a]	0.00918

[a] Calculated by the geochemical thermodynamic code MINTEQA2 (Allison et al. 1991).

Table 2. Properties of Sediments Used in the Natural Sediment Experiment

	Total Sediment					*<2-mm Fraction*			*>2-mm Fraction*
Sediment Code	*Gravel/Sand/ Silt+Clay (wt. %)* [a]	*pH*	*Bulk Density ($kg\ m^{-3}$)*	*Porosity ($m^3\ m^{-3}$)*	*CEC ($meq\ kg^{-1}$)*	*Bulk Density ($kg\ m^{-3}$)*	*Porosity ($m^3\ m^{-3}$)*	*CEC ($meq\ kg^{-1}$)*	*CEC ($meq\ kg^{-1}$)*
A	11.5 / 88.0 / 0.5	8.34	1900	0.30	46.7	1860	0.31	59.2	26.2
B	39.0 / 54.0 /7.0	9.01	2140	0.22	22.6	1840	0.28	16.8	16.9
C	28.0 / 69.5 / 2.5	9.03	2000	0.21	22.3	1820	0.26	14.5	6.1
D	44.0 / 55.6 / 0.4	9.25	2100	0.22	20.0	1840	0.30	13.1	18.2
E	44.0 / 53.7 / 2.3	9.02	2030	0.19	15.5	1800	0.27	16.7	6.0
F	21.0 / 54.0 / 25.0	8.38	2030	0.24	23.5	1960	0.25	19.1	6.0
G	52.0 / 43.0 / 5.0	9.18	2180	0.20	19.6	1700	0.27	17.0	NA
H	64.8 / 35.1 / 0.1	8.20	1930	0.31	73.0	1810	0.31	81.0	19.0

[a] Gravel is ≥2-mm; Sand is <2-mm and ≥50-μm; Silt +Clay is <50-μm.

Table 3. Sr Kd Values, Retardation Factors and Correlation Coefficients from the Natural Sediment Experiment

	Kd_{tot}	$Kd_{<2mm}$	$Kd_{>2mm}$	$Kd_{gc,g=x}$ [a]	$Kd_{gc,g=0}$ [a]	$Kd_{gc,surf}$ [a]	$Kd_{gc,x=0.42}$ [a]
Sediment A	38 ± 3	50 ± 2	22 ± 1	47	44	45	47
Sediment B	37 ± 4	51 ± 3	20 ± 1	39	31	34	39
Sediment C	20 ± 4	34 ± 1	12 ± 4	28	24	25	28
Sediment D	19 ± 3	23 ± 0	13 ± 1	19	13	14	17
Sediment E	18 ± 3	21 ± 1	10 ± 1	16	12	13	15
Sediment F	31 ± 4	33 ± 3	13 ± 3	29	26	27	29
Sediment G	23 ± 3	27 ± 1	13 ± 6	20	13	15	19
Sediment H	27 ± 2	31 ± 1	10 ± 2	27	31	15	19
Avg. Kd	27 ± 8	34 ± 11	14 ± 4	28 ± 11	24 ± 11	24 ± 11	27 ± 11
Avg. %Δ-Kd_{tot} [b]	0	28 ± 21	-45 ± 10	5 ± 19	-10 ± 27	-13 ± 25	0 ± 24
Corr. Coef. with Kd_{tot} [c]	1.00	0.91***	0.83**	0.91***	0.85**	0.78*	0.87**
Avg Rf [d]	231 ± 64	296 ± 96	126 ± 38	241 ± 74	204 ± 70	203 ± 81	231 ± 86

[a] Equations 4 through 7 and 9 were used to calculate these Kd values.
[b] Equation 8 was used to calculate %Δ-Kd_{tot}.
[c] Correlation coefficients between the various Kd constructs and Kd_{tot}. *, **, and *** indicate significance at the 5% level ($P \leq 0.05$), 1% level ($P \leq 0.01$), and 0.1% level ($P \leq 0.01$), respectively, for 7 degrees of freedom.
[d] Retardation factors were calculated using Equation 2, Kd values from this table, and porosity and bulk density of the entire sediment from Table 2.

Table 4. Correlation Coefficients Between Sr Kd Values and Sediment Properties for the Natural Sediment Experiment

	Gravel Fraction (f)	*Bulk Density of Entire Sediment*	*Porosity of Entire Sediment*	*CEC of Entire Sediment*
Kd_{tot}	-0.46	-0.23	0.56	0.35
$Kd_{<2mm}$	-0.51	-0.22	0.44	0.26
$Kd_{>2mm}$	-0.59* [a]	-0.06	0.31	0.04
$Kd_{gc,g=x}$	-0.61*	-0.42	0.59*	0.37
$Kd_{gc,g=0}$	-0.48	-0.64*	0.79**	0.63*
$Kd_{gc,surf}$	-0.79**	-0.36	0.42	0.14
%Δ-$Kd_{<2mm}$ [b]	-0.28	-0.08	-0.15	-0.13
%Δ-$Kd_{>2mm}$	-0.21	0.32	-0.47	-0.56
%Δ-$Kd_{gc,g=x}$	-0.51	-0.47	0.23	0.15
%Δ-$Kd_{gc,g=0}$	-0.31	-0.78*	0.67*	0.64*
%Δ-$Kd_{gc,surf}$	-0.81**	-0.33	0.03	-0.16

[a] * and ** indicate significance at the 5% level ($P \leq 0.05$) and 1% level ($P \leq 0.01$), respectively, for 7 degrees of freedom.
[b] Equation 8 was used to calculate %Δ-Kd_x.

Table 5. Properties of Sediments Used in the Gravel-Amended Sediment Experiment

Gravel Added (%, wt)	*CEC (meq kg^{-1})*	*pH*	*Bulk Density (kg m^{-3})*	*Porosity (m^3 m^{-3})*
0	140.3	8.38	1960	0.25
20	118.2	8.44	1980	0.24
40	95.9	8.52	2010	0.23
60	73.3	8.61	2050	0.22
80	51.6	8.67	2100	0.21
100	29.5	8.7	2160	0.19

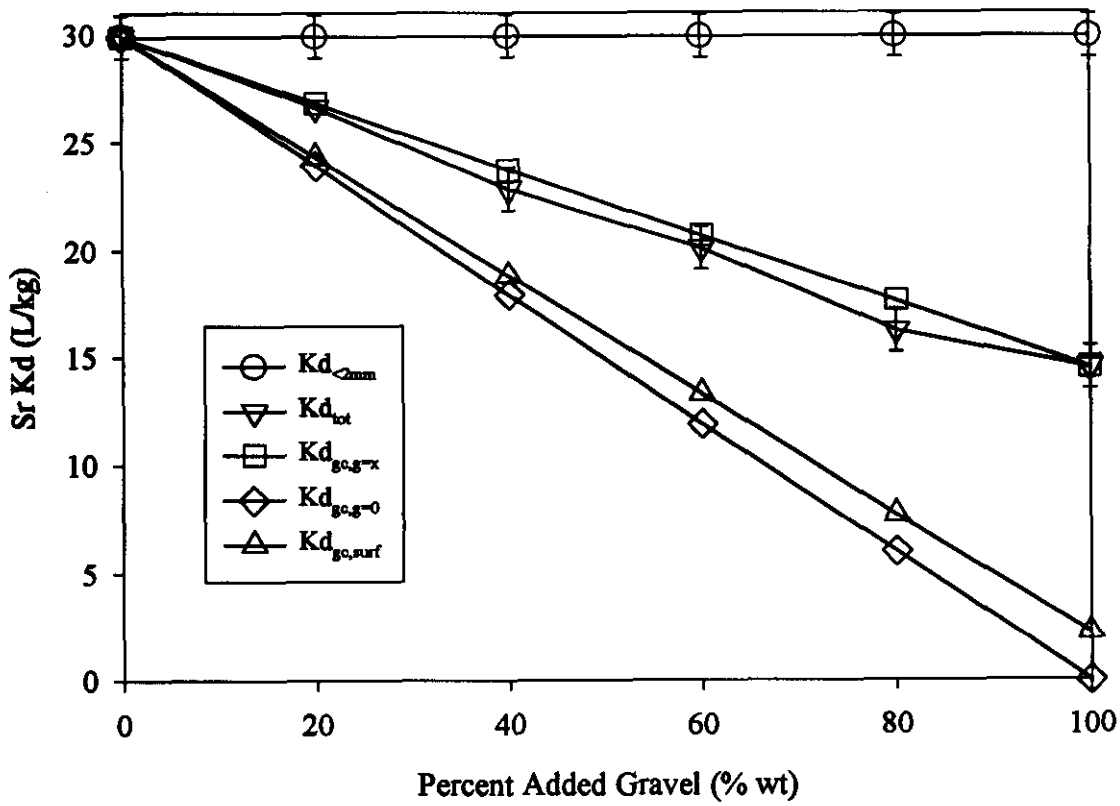

Fig. 1. Measured and gravel-corrected Sr Kd Values from the Gravel-Amended Experiment. $Kd_{<2mm}$ is 29.9 L kg^{-1}; $Kd_{>2mm}$ is 15 L kg^{-1}. Kd_{tot} is the mean and standard deviation of 4 replicates. $Kd_{gc,g=0}$, $Kd_{gc,g=x}$, and $Kd_{gc,surf}$ calculated from Equation 4, 5, and 6, respectively.

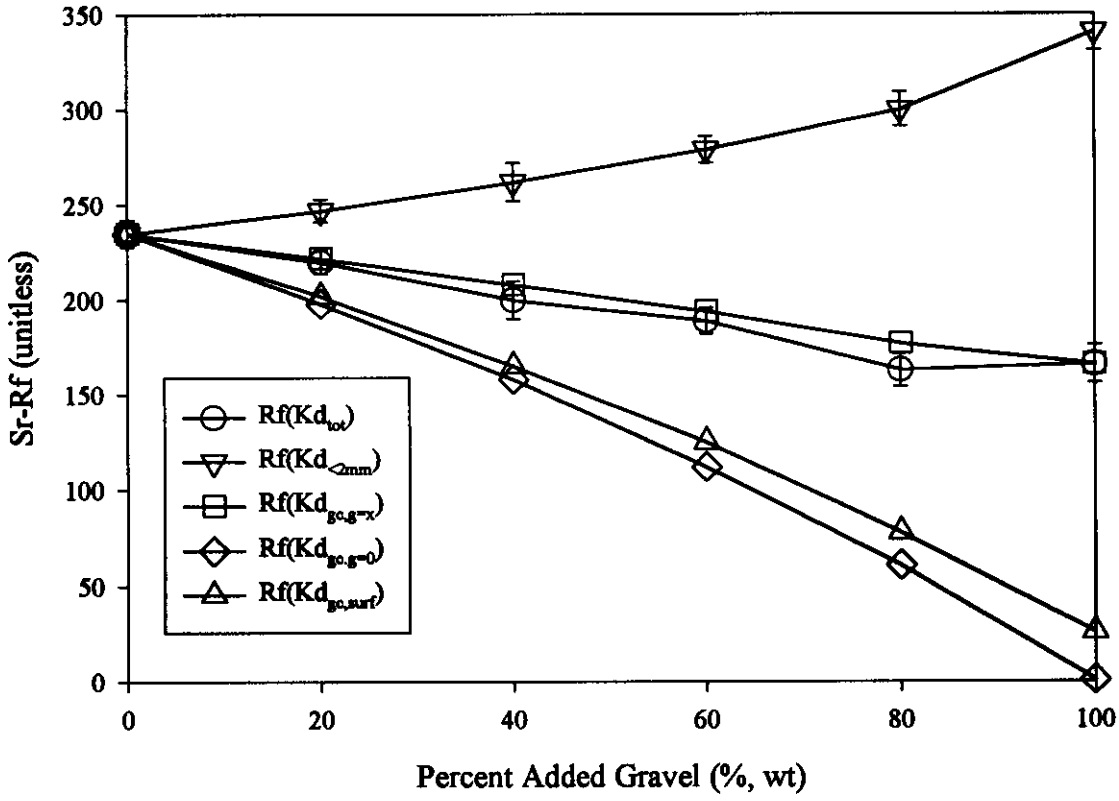

Fig. 2. Strontium retardation factors (Rf) as a function of added gravel. Rf values calculated with Kd_{tot}, $Kd_{<2mm}$, $Kd_{gc,g=0}$ (Equation 4), $Kd_{gc,g=x}$ (Equation 5), and $Kd_{gc,surf}$ (Equation 6), and measured bulk density and porosity values (Table 4). $Rf(Kd_{tot})$ is the mean and standard deviation of 4 replicates. Rf values from gravel-corrected Kd values were calculated using means, therefore no measure of variability is available.

Appendix B - Kd Values for Far-field Sediment Conditions

Appendix B. Kd Values for Far-field Sediment Conditions[a]				
Radio-nuclide	Reasonably Conservative Kd (mL/g)	"Best" Kd (mL/g)	Kd Range (mL/g)	Justification/References[b]
^{3}H, Cl, Tc	0	0	0 to 0.6	Tc exists predominantly as TcO_4^-. A review of Hanford sediment Tc-Kd values showed a range of -2.8 to 0.6 mL/g for 15 observations; median was 0.1 mL/g (1). Later studies did not change this range but did decrease the median slightly to -0.1 mL/g (2). Negative Kd values are physically possible and may not be an experimental artifact (2). ^{3}H is expected to move along with water. Cl is expected to behave as a dissolved anionic species. Most recent results using ILAW specific borehole sediments [299-E17-21] yielded Tc-Kd of 0 mL/g. See Kaplan et al. (18) for details.
Ac, Am, Ce, Cm, Eu	60	300	60 to 1300	Am-Kd: 67 to >1200 mL/g (3). Am-Kd: 125 to 833 mL/g (4)
C	0.5	5	0.5 to 1000	Assumed dominant species: HCO_3^-. Three processes will be acting on the ^{14}C to take it out of solution: adsorption onto the calcite surface, volatilization as CO_2 gas, and precipitation into the calcite structure. The latter process is largely irreversible, therefore it is not well represented by the K_d construct (K_d assumes that adsorption occurs as readily as desorption). Volatilization is entirely removed from the definition of the K_d construct. In systems that contain higher concentrations of carbonate minerals, such as the calcrete layer in the 200 West Area, an appreciably higher Kd should be used to account for the isotopic dilution/precipitation reaction that may occur. A Kd of 100 mL/g would be appropriate for such a system. Since most of the 100 and 200 plateau areas contain <1% carbonate, lower Kd values are warranted for these areas, such as 0.5 mL/g. K_d values of ^{14}C of >250 mL/g have been measured in calcite ([5]). At 100K, the C-14 is widely distributed down gradient from a major source (crib) associated with reactor operations. (Additional references: 6, 7, 8, 9, 10). Estimated range.
Co	1000	2000	1000 to 12500	Na system, 1290 to 2120 mL/g (11) Ca system, 2000 to 3870 mL/g (11) Hanford sediment/groundwater system 11600 to 12500 mL/g (12)
Cs	500	2000	500 to 4000	Na system, 1410 to 1590 mL/g (11) Hanford sediment/groundwater system, 540 to 3180 mL/g (12).). Most recent results using ILAW specific borehole sediments [299-E17-21] yielded Kd of 2,030 ± 597. See Kaplan et al. (18) for details.
I	0	0.1	0.0 to 15	A review of Hanford sediment I-Kd values showed a range of 0.7 to 15 mL/g for 9 observations; median was 0.7 mL/g (1). Later studies increased this range to 0.2 to 15 mL/g; the median was decreased to 0.3 mL/g (2). Most recent results using ILAW specific borehole sediments [299-E17-21] yielded Kd of 0 mL/g (18).

Ni, Sn, Nb	50	300	50 to 2500	Ni: Hanford sediment/groundwater system, 440 to 2350 mL/g (12) Ni: A study of a broad range of sediments, including those from Hanford had Ni-Kd's of 50 to 340 mL/g (13).
Np	2	15	2 to 25	A review of Hanford sediment Np-Kd values showed range of 2.4 to 21.7 mL/g for 4 observations; median was 17.8 mL/g (1). Later studies increased the slightly to 2.2 to 21.7 mL/g; the median was slightly lowered, 15 mL/g (2).
Pb	8000	10,000	8000 to 80000	pH 6 and no competing ions: 13,000 to 79,000 mL/g (14)
Pu	50	150	50 to 2000	Pu(V, VI): pH 4 to 12: 80 to >1980 mL/g (15)
Ra, Sr	5	14	5 to 200	Sr Kd values: Na system, 173 mL/g, 49 to 50 mL/g (11) Ca system, 8 to 13 mL/g, 5 to 19 mL/g (11) 5 to 120 mL/g (15) 19.1 to 21.5 mL/g (12) Na system, pH 7 to 11, 14.9 to 25.1 mL/g (16) Most recent data using ILAW borehole sediment [299-E17-21] yielded 14.3 ± 1.6. See (18).
Ru	10	20	10 to 1,000	Estimated (17 as cited in 11)
Se	3	7	3 to 15	Hanford groundwater/sediment system: -3.44 to 0.78 mL/g (12). Most recent data using ILAW borehole sediment [299-E17-21] yielded Kd values ranging from 3.75 to 10.85 mL/g and had an average of 6.7 ± 1.9 mL/g (18).
Th, Zr	40	1000	40 to 2500	Estimated. Zr: pH 6 to 12 : 90 to >2000 mL/g (15)
U	0.5	0.6	0.1 to 80	A review of Hanford sediment U-Kd values showed range of 0.1 to 79.3 mL/g for 13 observations; median was 0.6 mL/g (1). Results from later studies support the range (2). In all reported data, some U was adsorbed by Hanford sediments and >90% of the values were between 0.6 and 4 mL/g. Most recent work with the ILAW Borehole sediment [299-E17-21] yielded Kd of 0.6 ± 0.1. See (18).

[a] Kd values in this table describe sorption of radionuclides to Hanford sediment-dominated sequence under far field conditions. The aqueous phase is assumed to be untainted Hanford groundwater except for trace levels of radionuclide and the solid phase is assumed to be natural Hanford sand-dominated sequence sediment. The literature values upon which the values were based upon had an aqueous phase near neutral pH, ionic strength between ~0 to 0.01, trace radionuclide concentrations.

[b] References: 1 = Kaplan and Serne 1995b; 2 = Kaplan et al. 1996; 3 = Routson et al. 1976; 4 =Sheppard et al. 1976; 5 = Martin 1996; 6 = Striegl and Armstrong 1990; 7 = Garnier 1985; 8 = Allard et al. 1981; 9 = Mozeto et al. 1984; 10 = Zhang et al. 1995; 11 = Routson et al. 1978; 12 = Serne et al. 1993; 13 = Serne and Relyea 1983; 14 = Rhoades et al. 1994; 15 = Rhodes 1957; 16 = Nelson 1959; 17 = Rhodes 1957a,b; 18= Kaplan et al. 1998.

Appendix C - Discussion on Double Layer and Film Thickness

Double Layer Thickness vs. Film Layer Thickness

The double layer thickness was estimated from the Debye-Huckel Parameter (K) (Hiemenz and Rajagopalan 1997):

$$K = \left[\left(\frac{1000 e^2 N_A}{\varepsilon k_B T} \right) \sum_i z_i^2 M_i \right]^{1/2} \qquad \text{(A)}$$

Where K^{-1} (m) is sometimes used to estimate the double layer thickness, e is the electric charge (or charge of an electron, units = C), N_A is Avogadro's number, ε is fluid permittivity (C V^{-1} m^{-1}), k_B is Boltzmann's constant (J K^{-1}), z is the valence of the electrolyte, and M is the electrolyte concentration (M).

Assuming Ca^{2+} and SO_4^{2-} are the dominant ions at an ionic strength of 10 mM, the **double layer thickness based on Equation A is 1.5e-9 m.**

The film thickness was calculated with the following equation taken from Hillel (1980):

$$\lambda = \frac{\theta}{\rho_b A_{ss}} \qquad \text{(B)}$$

Where λ is the film thickness (cm), θ is the volumetric water content, A_{ss} is the specific surface area (cm^2/g) and ρ_b is the bulk density (g/cm^3). Using θ = 0.6, ρ_b = 1.25 g/cm^3, and A_{ss} of 2000 cm^2/g in Equation B, the **film thickness (λ) = 2.4 μm**.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press. New York.

Hiemenz, P. C., and R. Rajagopalan. 1997. *Principles of Colloid and Surface Chemistry, Third Edition.* Marcel Dekker, Inc. New York.

Appendix D - Information Requested For Near Field Geochemical Transport Modeling

Reactive transport modeling of the waste form leaching and near field is being performed using the computer code STORM that is described in the Waste Form Leaching Data Package (McGrail et al. 1999).

The STORM code requires that the user provide the chemical formulas for the reactions needed to form the solid minerals that constitute the sediments and engineered barriers surrounding the glass waste forms. The Geochemical Data Package provides guidance in this appendix. The mineralogy of the Hanford sand sediments that might be used for backfill and the native Hanford formation sands and gravels have not been characterized at the ILAW site. However some quantitative mineralogy of Hanford formation sediments taken from outcrops and from the sides of other solid waste disposal facilities in the 200E and 200W areas have been reported. The data in Serne et al. (1993) pages 5-28 list detailed mineralogical, geochemical, hydrologic and physical characterization information for four sediments. This information can be used as input to STORM.

In FY00 about ten of the 21 samples from the ILAW borehole [299-E17-21] drilled in FY98 will be characterized for quantitative mineralogy and perhaps amorphous hydrous oxide content using the same techniques discussed in Serne et al. (1993). The 21 samples were used to obtain site specific K_d values, cation exchange capacities, particle sizes and hydrologic parameters in FY98-99. These data have been documented in topical reports [Kaplan et al. 1998 and Reidel et al. 1998] and companion 2001 Data Packages [Khaleel 1999 and Reidel and Horton 1999].

Mineralogy data needed for the STORM code reactive transport calculations for cement and concrete and are available in the following topical reports [Criscenti and Serne 1990, Criscenti et al. 1996, and Krupka and Serne 1996} and references cited therein. Hydrologic and physical properties of cement and concrete are discussed in the Near Field Hydrology 2001 Data Package [Myer and Serne 1999] and references cited therein.

For the 2001 ILAW PA all chemical dissolution/precipitation reactions for the backfill sediments, natural sediments, cements and concrete are assumed to reach equilibrium in each time step during the transport modeling. There is limited kinetic data available for the dissolution/precipitation reactions for these minerals/materials but the geochemists could not tabulated the information in time for the 2001 data packages. However kinetic data will be tabulated and made available to the STORM transport modelers in time for the 2003 PA activity. The amount of effort expended in tabulating kinetic information will be determined based on the importance of kinetics deciphered from critically analyzing the results of the near field transport modeling in the 2001 PA.

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Westinghouse Savannah River Company
Building: 773-A, Room: B-121
Aiken, SC 29808

Dr. T. T. Chuck Vandergraaf
Atomic Energy Of Canada, Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba ROE 1LO
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APPENDIX O

EXPOSURE SCENARIOS AND UNIT DOSE FACTORS FOR THE HANFORD IMMOBILIZED LOW-ACTIVITY TANK WASTE PERFORMANCE ASSESSMENT

Paul D. Rittmann PhD CHP

December 1999

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Exposure Scenarios and Unit Dose Factors for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment

by Paul D. Rittmann PhD CHP

Performance assessment (PA) dose calculations involve models and parameters from many disciplines to predict the migration of radioactive material from low-level disposal sites and the potential impacts this may have on members of the public in the future. Of particular interest is the dose calculation assumptions employed for the Hanford Immobilized Low-Activity Tank Waste (ILAW) Performance Assessment (PA). Exposure scenarios and model parameters must be selected which will be acceptable to the DOE as well as local technical experts on the Hanford Environmental Dose Overview Panel (HEDOP).

The particular combination of activities by which an individual accumulates radiation dose from a disposal site is known as an exposure scenario. For the ILAW PA the exposure scenarios are constructed from the land use scenarios (HNF-EP-0828, Rev 2), of which there are three general categories.

(1) The water infiltration rate at the disposal site is very low due to an engineered barrier. Ground water contamination is expected to be very small, or even non-existent. The main contaminants leaving the waste site are gases and vapors which diffuse upward through the soil to the ground surface. Potential exposure scenarios involve individuals living 100 meters downwind from the waste, or directly above the waste, where the contaminant emission rate is greatest.

(2) The water infiltration rate at the disposal site remains similar to present natural infiltration rates. Large scale irrigation for commercial farming is excluded. Potential exposure scenarios include people living 100 meters from the waste once contamination has reached the groundwater, and individuals living above the waste who drill a well through it.

(3) The water infiltration rate at the disposal site is much larger than the present natural infiltration rate due to widespread irrigation of the central plateau of the Hanford Site. Potential exposure scenarios involve ways that water from a well 100 meters from the disposal site may be used. Onsite exposures are precluded by the active irrigation.

Since many waste disposal site performance assessments have been prepared, both for the Hanford Site and other DOE-managed facilities, there is a body of knowledge associated with these assessments. Future PA documents must be consistent with previous PA documents to a considerable degree. However, there is always room for improvement. One such area is the range of potential doses to individuals who may live on or near the disposal site some time in the future. The reason for doing this is to ensure that potential doses are not underestimated. The low end of the dose range will be zero. The high end depends on the assumed exposure scenarios and the model parameters selected to describe the scenario. This report describes possible exposure scenarios, selects average (or typical) model parameters, and calculates unit dose factors for these scenarios. This approach enables meaningful comparisons between scenarios, and provides assurance that bounding cases have indeed been considered.

1.0 EXPOSURE SCENARIO DESCRIPTIONS

The potential exposure scenarios are divided into two general categories, offsite and onsite. These originated by considering the delays in exposure which can be generally expected from waste disposal sites on the Hanford Site. The offsite location receives the majority of the dose after contaminants have migrated from the disposal site into the groundwater and are brought to the surface through a well. Exposure of the offsite individual requires considerable delay between site closure and the eventual appearance of radioactivity in the ground water. Only radionuclides with long half lives, such as plutonium, will be significant hazards. Radionuclides with shorter half lives, such as cesium-137 and strontium-90, normally will decay to insignificant amounts before becoming part of the groundwater contamination. In order for the short half life nuclides to be significant exposure hazards, someone must actively expose themselves to the buried waste by moving onto the disposal site and digging into it. Hence the onsite scenarios were developed.

The general features of the exposure scenarios used in performance assessments are shown in Table 1.

Table 1. General Features of Performance Assessment Exposure Scenarios.

Feature	Onsite Receptor	Offsite Receptor
Time delay following site closure	no less than 100 years	any time after site closure
Receptor location	directly over the waste disposal site	no closer than 100 meters from the edge of the buried waste
Contamination sources	(1) gases & vapors - migrate upward from the waste (2) well water (3) exhumed waste	(1) gases & vapors carried by the wind to the offsite location (2) well water
Exposure scenarios	(1) well driller - person actually drilling through the waste (2) residential - person living near the well	(1) industrial - people working at some commercial enterprise (2) residential - person living near the well (3) farmer - subsistence farming operation (4) native American Indian

The offsite exposures occur as a result of the environmental transport of radioactive contamination to locations near the waste disposal site. The usual location is 100 meters from the edge of the buried waste, or wherever the ground water contamination would be greatest. The principal transport mechanism is the migration of contaminants from the waste through the vadose soil and into the ground water. For most nuclides this involves a considerable time delay (i.e., hundreds of years) between site closure and arrival of the contamination. In addition, different nuclides travel at different rates through the soil, so they arrive at the well at times which may differ by more than the 70 year lifetime of the offsite individual. The offsite individual is also exposed to any airborne emissions from the waste disposal site. The airborne emissions result from the upward migration of certain radionuclides. The airborne emissions normally lead to less dose than the ground water contamination.

The onsite exposures are the result of human activity directly over the buried waste, for example, a residence or business. Since local regulations would prohibit such activities, the onsite exposure scenarios are assumed to be delayed for 100 years following site closure. After this delay, it is assumed that knowledge of the disposal site location is lost or ignored, and individuals unknowingly trespass. To establish bounding doses for this individual, it is assumed that a well is drilled through the waste. The waste materials brought to the surface are not recognized as waste. It is assumed that the appearance of the exhumed waste differs little from the native soil, and it becomes part of a garden.

The intent of these exposure assumptions is to establish reasonable bounds on the potential doses resulting from the waste disposal site. The exposure scenarios result from consideration of how the radioactivity can move, where it moves, and how people might be exposed to it in future years.

1.1 No Water Infiltration Exposure Scenarios

Since the water infiltration rate is expected to be very low due to the presence of an engineered barrier, little contamination will reach the ground water. However, gases and vapors will diffuse from the waste through the soil. These gaseous contaminants enter the air above the disposal site and may be carried by the wind to receptors located near the site. In addition, there may be inadvertent intrusion into the disposal site.

Table 2 summarizes the various exposure scenarios analyzed for the no water infiltration case. Note that skin absorption refers to radioactive materials on the skin being absorbed into the body by passage through the skin. Note also that the first scenario (Offsite Farmer) applies any time after site closure, while the remaining scenarios require a minimum of 100 years delay before they can occur.

One exposure scenario requires modeling the average dilution and dispersion of gases released from the surface as they travel downwind to someone living nearby. Since the airborne emission from the disposal site is in the form of gases and vapors, there will be no appreciable deposition of radioactivity on ground. However, plants and animals do absorb certain gases

directly from the air, leading to an ingestion dose to individuals consuming such produce. The emission rate from the ground surface may vary with time as the waste ages and radioactivity decays. The bounding doses for this scenario are achieved sometime after site closure.

A second exposure scenario involves a residence located above the disposal site with a porous floor. Gas concentrations in the dwelling would depend on the emission rate from the soil and the assumed ventilation rate in the dwelling. For an individual to be living above the disposal site, all knowledge of the site must have been lost. The dose calculation cannot begin until 100 years have elapsed from site closure.

Table 2. Exposure Scenarios for the No Water Infiltration Case.

Offsite Farmer -- gas/vapor emanations from the disposal site are carried downwind to a subsistence farm
▸ inhalation of plume ▸ ingestion (plants & animals) ▸ external radiation exposure from plume ▸ skin absorption from air
Onsite Resident -- gas/vapor emanations into a residence over the disposal site
▸ inhalation (higher concentrations in a dwelling) ▸ external radiation exposure (from soil and air) ▸ skin absorption (from air)
Intruder -- individual present while a well is being drilled through the waste disposal site
▸ inhalation (resuspended dust & gaseous emissions) ▸ ingestion (trace amounts of soil) ▸ external radiation exposure ▸ skin absorption (contact with soil)
Post-intrusion Resident -- lives near the exhumed waste
▸ inhalation (resuspended dust & gaseous emissions) ▸ ingestion (trace amounts of soil & garden produce) • external radiation exposure (working in garden) • skin absorption (contact with soil)

Notes: "Skin absorption" refers to radioactivity on the skin being absorbed into the body by passage through the skin. The first scenario applies any time after site closure, while the other three require a delay of at least 100 years before they can occur.

The third and fourth exposure scenarios listed on Table 2 assume the waste is unintentionally disturbed by human activity such as drilling a well through it. It is assumed that such intrusion is prevented for the first 100 years following site closure. After this period, it is assumed that knowledge of the disposal site becomes unavailable or is ignored. In addition, any markers or warnings are ignored. Compliance with performance objectives for the intruder (HNF-EP-826, Rev 2) is measured through reasonable exposure scenarios during and after the inadvertent intrusion.

Exposure scenario development begins with listing various ways the intruder can be exposed to the exhumed waste. These include inhalation of resuspended dust & gaseous emissions, ingestion of trace amounts of soil in the course of other activities, ingestion of garden produce, external radiation exposure, and absorption of contaminants that come in contact with skin.

There are two primary exposure scenarios for the intruder. The first describes the exposure to an individual digging a well through the disposal site. The second describes the exposure to an individual residing near the well afterward. Other forms of intrusion, such as digging footings for buildings, are considered unlikely due to the depth of the waste.

In this scenario, one or more individuals are exposed to the waste because the waste site has been returned to the public and no restrictions on land use prevent such an event. The drilling of water wells is a fairly common occurrence. However, the likelihood of a driller actually encountering the buried waste is low, since there are many places to drill, but few are over the buried waste.

The well extends from the ground surface to the unconfined aquifer. The diameter of the well could range from 4 inches up to 12 inches. The larger the diameter, the more waste will be brought to the surface. Prior Hanford performance assessments assumed that the well diameter is 12 inches (30 cm). This value certainly establishes an upper bound on the volume exhumed by a well-drilling operation. A more common diameter for a well is 6 inches (15 cm). This average diameter (15 cm) will be assumed in this report.

The total volume of soil produced by the well drilling is the product of the well cross sectional area and the thickness of soil between the unconfined aquifer and the ground surface. In the 200 Areas, for example, this thickness is about 80 meters. In this example, the total volume of soil excavated is 1.4 m^3.

Soil volume from well = $(3.14159)(0.15m/2)^2(80\ m) = 1.4\ m^3$

The volume of waste exhumed is the product of the well cross sectional area and the waste thickness. The disposal facility design will determine the waste thickness. By way of example, if the waste is 8 meters thick, then the total volume of waste excavated by the drilling operation would be 0.14 m^3. For comparison, the Grouted Waste PA (WHC-SD-WM-EE-004) used a waste volume of 0.64 m^3.

The individuals doing the drilling are exposed to the waste through inhalation of resuspended dust and gaseous emissions, ingestion of trace amounts, external exposure to the contamination, and dermal contact with the contaminated soil. The total exposure time is assumed to be 5 working days, or 40 hours. A portion of the waste at the time of drilling may still be in a form that cannot be resuspended and inhaled. An example is waste in the form of glass beads which are corroding slowly with time.

The dose to the driller depends on the area over which the contamination is spread. In the Grouted Waste performance assessment (WHC-SD-WM-EE-004, Rev 1) the area used was 100 m^2. This value will also be used in the present calculations. The 200 West Area Burial Ground performance assessment (WHC-EP-0645, Rev 0) did not consider doses to the driller in detail, since for all nuclides, the dose to the driller is less than the dose to the post-drilling resident. Previous PAs that calculate dose to the driller also assumed the activity is uniformly mixed in the top 15 cm of soil. Thus the exhumed waste is diluted to a total volume of $(100\ m^2)(0.15\ m)=15\ m^3$.

After the drillers leave, the mound of exhumed material is assumed to be spread around to level the ground for a garden. It will be assumed that the waste appears no different than the normal soil and thus is treated just like soil would be. Three important parameters affect the eventual dose received by the individual who works the garden. These are the depth of contamination in the soil, the area over which the contamination is spread, and the portion of the person's diet which comes from the garden. This section discusses these parameters and establishes values for them.

The customary tilling to prepare the soil for planting is assumed to only affect the top 15 cm (6 inches) of soil. This 15 cm tilling depth has been used in prior Hanford Site performance assessments. The greatest tilling depth likely to be encountered is about 60 cm, while the most shallow depth would be no tilling at all. The deeper the soil is tilled, the more dilute the waste becomes in the surface layer. The 15 cm depth is typical for root systems of garden vegetables. The nuclide concentration in plants due to root uptake is based on the average concentration to which the roots are exposed. If the tilling depth were greater than the root depth, the concentration in the material inhaled and ingested would be reduced. This would also lower the resulting doses. The 15 cm tilling depth will be assumed in the base analysis case. The upper bound on the soil concentration will be assumed to be the 10 cm depth, while the lower bound will be assumed to be the 60 cm depth. Many garden plants have root systems which penetrate deeper than 15 cm. However, it will be assumed that most of the nutrients taken from the soil will come from the top 15 cm, so that corrections for root depth will not be necessary.

Having chosen a tilling depth, the dose received by the gardener is proportional to the product of the soil concentration and the quantity of garden produce consumed. The proportionality with soil concentration assumes the contaminants are present in trace amounts which neither affect the growth of the plant, nor exceed solubility limits in the plant tissues. This relationship is summarized in the equation below.

Gardener Dose $\propto$ (Soil Conc)(Quantity Eaten) (1)

In general, the soil concentration is inversely proportional to the area over which the waste is spread. For estimating soil concentration in the garden, the smallest and largest areas can be tied to reasonable spreading thicknesses. The smallest reasonable thickness is 1 cm, because thinner layers require excessive effort to achieve. The largest useful thickness is the tilling depth, 15 cm. The garden area is the total volume of soil exhumed by drilling divided by the assumed thickness. In the 200 Area example where 1.4 m^3 is exhumed, the range of distributed thicknesses gives rise to a range of garden areas from 10 m^2 to 140 m^2. For areas between these limits, the soil concentration is inversely proportional to the area over which the material taken from the well is spread. Larger areas are possible, but the distribution of waste activity will be non-uniform.

The quantity of food derived from the garden is proportional to the garden size. To estimate food production per unit garden area, two approaches are used. The first is commercial food production in Washington State (WA Department of Agriculture 1994). Using the statewide food production per acre figures, the estimated garden area can be computed. The computed total garden area (194 m^2) is mostly for production of grain.

The second approach to estimating garden size uses garden production estimates published by the Washington State University (WSU) Cooperative Extension (1980). The document provides estimates of pounds of produce per 10 foot row in a garden. In addition, it gives recommended row spacings. The spacing was treated as the row width to compute production per unit area. The WSU production estimates are higher than the commercial production averages hence the needed garden area is smaller (161 m^2). These were assumed to be optimum values under excellent growing conditions.

Thus an efficiently planned and maintained garden of 200 m^2 can be assumed to supply most of one average person's garden produce needs. The quantity of food obtained from the garden by one person is proportional to the area of the garden up to a maximum of 200 m^2. Beyond 200 m^2 there is more food than the individual can eat. With more than one person in the household, the needed garden area increases proportionately. However, since the typical gardener obtains about 25% of his vegetable diet from a garden (see Section 2.2.3) a family of four would have a garden no larger than 200 m^2.

Recall that (1) the soil concentration is inversely proportional to the garden area, and (2) the quantity eaten is directly proportional to the garden area. Thus, the gardener's ingestion dose is largely independent of the garden area up to a maximum area of about 200 m^2. Once the garden area exceeds this maximum area, the ingestion dose decreases in proportion to the area. This maximum garden area will be assumed in the ILAW PA.

The chosen garden area of 200 m^2 differs considerably from prior Hanford performance assessments (eg., WHC-SD-WM-EE-004 and WHC-EP-0645) which have used a garden area of

2500 m^2. The more realistic area of 200 m^2 leads to ingestion doses which are 12.5 times greater than before for the same volume of waste exhumed. One justification for the larger area assumption used in prior performance assessments is that after a few hundred years the waste has not yet decomposed into fine particles suitable for uptake into plants. The large particles cannot be resuspended into the air, and prevent the plants from absorbing as much. In effect, the dilution factor is one or more orders of magnitude greater. In the present performance assessment, the unavailable portion will be estimated from glass corrosion characteristics.

For the post-intrusion resident, the range of possible contaminated garden sizes will be taken to be 10 m^2 to 200 m^2. Not all of the larger garden could be contaminated by the exhumed waste, but the individual collects food from all parts of the garden so the effect is the same.

The tilling assumption affects the dose calculations only by making the surface soil concentrations more uniform. Without tilling, the nuclide concentrations in the surface soil could range from that of the waste matrix to zero (background radioactivity is not considered). Conceivably some plants might be unable to grow in certain parts of the garden due to the high waste concentration. The tilling assumption ensures that the vegetable pathways will contribute to the overall dose to the gardener. In practice, the exhumed waste will not be uniformly spread over the garden area. However, the gardener roams the garden and averages out the exposure rate and soil ingestion. The produce grown in the garden will have varying levels of contamination, but the individual consumes portions grown in various parts of the garden, so that assuming an average soil concentration approximates the average produce concentration.

1.2 Low Water Infiltration Exposure Scenarios

In this land use category, the natural water infiltration causes contaminants in the disposal site to migrate into the ground water. Any human activities directly over the waste disposal site are assumed to be delayed at least 100 years. Human activities related to radiation exposure offsite begin after site closure, but really don't become interesting until the ground water plume reaches a well located 100 meters from the disposal site. Although there could be two general categories for the exposure scenarios, human intrusion and offsite scenarios, only the offsite scenarios will be considered (HNF-EP-0828).

The offsite scenarios establish compliance with performance objectives at the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposal site (HNF-EP-0826). Exposure scenario development begins with listing various ways the well water could be used and selecting those activities that could lead to significant radiation exposure. Table 3 lists potential dose contributors. Some of the listed pathways turn out to be insignificant. Because the irrigation activities are not directly over the disposal site water infiltration at the disposal site is not affected. Also note that skin absorption refers to radioactive materials on the skin being absorbed into the body by passage through the skin.

The per capita water withdrawal rate from domestic wells mentioned in Miller (1980) (page 27), is 65 gallons per day, or 90,000 liters per year. This figure covers the principal domestic uses, namely, washing and bathing, drinking and cooking for one person.

Table 3. Exposure Pathways for the Low Water Infiltration Case.

(1) Drinking the well water (also cooking with it)
▸ ingestion
(2) Showering and bathing with the well water
▸ inhalation (sprays) • ingestion (small amounts) • external radiation exposure (immersion) • skin absorption (contact with water)
(3) Irrigating a garden
▸ inhalation (sprays & resuspended dust) ▸ ingestion (produce & trace amounts of soil) ▸ external radiation exposure (while in garden) • skin absorption (contact with soil)
(4) Drinking water for house pets and livestock
▸ ingestion (eggs, poultry, milk) ▸ external radiation exposure (proximity to animal)
(5) Irrigating livestock pastures
▸ inhalation (sprays & resuspended dust) ▸ ingestion (beef & milk) ▸ external radiation exposure (while in pasture)
(6) Sleeping on soil contaminated by irrigation
▸ inhalation (resuspended dust) ▸ external radiation exposure (while on ground) ▸ skin absorption (contact with soil)
(7) Sweat lodge/wet sauna
▸ inhalation (steam) ▸ skin absorption (contact with steam) ▸ external radiation exposure (soil, walls, steam)

As ground water enters the Columbia River, it is diluted by the large flow of surface water. From 1989 to 1999 the average flow rate measured at Priest Rapids Dam is about 3360 cubic meters per second (PNNL-6415). Radioactive contamination in the ground water would then be transported to various water intakes for use as irrigation and public drinking supplies. Doses to an individual irrigating from the Columbia River would be orders of magnitude smaller than doses to the same farmer irrigating from a well which penetrates the aquifer down gradient from the waste site. For this reason, the dose to an individual irrigating from the Columbia River will not be considered. However, since a large number of people would be affected by contamination in the river, a total population dose will be estimated.

As in prior performance assessments (eg., WHC-SD-WM-EE-004 and WHC-EP-0645) a total population of 5 million people between the Hanford Site and the Pacific Ocean will be assumed to derive all of their drinking water from the Columbia River. The population estimate is an upper bound. The lower bound is the population at an earlier time, assumed to be 1 million persons.

In addition, the average irrigation rate along the river will be assumed to be 25 cm/y (WHC-SD-WM-EE-004). This value was obtained as an average in counties along the Columbia River, and thereby differs from the irrigation rate assumed for individuals living near the Hanford Site. Again, this average over a large population will have an insignificant range.

Offsite exposure scenarios will use one or more of the listed pathways. Some pathways may be ruled out by characteristics of the environmental setting. For example, irrigation of a garden from a well is reasonable, but irrigation of pastures may not be possible, depending on the bounding pumping rate from the well. Possible exposure scenarios have been selected to represent future uses of the land. They are listed in Table 4.

The exposure scenarios listed in Table 4 use the naming convention of DOE/RL-91-45, *Hanford Site Risk Assessment Methodology* (HSRAM), Revision 3. The customary disposal site performance assessment all-pathways scenarios is included as an alternate for the agricultural scenario. Differences in modelling assumptions are discussed in later sections.

The native american subsistence resident (NASR) is based on discussions presented in DOE/RL-96-16. This individual represents a bounding case whose intakes of contaminated foodstuffs and exposures to environmental contamination are maximized.

Table 4. Exposure Scenarios for the Low Water Infiltration Case.

Industrial Scenario - represents potential doses to workers in a commercial industrial setting. Drinking water comes from the well (1), as does water used in showering (2), but no other pathway applies.
Residential Scenario - represents potential doses to individuals living in a community near the disposal site. These individuals drink from the well (1), shower regularly (2), irrigate a garden (3), give it to their pets (4), water a lawn and sleep on it occasionally (6).
Agricultural Scenario - represents potential doses to individuals who may take up residence on the Hanford Site to operate a subsistence farm. These individuals drink from their well (1), shower regularly (2), irrigate a garden (3), give it to their pets and livestock (4), irrigate a pasture for their cow (5), water a lawn and sleep on it occasionally (6). This scenario includes all of the pathways listed in Table 3 except the sauna.
Native American Subsistence Resident (NASR) Scenario - represents potential doses to individuals practicing the traditional subsistence lifestyle of the native American Indian. This includes hunting, fishing, gathering wild produce, and using a sweat lodge. These individuals also have a well for drinking, bathing, irrigating, and providing water for pets and livestock. All of the pathways listed on Table 3 are used.

1.3 High Water Infiltration Exposure Scenarios

In this land use category, the water infiltration rate at the disposal site is much larger than the present natural infiltration rate due to widespread irrigation of the central plateau of the Hanford Site. The higher infiltration rate changes the rate at which radioactivity is released from the disposal site as well as the rate at which it travels through the vadose zone. In addition, it acts to dilute the radioactivity entering the ground water. Thus the resulting ground water concentrations could be higher or lower than in the low infiltration case.

As with the low infiltration case, compliance with performance objectives is measured at the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposal site (HNF-EP-0826). The offsite exposure scenarios discussed for the low water infiltration case also apply here. The only difference is the contaminant concentration in the ground water pumped from the well. Since water concentrations determine the dose, it is essential to have a credible model for the release and transport of waste contaminants through the soil.

2.0 EXPOSURE PATHWAY PARAMETERS

This section summarizes the recommended parameters and models to be used in calculating the radiation doses for the various scenarios in the ILAW PA. What follows is a description of each parameter, typical values, and the justification for the values chosen for this performance assessment. Where these parameters differ from prior performance assessments for Hanford disposal sites, the differences are explained. The mathematical models are described to illustrate how the parameters are used in calculations.

For the most part this is simply an expanded version of a previous supporting document (WHC-SD-TI-707). The discussion of data and models is divided into several topical areas, namely, nuclear properties, human activities, animal, plant, and soil characteristics.

An additional consideration is the potential effects on special groups of individuals who may be exposed in unique ways not normally considered. Information relevant to the modeling of dose to these special groups is included in each section.

2.1 Nuclear Parameters

The first parameters of interest are basic nuclear properties of the radionuclides which may be found in waste buried on the Hanford Site. The two main selection criteria for these nuclides is the radioactive half-life and the projected inventory in typical N-Reactor fuel. Radionuclides with half-lives greater than approximately one year are considered.

Table 5 shows the decay half-life and the decay chain branching ratios. A branching ratio is the fraction of decays of a parent nuclide which produce a given progeny nuclide. These parameters are needed to determine the amount of a nuclide, and any radioactive progeny, which is present as a function of time. Values are taken from the Evaluated Nuclear Data File, Release VI (ENDF/B-VI). The conversion from seconds to years was carried out using the value 365.25 days per year. Also shown on this table are the short-lived progeny which are assumed to be in secular equilibrium with the parent. These short half-life progeny are also called "implicit daughters" because their radioactive emissions are not considered separately, but combined with the parent nuclide.

As noted in DOE/RL-97-69, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (section 3.4.7.4), new measurements of the half lives for Se-79 and Sn-126 show substantial increases. The newer values have been used in Table 5.

Table 5. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (years)	Short-lived progeny in equilibrium with parent
H-3	12.33	
Be-10	1.600E+06	
C-14	5,730	
Na-22	2.6019	
Si-32+D	329.56	P-32
Cl-36	300,992	
K-40	1.277E+09	
Ti-44+D	47.30	Sc-44
V-49	0.92539 (338 d)	
Mn-54	0.85454 (312.12 d)	
Fe-55	2.7299	
Co-60	5.2713	
Ni-59	74,999	
Ni-63	100.10	
Se-79	805,000	
Rb-87	4.800E+10	
Sr-90+D	28.149	Y-90
Zr-93	1.530E+06	
Nb-91	680	
Nb-93m	16.13	
Nb-94	20,300	
Mo-93	3,500	
Tc-99	211,097	
Ru-106+D	1.01736 (371.59 d)	Rh-106

Table 5. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (years)	Short-lived progeny in equilibrium with parent
Pd-107	6.50E+06	
Ag-108m+D	127.00	Ag-108 (0.087)
Cd-109	1.26653 (462.6 d)	
Cd-113m	14.10	
In-115	4.410E+14	
Sn-121m+D	54.998	Sn-121 (0.776)
Sn-126+D	246,000	Sb-126m, Sb-126 (0.14)
Sb-125	2.7299	
Te-125m	0.15880 (58 d)	
I-129	1.570E+07	
Cs-134	2.0619	
Cs-135	2.30E+06	
Cs-137+D	29.999	Ba-137m (0.9443)
Ba-133	10.520	
Pm-147	2.6233	
Sm-147	1.060E+11	
Sm-151	89.997	
Eu-150	35.798	
Eu-152	13.330	
Eu-154	8.5919	
Eu-155	4.680	
Gd-152	1.080E+14	
Ho-166m	1,200	
Re-187	5.000E+10	
Tl-204	3.7801	
Pb-205	1.520E+07	

Table 5. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (years)	Short-lived progeny in equilibrium with parent
Pb-210+D	22.300	Bi-210
Bi-207	32.198	
Po-209	102.0	
Po-210	0.37886 (138.38 d)	
Ra-226+D	1,600	Rn-222, Po-218, Pb-214, Bi-214, Po-214(0.9998)
Ra-228+D	5.7498	Ac-228
Ac-227+D	21.769	Th-227(0.9862), Fr-223(0.0138), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207(.99725), Po-211(.00275)
Th-228+D	1.9129	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212(0.6406), Tl-208(0.3594)
Th-229+D	7,340	Ra-225, Ac-225, Fr-221, At-217, Bi213, Po-213(0.9784), Tl-209(0.0216)
Th-230	75,380	
Th-232	1.405E+10	
Pa-231	32,759	
U-232	69.799	
U-233	159,198	
U-234	245,694	
U-235+D	7.037E+08	Th-231
U-236	2.342E+07	
U-238+D	4.468E+09	Th-234, Pa-234m, Pa-234 (0.0013)
Np-237+D	2.140E+06	Pa-233
Pu-236	2.8999	
Pu-238	87.697	
Pu-239	24,110	
Pu-240	6,563	
Pu-241+D	14.350	U-237 (2.39E-05)
Pu-242	373,507	

Table 5. Radionuclides to be Considered and Their Half Lives.

Nuclide	Half life (years)	Short-lived progeny in equilibrium with parent
Pu-244+D	8.000E+07	U-240 (0.9988), Np-240m, Np-240 (0.0012)
Am-241	432.70	
Am-242m+ D	141.00	Am-242(0.9955), Np-238(0.0045)
Am-243+D	7,370	Np-239
Cm-242	0.44611 (162.94 d)	
Cm-243	28.499	
Cm-244	18.100	
Cm-245	8,500	
Cm-246	4,730	
Cm-247+D	1.600E+07	Pu-243
Cm-248	339,981	
Cm-250+D	11,300	Pu-246(0.25), Am-246(0.25), Bk-250(0.14)
Bk-247	1,394	
Cf-248	0.91294 (333.45 d)	
Cf-249	350.60	
Cf-250	13.080	
Cf-251	897.98	
Cf-252	2.6449	

Note: Parentheses show (1) half-lives that are normally given in days, and (2) branching ratios that differ from 1.00.

Table 6 shows the radioactive decay chains which will be computed prior to and during the exposure scenarios. Radioactive decay normally reduces the dose that a receptor could receive. However, in the cases shown on Table 6, the ingrowth of the progeny nuclides with time may increase the dose from the parent nuclide. One example of this is Th-232, which has a very long half-life so that there is essentially no change in its activity during the year of exposure. Since the initial activity of the progeny nuclides (Ra-228 and Th-228) is assumed to be zero any increase will have maximum effect on the Th-232 doses. In addition, since the progeny

accumulate according to their much shorter half-lives, they are able to increase the dose from Th-232 significantly.

The decay chains used in these calculations are limited to four radioactive members by the assumption that the decay times will be less than 1000 years.

Table 6. Decay Chains Actually Computed.

Zr-93	→	Nb-93m				
Mo-93	→	Nb-93m				
Sb-125	→ .230	Te-125m				
Pm-147	→	Sm-147				
Eu-152	→ .2792	Gd-152				
Pb-210	→	Po-210				
Po-209	→ .9974	Pb-205				
Ra-226	→	Pb-210	→	Po-210		
Ra-228	→	Th-228				
Th-230	→	Ra-226	→	Pb-210	→	Po-210
Th-232	→	Ra-228	→	Th-228		
Pa-231	→	Ac-227				
U-232	→	Th-228				
U-233	→	Th-229				
U-234	→	Th-230	→	Ra-226	→	Pb-210
U-235	→	Pa-231	→	Ac-227		
Pu-236	→	U-232	→	Th-228		
Pu-238	→	U-234				
Pu-241	→	Am-241	→	Np-237		
Pu-244	→	Pu-240				

Table 6. Decay Chains Actually Computed.

Am-241	→	Np-237				
Am-242m	→ .827	Cm-242	→	Pu-238	→	U-234
	→ .173	Pu-242				
Am-243	→	Pu-239				
Cm-242	→	Pu-238	→	U-234		
Cm-243	→	Pu-239				
	→ .0024	Am-243				
Cm-244	→	Pu-240				
Cm-245	→	Pu-241	→	Am-241	→	Np-237
Cm-247	→	Am-243				
Cm-250	→ .14	Cf-250	→			
	→ .25	Cm-246	←			
Bk-247	→	Am-243				
Cf-248	→	Cm-244	→	Pu-240		
Cf-249	→	Cm-245	→	Pu-241	→	Am-241
Cf-250	→	Cm-246				
Cf-251	→	Cm-247				
Cf-252	→	Cm-248				

Notes:

Decay times are assumed to be less than 1000 years so that the ingrowth of progeny with long half-lives can be ignored.

There is a slight increase in the Pu-238 and U-234 for the Am-242m decay chain that is not shown. This is a result of the low-probability alpha decay of Am-242m. The complete chain is, Am-242m(0.00455)--->Np-238--->Pu-238--->U-234.

2.2 Human Parameters

Parameters for humans represented in the various exposure scenarios are the internal and external dose factors, and the food types and consumption rates for typical humans currently living near the Hanford Site.

2.2.1 Internal Dose Factors

Internal dose factors specify the effective dose equivalent (EDE) from a unit intake (ingested or inhaled) of a radionuclide. The dose is accumulated over a period of 50 years, known as the dose commitment period. This dose commitment period was set by the ICRP in Publication 26 (1977) when determining internal dose and relating it to whole body exposure.

If the nuclide has radioactive progeny with short half-lives, then the internal dose factors for these progeny are included with the parent isotope. It is assumed that the progeny are in secular equilibrium with the parent nuclide.

Currently, internal dose factors are based on the methods and assumptions of the International Commission on Radiological Protection (ICRP) prior to 1990. In 1990, the ICRP published Report Number 60 which revised these methods. Regulatory bodies in the United States have not yet adopted the improved methods, so they are not included here.

There are three internal dose factor collections which will be considered. The first is widely used in performance assessments for the United States Department of Energy (DOE/EH-0071). The second was prepared under the sponsorship of the United States Environmental Protection Agency (EPA-520/1-88-020). This set is also acceptable for use in performance assessments at DOE sites (DOE/LLW-93 and DOE M 435.1-1 Implementation Guide Chapter IV). The third was computed for the GENII software (PNNL-6584), which is often used at the Hanford Site. The GENII internal dose factors were recently revised (WHC-SD-WM-TI-596).

The dose factors from the three collections have been converted to the common units of mrem per pCi intake in Tables 7 and 8 below. For the ingestion dose factors, Table 7 shows the assumed values for f1, which is the fraction of the activity ingested that enters body fluids. "DF" is an abbreviation for dose factor. For the inhalation dose factors, Table 8 lists the assumed lung model category. The "V" for tritium stands for vapor, and includes a 50 percent increase due to absorption through the skin. The "Org" for C-14 means that the carbon is assumed to have an organic chemical form. The "D", "W", and "Y" mean the material clears the lungs in a matter of days, weeks, or years, respectively.

Comparison ratios of the GENII and DOE dose factors divided by the EPA dose factors are shown in Tables 7 and 8. Dose factors that differ less than 5% from the EPA numbers are not shown in the ratio columns. The only nuclides with differences greater than 25 percent are

Co-60, Nb-94, Tc-99, Ru-106, Ag-108m, In-115, Sn-126, Re-187, Bi-207, Ra-226, Ra-228, Th-228, Np-237, Pu-241, and Bk-247.

The internal dose factors for Nb-91 are not listed in any dose factor collection and were assumed to be bounded by the values for Nb-93m. Both nuclides emit low energy electrons and photons, as shown on the nuclear decay data summary of Table 9. For Nb-91, there is a continuous spectrum of low energy photons associated with the electron capture and positron decay. However, this continuous spectrum is a minor addition to the photon spectrum. The total electron plus photon energy for Nb-91 (15 keV) is less than that for Nb-93m (26 keV). Therefore, the internal dose factor for Nb-91 should be less than that for Nb-93m.

An additional consideration is the half-life of the two isotopes compared with expected residence times in the body. Inhalation class Y niobium is retained in the lungs for a considerable length of time. Most is removed during the first several years, but some is retained indefinitely. The organ with the largest dose for class Y Nb-93m is the lungs. Most (87%) of the dose from Nb-93m accrues during the first 10 years after inhalation. Thus, the effect of Nb-93m's shorter half-life is small. It will be assumed that the internal dose factors for Nb-91 are bounded by those for Nb-93m.

In addition to Nb-91, the internal dose factors for Po-209 are not listed in any dose factor collection and had to be computed by comparison with Po-210. Corrections were made for the energy of the alpha particles emitted, and the decay half-life using the equation shown below.

$$\text{Dose Factor} \propto \frac{E_\alpha}{\lambda_{eff}}\left[1 - e^{-\lambda_{eff} T_d}\right] \qquad (2)$$

where,

$E\alpha$ = total alpha energy per decay. For Po-209 this is 4.882 Mev per decay, while for Po-210 this is 5.3045 Mev per decay.

λ_{eff} = effective removal constant, which combines both the biological elimination and the radioactive decay of the nuclide.

T_d = dose commitment period used in the dose factor collections shown in Tables 7 and 8, namely, 50 years.

The biological removal half time for polonium is 50 days (ICRP 30). The decay half-life of Po-209 is 102 year, thus its λ_{eff} is 0.01388 per day. The decay half-life of Po-210 is 138 days, thus its λ_{eff} is 0.01889 per day. Since these are so large, the dose integration term in brackets is nearly 1 after 50 years. The ratio of Po-209 to Po-210 internal dose factors is shown below. This ratio was applied to the Po-210 inhalation and ingestion dose factors to arrive at the Po-209 internal dose factors.

$$\frac{\text{Po-209 Dose Factor}}{\text{Po-210 Dose Factor}} = \frac{4.882 \text{ Mev} * 0.01889 \text{ per day}}{5.3045 \text{ Mev} * 0.01388 \text{ per day}} = 1.252$$

The dose factor collection from the EPA (EPA-520/1-88-020) will be used in the ILAW PA. These are the only internal dose factors currently approved by the DOE for use in performance assessments (DOE M 435.1-1). The differences with the other collections is minor. Ratios of the GENII and EPA internal dose factors to the DOE dose factors are shown in Table 8.

Special groups of people such as children and diabetics, will have different internal dose factors due to differences in organ mass and retention times in the various tissues of the body. Internal dose factors for different age groups have been computed by the ICRP in Publication 56 (1989). However, these dose factors are for a limited number of nuclides. Unit dose factors for individuals whose metabolic characteristics differ considerably from those of the reference individual will also differ from those presented in Tables 7 and 8. As explained in DOE M 435.1-1 Chapter IV, the use of dose factors for representative members of the public is desirable to avoid overly conservative results. A bounding case exposure scenario evaluates possible upper limits.

Absorption through the skin, and injection from an injury are not considered since they are not likely to add significantly to the doses computed in the intruder and irrigation scenarios. These may be computed using an internal dosimetry program such as CINDY (PNNL-7493). Values have been published (PNNL-10190) and are basically the ingestion dose factor divided by the internal transfer factor (f1).

Any special exposure pathways associated with extended dermal contact with contaminated soil or vegetation will require appropriate dermal absorption dose factors. Dermal absorption methods for radionuclides were recently included in a revision to the MEPAS[1] program (PNNL-10523).

[1]MEPAS is a registered trademark of Battelle Memorial Institute.

Table 7. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII/EPA	DOE/EPA
H-3	1	6.12E-08	6.40E-08	6.30E-08		
Be-10	0.005	4.70E-06	4.66E-06	4.20E-06		0.90
C-14	1	2.06E-06	2.09E-06	2.10E-06		
Na-22	1	1.06E-05	1.15E-05	1.20E-05	0.92	
Si-32+D	0.01	1.11E-05	1.10E-05	9.40E-06		0.85
Cl-36	1	2.95E-06	3.03E-06	3.00E-06		
K-40	1	1.79E-05	1.86E-05	1.90E-05		
Ti-44+D	0.01	2.35E-05	2.46E-05	1.91E-05		0.78
V-49	0.01	6.04E-08	6.14E-08	5.40E-08		0.88
Mn-54	0.1	2.76E-06	2.77E-06	2.70E-06		
Fe-55	0.1	6.15E-07	6.07E-07	5.80E-07		
Co-60	0.3	2.65E-05	2.69E-05	2.60E-05		
Ni-59	0.05	2.05E-07	2.10E-07	2.00E-07		
Ni-63	0.05	5.72E-07	5.77E-07	5.40E-07		0.94
Se-79	0.8	8.33E-06	8.70E-06	8.30E-06		
Rb-87	1	4.73E-06	4.92E-06	4.80E-06		
Sr-90+D	0.3	1.31E-04	1.53E-04	1.40E-04	0.86	0.92
Zr-93	0.002	1.64E-06	1.66E-06	1.60E-06		
Nb-91	0.01	5.05E-07	5.22E-07	5.30E-07		
Nb-93m	0.01	5.05E-07	5.22E-07	5.30E-07		
Nb-94	0.01	7.25E-06	7.14E-06	5.10E-06		0.71
Mo-93	0.8	1.21E-06	1.35E-06	1.30E-06	0.90	
Tc-99	0.8	2.23E-06	1.46E-06	1.30E-06	1.53	0.89
Ru-106+D	0.05	2.73E-05	2.74E-05	2.10E-05		0.77
Pd-107	0.005	1.50E-07	1.49E-07	1.40E-07		0.94
Ag-108m+D	0.05	7.58E-06	7.62E-06	7.50E-06		
Cd-109	0.05	1.32E-05	1.31E-05	1.20E-05		0.92
Cd-113m	0.05	1.62E-04	1.61E-04	1.50E-04		0.93
In-115	0.02	8.68E-05	1.58E-04	1.40E-04	0.55	0.89

Table 7. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Sn-121m+D	0.02	2.24E-06	2.25E-06	1.99E-06		0.88
Sn-126+D	0.02	2.08E-05	2.11E-05	1.83E-05		0.87
Sb-125+D	0.1	2.83E-06	2.81E-06	2.60E-06		0.93
Te-125m	0.2	3.72E-06	3.67E-06	3.40E-06		0.93
I-129	1	2.49E-04	2.76E-04	2.80E-04	0.90	
Cs-134	1	6.82E-05	7.33E-05	7.40E-05	0.93	
Cs-135	1	6.86E-06	7.07E-06	7.10E-06		
Cs-137+D	1	4.74E-05	5.00E-05	5.00E-05	0.95	
Ba-133	0.1	3.05E-06	3.40E-06	3.20E-06	0.90	0.94
Pm-147	0.0003	1.06E-06	1.05E-06	9.50E-07		0.90
Sm-147	0.0003	1.86E-04	1.85E-04	1.80E-04		
Sm-151	0.0003	3.87E-07	3.89E-07	3.40E-07		0.87
Eu-150	0.001	6.34E-06	6.36E-06	6.20E-06		
Eu-152	0.001	6.48E-06	6.48E-06	6.00E-06		0.93
Eu-154	0.001	9.61E-06	9.55E-06	9.10E-06		
Eu-155	0.001	1.53E-06	1.53E-06	1.30E-06		0.85
Gd-152	0.0003	1.61E-04	1.61E-04	1.50E-04		0.93
Ho-166m	0.0003	8.13E-06	8.07E-06	7.80E-06		
Re-187	0.8	1.45E-08	9.51E-09	8.30E-09	1.52	0.87
Tl-204	1	3.46E-06	3.36E-06	3.20E-06		
Pb-205	0.2	1.64E-06	1.63E-06	1.50E-06		0.92
Pb-210+D	0.2	5.40E-03	5.37E-03	5.11E-03		
Bi-207	0.05	5.49E-06	5.48E-06	4.90E-06		0.89
Po-209	0.1	2.39E-03	2.38E-03	2.00E-03		0.84
Po-210	0.1	1.90E-03	1.90E-03	1.60E-03		0.84
Ra-226+D	0.2	9.51E-04	1.33E-03	1.10E-03	0.72	0.83
Ra-228+D	0.2	8.44E-04	1.44E-03	1.20E-03	0.59	0.83
Ac-227+D	0.001	1.44E-02	1.48E-02	1.46E-02		
Th-228+D	0.0002	5.79E-04	8.11E-04	7.54E-04	0.71	0.93

Table 7. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Th-229+D	0.0002	3.87E-03	4.03E-03	3.91E-03		
Th-230	0.0002	5.48E-04	5.48E-04	5.30E-04		
Th-232	0.0002	2.73E-03	2.73E-03	2.80E-03		
Pa-231	0.001	1.06E-02	1.06E-02	1.10E-02		
U-232	0.05	1.31E-03	1.31E-03	1.30E-03		
U-233	0.05	2.90E-04	2.89E-04	2.70E-04		0.93
U-234	0.05	2.84E-04	2.83E-04	2.60E-04		0.92
U-235+D	0.05	2.67E-04	2.67E-04	2.51E-04		0.94
U-236	0.05	2.69E-04	2.69E-04	2.50E-04		0.93
U-238+D	0.05	2.70E-04	2.68E-04	2.43E-04		0.91
Np-237+D	0.001	5.22E-03	4.44E-03	3.90E-03	1.18	0.88
Pu-236	0.001	1.16E-03	1.17E-03	1.30E-03		1.11
Pu-238	0.001	3.19E-03	3.20E-03	3.80E-03		1.19
Pu-239	0.001	3.53E-03	3.54E-03	4.30E-03		1.21
Pu-240	0.001	3.53E-03	3.54E-03	4.30E-03		1.21
Pu-241+D	0.001	6.79E-05	6.85E-05	8.60E-05		1.26
Pu-242	0.001	3.35E-03	3.36E-03	4.10E-03		1.22
Pu-244+D	0.001	3.32E-03	3.32E-03	4.00E-03		1.20
Am-241	0.001	3.62E-03	3.64E-03	4.50E-03		1.24
Am-242m+D	0.001	3.50E-03	3.52E-03	4.20E-03		1.19
Am-243+D	0.001	3.62E-03	3.63E-03	4.50E-03		1.24
Cm-242	0.001	1.15E-04	1.15E-04	1.10E-04		
Cm-243	0.001	2.50E-03	2.51E-03	2.90E-03		1.16
Cm-244	0.001	2.01E-03	2.02E-03	2.30E-03		1.14
Cm-245	0.001	3.73E-03	3.74E-03	4.50E-03		1.20
Cm-246	0.001	3.70E-03	3.70E-03	4.50E-03		1.22
Cm-247+D	0.001	3.40E-03	3.42E-03	4.10E-03		1.20
Cm-248	0.001	1.36E-02	1.36E-02	1.60E-02		1.18
Cm-250+D	0.001	7.76E-02	7.77E-02	7.77E-02		

Table 7. Ingestion Dose Factors, mrem/pCi Ingested.

Nuclide	f1	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Bk-247	0.001	3.81E-03	4.70E-03	2.30E-03	0.81	0.49
Cf-248	0.001	3.39E-04	3.34E-04	2.80E-04		0.84
Cf-249	0.001	4.75E-03	4.74E-03	4.60E-03		
Cf-250	0.001	2.13E-03	2.13E-03	1.90E-03		0.89
Cf-251	0.001	4.82E-03	4.85E-03	4.60E-03		0.95
Cf-252	0.001	1.09E-03	1.08E-03	9.40E-04		0.87

Notes:

(1) GENII Internal DF are from the July 1999 library revision by PDR. EPA Inhalation & Ingestion dose factors from Federal Guidance Report Number 11, EPA-520/1-88-020, Sept 1988. DOE Ingestion & Inhalation dose factors from DOE/EH-0071, (DE88-014297), July 1988. All are 50 year committed EDE.

(2) "DF" means dose factor. "f1" is the fraction of ingested activity reaching body fluids.

(3) The short-lived radioactive progeny shown on Table 5 are assumed to be in secular equilibrium with their parent nuclide. The dose factors for implicit daughters have been added to the parent dose factor to give the values shown.

(4) The last two columns show ratios of GENII and DOE ingestion dose factors to the EPA dose factors. Ratios of dose factors within 5% of the EPA value are not shown.

Table 8. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII/EPA	DOE/EPA
H-3	H_2O	9.02E-08	9.60E-08	9.45E-08	0.94	
Be-10	Y	3.54E-04	3.54E-04	3.50E-04		
C-14	Organic	2.06E-06	2.09E-06	2.10E-06		
Na-22	D	7.11E-06	7.66E-06	8.00E-06	0.93	
Si-32+D	Y	1.02E-03	1.03E-03	1.01E-03		
Cl-36	W	2.21E-05	2.19E-05	2.00E-05		0.91
K-40	D	1.19E-05	1.24E-05	1.20E-05		
Ti-44+D	D	4.18E-04	4.52E-04	4.50E-04	0.92	
V-49	W	3.46E-07	3.45E-07	2.80E-07		0.81
Mn-54	W	6.36E-06	6.70E-06	6.40E-06	0.95	
Fe-55	D	2.74E-06	2.69E-06	2.60E-06		
Co-60	Y	2.00E-04	2.19E-04	1.50E-04	0.91	0.68
Ni-59	D	1.28E-06	1.32E-06	1.30E-06		
Ni-63	D	3.06E-06	3.10E-06	3.00E-06		
Se-79	W	9.49E-06	9.84E-06	8.90E-06		0.90
Rb-87	D	3.18E-06	3.23E-06	3.30E-06		
Sr-90+D	D	2.10E-04	2.48E-04	2.37E-04	0.85	
Zr-93	D	3.16E-04	3.21E-04	3.20E-04		
Nb-91	Y	2.94E-05	2.92E-05	2.80E-05		
Nb-93m	Y	2.94E-05	2.92E-05	2.80E-05		
Nb-94	Y	3.91E-04	4.14E-04	3.30E-04	0.94	0.80
Mo-93	Y	2.80E-05	2.84E-05	2.80E-05		
Tc-99	W	9.00E-06	8.33E-06	7.50E-06	1.08	0.90
Ru-106+D	Y	4.75E-04	4.77E-04	4.40E-04		0.92
Pd-107	Y	1.29E-05	1.28E-05	1.30E-05		
Ag-108m+D	Y	2.58E-04	2.83E-04	2.00E-04	0.91	0.71
Cd-109	D	1.15E-04	1.14E-04	1.00E-04		0.88
Cd-113m	D	1.54E-03	1.53E-03	1.40E-03		0.92

Table 8. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII/EPA	DOE/EPA
In-115	D	2.02E-03	3.74E-03	3.40E-03	0.54	0.91
Sn-121m+D	W	1.18E-05	1.19E-05	9.26E-06		0.78
Sn-126+D	W	1.00E-04	1.01E-04	7.54E-05		0.75
Sb-125+D	W	1.23E-05	1.22E-05	9.80E-06		0.80
Te-125m	W	7.18E-06	7.29E-06	6.70E-06		0.92
I-129	D	1.51E-04	1.74E-04	1.80E-04	0.87	
Cs-134	D	4.28E-05	4.63E-05	4.70E-05	0.92	
Cs-135	D	4.49E-06	4.55E-06	4.50E-06		
Cs-137+D	D	2.98E-05	3.19E-05	3.20E-05	0.93	
Ba-133	D	6.00E-06	7.81E-06	6.90E-06	0.77	0.88
Pm-147	Y	3.92E-05	3.92E-05	3.40E-05		0.87
Sm-147	W	7.48E-02	7.47E-02	7.10E-02		
Sm-151	W	3.01E-05	3.00E-05	2.90E-05		
Eu-150	W	2.50E-04	2.68E-04	2.70E-04	0.93	
Eu-152	W	2.11E-04	2.21E-04	2.20E-04		
Eu-154	W	2.78E-04	2.86E-04	2.60E-04		0.91
Eu-155	W	4.12E-05	4.14E-05	3.90E-05		0.94
Gd-152	D	2.44E-01	2.43E-01	2.40E-01		
Ho-166m	W	7.46E-04	7.73E-04	7.20E-04		0.93
Re-187	W	5.86E-08	5.44E-08	4.90E-08	1.08	0.90
Tl-204	D	2.46E-06	2.41E-06	2.30E-06		
Pb-205	D	3.97E-06	3.92E-06	3.70E-06		0.94
Pb-210+D	D	1.39E-02	1.38E-02	1.32E-02		
Bi-207	W	1.96E-05	2.00E-05	1.40E-05		0.70
Po-209	D	1.19E-02	1.18E-02	1.01E-02		0.86
Po-210	D	9.65E-03	9.40E-03	8.10E-03		0.86
Ra-226+D	W	8.22E-03	8.60E-03	7.91E-03		0.92
Ra-228+D	W	4.40E-03	5.08E-03	4.49E-03	0.87	0.88

Table 8. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Ac-227+D	D	6.71E+00	6.72E+00	6.72E+00		
Th-228+D	W	3.47E-01	3.45E-01	3.13E-01		0.91
Th-229+D	W	2.16E+00	2.16E+00	2.02E+00		0.94
Th-230	W	3.27E-01	3.26E-01	3.20E-01		
Th-232	W	1.64E+00	1.64E+00	1.60E+00		
Pa-231	W	1.29E+00	1.28E+00	1.30E+00		
U-232	Y	6.56E-01	6.59E-01	6.70E-01		
U-233	Y	1.35E-01	1.35E-01	1.30E-01		
U-234	Y	1.32E-01	1.32E-01	1.30E-01		
U-235+D	Y	1.24E-01	1.23E-01	1.20E-01		
U-236	Y	1.26E-01	1.25E-01	1.20E-01		
U-238+D	Y	1.18E-01	1.18E-01	1.20E-01		
Np-237+D	W	6.32E-01	5.40E-01	4.90E-01	1.17	0.91
Pu-236	W	1.45E-01	1.45E-01	1.60E-01		1.10
Pu-238	W	3.90E-01	3.92E-01	4.60E-01		1.17
Pu-239	W	4.30E-01	4.29E-01	5.10E-01		1.19
Pu-240	W	4.30E-01	4.29E-01	5.10E-01		1.19
Pu-241+D	W	8.17E-03	8.25E-03	1.00E-02		1.21
Pu-242	W	4.08E-01	4.11E-01	4.80E-01		1.17
Pu-244+D	W	4.03E-01	4.03E-01	4.80E-01		1.19
Am-241	W	4.41E-01	4.44E-01	5.20E-01		1.17
Am-242m+D	W	4.24E-01	4.26E-01	5.10E-01		1.20
Am-243+D	W	4.41E-01	4.40E-01	5.20E-01		1.18
Cm-242	W	1.75E-02	1.73E-02	1.70E-04		
Cm-243	W	3.07E-01	3.07E-01	3.50E-01		1.14
Cm-244	W	2.48E-01	2.48E-01	2.70E-01		1.09
Cm-245	W	4.55E-01	4.55E-01	5.40E-01		1.19
Cm-246	W	4.51E-01	4.51E-01	5.40E-01		1.20

Table 8. Inhalation Dose Factors, mrem/pCi Inhaled.

Nuclide	Lung Model	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Cm-247+D	W	4.15E-01	4.14E-01	4.90E-01		1.18
Cm-248	W	1.65E+00	1.65E+00	1.90E+00		1.15
Cm-250+D	W	9.43E+00	9.40E+00	9.40E+00		
Bk-247	W	4.65E-01	5.74E-01	5.50E-01	0.81	
Cf-248	Y	5.11E-02	5.07E-02	4.30E-02		0.85
Cf-249	W	5.77E-01	5.77E-01	5.50E-01		
Cf-250	W	2.63E-01	2.62E-01	2.20E-01		0.84
Cf-251	W	5.87E-01	5.88E-01	5.60E-01		
Cf-252	Y	1.55E-01	1.57E-01	1.30E-01		0.83

Notes:

(1) GENII Internal DF are from the July 1999 library revision by PDR. EPA Inhalation & Ingestion dose factors from Federal Guidance Report Number 11, EPA-520/1-88-020, Sept 1988. DOE Ingestion & Inhalation dose factors from DOE/EH-0071, (DE88-014297), July 1988. All are 50 year committed EDE.

(2) "DF" means dose factor. "Lung" refers to the ICRP lung model classification, "H2O" is tritium vapor (which includes skin absorption), "Organic" means organic carbon, "D" is days, "W" is weeks, and "Y" is years.

(3) The short-lived radioactive progeny shown on Table 5 are assumed to be in secular equilibrium with their parent nuclide. The dose factors for implicit daughters have been added to the parent dose factor to give the values shown.

(4) The last two columns show ratios of GENII and DOE inhalation dose factors to the EPA dose factors. Ratios of dose factors within 5% of the EPA value are not shown.

Table 9. Nuclear Decay Data for Nb-91 and Nb-93m.

Nb-91 (680 y)	Particle energy, keV	fraction of decays	Weighted energy, keV
EC	1254.6	0.99836	417.51
positron	232.6	0.00164	0.13
electron	13.47	0.2348	3.16
photon	15.69	0.18319	2.87
	15.77	0.35027	5.52
	17.66	0.10136	1.79
	511	0.00328	1.68
Total for electrons + photons:			15 keV
Nb-93m (16.13 y)	Particle energy, keV	fraction of decays	Weighted energy, keV
IT	30.77	1	30.77
electron	11.78	0.1440	1.70
	14.15	0.0365	0.52
	28.07	0.1340	3.76
	28.31	0.0262	0.74
	28.40	0.4710	13.38
	30.39	0.1360	4.13
photon	16.52	0.0310	0.51
	16.61	0.0590	0.98
	18.61	0.0175	0.33
	30.77	5.5 E-06	0.00
Total for electrons + photons:			26 keV

Note: The last column shows the product of the particle energies and the fraction of decays with this energy particle. Although the Nb-93m half life is short enough that the total retained in the body (and hence the dose) decreases partly by radioactive decay, its total electron plus positron energy is large enough to make up for the loss by decay. Data from ENDF/B-VI.

2.2.2 External Dose-Rate Factors

External dose-rate factors give the expected dose equivalent rate to an individual standing in the center of a large contaminated area. The dose rate factors have units of dose equivalent rate per unit soil concentration. The contamination is assumed to be uniformly spread over a very large area. The dose rate factors are derived for infinite sources of varying thickness. If the area becomes smaller than a few hundred square meters, then the dose rate factors must be adjusted downward. The thickness of the contaminated layer affects the dose rate and must be considered. For typical exposure scenarios the soil thickness is 15 cm. Radionuclides are assumed to be uniformly distributed through this thickness as a result of cultivating the soil for the purpose of growing a garden.

External dose rates from a layer of contaminated surface soil are available from various sources. Three sources that have been used on the Hanford Site are the DOE surface gamma dose-rate conversion factors (DOE/EH-0070), the EPA values in Federal Guidance Report Number 12 (EPA-402-R-93-081), and the external dose factors recently computed for the GENII program. The three sets of external dose rate factors are shown in Table 10. They have been converted to the common units of mrem/hour per Ci/m^2 for purposes of comparison.

The DOE surface gamma conversion factors (DOE/EH-0070) are derived from an assumed contamination thickness of zero. The contamination lies on top of the soil surface in a layer which is infinitely thin, perfectly flat, and infinite in extent. These assumptions necessarily exaggerate the dose rates for the ILAW PA. Strong beta-emitting nuclides such as Sr-90 produce no external dose since the bremsstrahlung radiation was ignored.

The GENII external dose rate factors (PNNL-6584) were computed using a version of the ISOSHLD program known as EXTDF which is part of the GENII software package. Bremsstrahlung radiation is computed for all beta emitters. The dose rate factors assume the contamination is distributed through the top 0.15 meters (6 inches) of soil. The surface soil is given a density of 1.5 grams per cubic centimeter. Again the surface layer is perfectly flat and infinite in extent. The finite thickness adds realism, since the contamination is worked into the soil during normal tilling operations. These dose rate factors have been used in prior Hanford Site performance assessments.

The EPA external dose rate factors (EPA-402-R-93-081) were computed using a Monte Carlo approach with the best available input data and dosimetric models, except that ICRP 30 organ weighting factors rather than ICRP 60 weighting factors were used. These are considered to be the best external dose rate factors currently available and will be used in the ILAW PA.

The EPA values are for a soil contamination thickness of 15 cm. The number shown for Eu-150 is listed as Eu-150b in the EPA compilation. The reference does not give values for Nb-91 and Po-210. Therefore, the values computed by EXTDF were used instead.

Table 10. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII	EPA	DOE	GENII/EPA	DOE/EPA
H-3	3.49E-08	0.0	0.0	EPA=0	
Be-10	4.33E-01	5.37E-01	0.0	0.806	DOE=0
C-14	7.51E-03	6.82E-03	0.0		DOE=0
Na-22	6.75E+03	5.98E+03	2.40E+04	1.13	4.01
Si-32+D	9.62E+00	5.70E+00	0.0	1.69	DOE=0
Cl-36	8.58E-01	1.16E+00	5.32E-04	0.740	0.000459
K-40	4.87E+02	4.33E+02	1.56E+03	1.12	3.60
Ti-44+D	7.10E+03	6.00E+03	2.57E+04	1.18	4.28
V-49	0.0	0.0	8.60E-01		EPA=0
Mn-54	2.53E+03	2.27E+03	9.59E+03	1.11	4.22
Fe-55	1.07E-01	0.0	2.52E+00	EPA=0	EPA=0
Co-60	7.51E+03	6.87E+03	2.59E+04		3.77
Ni-59	1.31E-01	0.0	4.75E+00	EPA=0	EPA=0
Ni-63	1.91E-04	0.0	0.0	EPA=0	
Se-79	5.37E-03	9.44E-03	0.0	0.569	DOE=0
Rb-87	4.02E-02	7.13E-02	0.0	0.564	DOE=0
Sr-90+D	1.97E+01	1.17E+01	0.0	1.68	DOE=0
Zr-93	1.34E-04	0.0	0.0	EPA=0	
Nb-91	5.74E+00	5.74E+00	8.36E+01		14.6
Nb-93m	4.33E-02	5.28E-02	1.17E+01	0.820	222
Nb-94	4.67E+03	4.29E+03	1.81E+04		4.22
Mo-93	2.43E-01	2.99E-01	6.59E+01	0.813	220
Tc-99	5.04E-02	6.35E-02	7.14E-03	0.794	0.112
Ru-106+D	7.32E+02	5.83E+02	2.40E+03	1.26	4.12
Pd-107	4.16E-06	0.0	0.0	EPA=0	

Table 10. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Ag-108m+D	5.37E+03	4.37E+03	1.90E+04	1.23	4.35
Cd-109	2.61E+00	7.47E+00	1.08E+02	0.349	14.5
Cd-113m	4.28E-01	3.24E-01	0.0	1.32	DOE=0
In-115	2.56E-01	2.01E-01	0.0	1.27	DOE=0
Sn-121m+D	5.15E+00	1.07E+00	0.0	4.81	DOE=0
Sn-126+D	6.56E+03	5.36E+03	2.37E+04	1.22	4.42
Sb-125+D	1.49E+03	1.12E+03	5.05E+03	1.33	4.51
Te-125m	8.78E+00	7.67E+00	2.40E+02	1.14	31.3
I-129	5.54E+00	6.57E+00	2.51E+02	0.843	38.2
Cs-134	5.23E+03	4.24E+03	1.80E+04	1.23	4.25
Cs-135	1.46E-02	1.94E-02	0.0	0.753	DOE=0
Cs-137+D	1.82E+03	1.53E+03	6.59E+03	1.19	4.31
Ba-133	1.10E+03	9.36E+02	4.78E+03	1.18	5.11
Pm-147	2.74E-02	2.53E-02	4.68E-02		1.85
Sm-147	0.0	0.0	0.0		
Sm-151	1.95E-03	4.99E-04	5.93E-02	3.91	119
Eu-150	5.04E+03	3.96E+03	0.0	1.27	DOE=0
Eu-152	3.60E+03	3.05E+03	1.27E+04	1.18	4.16
Eu-154	3.74E+03	3.34E+03	1.38E+04	1.12	4.13
Eu-155	8.98E+01	9.24E+01	8.16E+02		8.83
Gd-152	0.0	0.0	0.0		
Ho-166m	4.67E+03	4.64E+03	1.88E+04		4.05
Re-187	0.0	0.0	0.0		
Tl-204	1.93E+00	2.04E+00	1.48E+01		7.25
Pb-205	8.75E-02	3.58E-03	8.61E+00	24.4	2410
Pb-210+D	3.85E+00	3.00E+00	3.42E+01	1.28	11.4
Bi-207	4.92E+03	4.11E+03	1.72E+04	1.20	4.18
Po-209	8.95E+00	8.95E+00	4.10E+01		4.58
Po-210	2.68E-02	2.32E-02	9.81E-02	1.16	4.23

Table 10. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Ra-226+D	5.61E+03	4.78E+03	1.92E+04	1.17	4.02
Ra-228+D	3.04E+03	2.62E+03	1.04E+04	1.16	3.97
Ac-227+D	1.08E+03	9.61E+02	5.00E+03	1.12	5.20
Th-228+D	4.92E+03	4.20E+03	1.66E+04	1.17	3.95
Th-229+D	9.04E+02	7.45E+02	4.09E+03	1.21	5.49
Th-230	4.11E-01	6.05E-01	1.03E+01	0.679	17.0
Th-232	2.13E-01	2.63E-01	7.60E+00	0.810	28.9
Pa-231	9.09E+01	9.11E+01	4.08E+02		4.48
U-232	3.10E-01	4.52E-01	1.17E+01	0.686	25.9
U-233	4.81E-01	6.86E-01	5.70E+00	0.701	8.31
U-234	1.89E-01	2.03E-01	9.21E+00		45.4
U-235+D	2.52E+02	3.74E+02	2.17E+03	0.674	5.80
U-236	9.85E-02	1.08E-01	8.36E+00		77.4
U-238+D	7.10E+01	5.87E+01	2.81E+02	1.21	4.79
Np-237+D	7.13E+02	5.28E+02	3.06E+03	1.35	5.8
Pu-236	9.45E-02	1.14E-01	1.13E+01	0.829	99.1
Pu-238	1.06E-01	7.65E-02	9.79E+00	1.39	128
Pu-239	1.59E-01	1.44E-01	4.31E+00	1.10	29.9
Pu-240	7.29E-02	7.43E-02	9.35E+00		126
Pu-241+D	9.43E-03	9.29E-03	4.40E-02		4.74
Pu-242	9.57E-02	6.49E-02	7.78E+00	1.47	120
Pu-244+D	1.17E+03	9.04E+02	3.86E+03	1.29	4.27
Am-241	1.45E+01	2.22E+01	3.41E+02	0.653	15.4
Am-242m+D	3.58E+01	3.28E+01	2.66E+02		8.11
Am-243+D	4.49E+02	4.42E+02	2.94E+03		6.65
Cm-242	5.97E-02	8.59E-02	1.07E+01	0.695	125
Cm-243	2.90E+02	2.86E+02	1.67E+03		5.84
Cm-244	5.09E-02	6.39E-02	9.46E+00	0.797	148
Cm-245	1.32E+02	1.71E+02	9.74E+02	0.772	5.7

Table 10. External Dose Rate Factors, mrem/h per Ci/m².

Nuclide	GENII	EPA	DOE	GENII/EPA	DOE/EPA
Cm-246	4.19E-02	5.89E-02	8.37E+00	0.711	142
Cm-247+D	1.30E+03	8.74E+02	4.16E+03	1.49	4.76
Cm-248	3.83E-02	4.45E-02	6.71E+00	0.861	151
Cm-250+D	1.20E+03	8.55E+02	4.40E+03	1.40	5.15
Bk-247	2.32E+02	2.14E+02	0.0		DOE=0
Cf-248	3.43E-02	6.32E-02	7.68E+00	0.543	122
Cf-249	9.82E+02	8.71E+02	4.02E+03	1.13	4.62
Cf-250	5.37E-02	6.01E-02	7.81E+00	0.894	130
Cf-251	2.40E+02	2.62E+02	1.55E+03		5.92
Cf-252	4.25E-02	8.91E-02	7.23E+00	0.477	81.1

Notes:
(1) GENII external DRF were computed using the EXTDF program. EPA external DRF are from Federal Guidance Report Number 12, EPA 402-R-93-081 (Sept 1993). DOE external DRF are from DOE/EH-0070 (July 1988).
(2) Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide.
(3) The conversion to area units from volume units assumes a thickness of 0.15 meters. The density correction applied to the EPA (1993) dose rate factors is 1.067. Because Nb-91 and Po-209 are not part of the EPA compilation, the GENII values were used.
(4) The last two columns show ratios of GENII and DOE external dose rate factors to the EPA dose rate factors. Ratios within 10% of the EPA value are not shown.

The GENII and EPA external dose rate factors are listed as dose rate per unit concentration in the soil. The unit concentration was converted to a unit area by multiplying by the contamination thickness of 15 cm. The DOE dose rate factors are already in area units. Note that the EPA dose rate factors were developed for a soil density of 1.6 g/cc. However, the ILAW PA will use a soil density for the surface layer of 1.5 g/cc. Therefore, the EPA dose rate factors were multiplied by the density correction factor of 1.067 to give the values shown on Table 10.

The three external dose factor collections are compared in Table 10. What is shown on this table are ratios of the GENII and DOE collections divided by the EPA collection. Differences less than 10 percent are not shown. Ratios for dose rate factors which are zero were not computed.

The GENII external dose rate factors agree fairly well (within 26%) for nuclides that emit penetrating gamma rays and have the largest dose rate factors. Examples are Na-22, Ti-44, Mn-54, Co-60, Nb-94, Ag-108m, Sn-126, Cs-134, Cs-137, Eu-150, Eu-152, Eu-154, Ho-166m,

Bi-207, Ra-226, Ra-228, and Th-228. The disagreement between GENII and the EPA collections is over the low energy photon emitters. However, for these nuclides the internal doses are typically much greater than the external, so the disagreement would not affect the total doses.

In general, the DOE external dose rate factors are larger than the EPA dose rate factors by more than a factor of 4. The exceptions (Be-10, C-14, Si-32, Cl-36, Se-79, Rb-87, Sr-90, Tc-99, Cd-113m, In-115, Sn-121m, Cs-135, and Pm-147) are for nuclides which produce most of their photons through bremsstrahlung. For these nuclides, the DOE external dose rate factors are much too small.

In all three references used in Table 10 the dose rates were computed at a height of 1 meter above the soil. The actual height has little effect on the dose rate. Table 11 demonstrates this by comparing dose rate factors computed by the EXTDF program at 100 cm and 10 cm. The table shows the ratios of the 10 cm dose rate divided by the 100 cm dose rate for nuclides where the difference between dose rate factors was greater than 10 percent. It must be noted that all these nuclides have external dose rates which are insignificant compared with the internal. The exclusively low energy photons emitted by these nuclides are noticeably attenuated by the additional 90 cm of air.

Table 11. Ratios of Dose Rate Factors at Two Elevations.

Nuclide	Ratio	Nuclide	Ratio
H-3	1.61	U-236	1.26
Fe-55	1.61	Pu-236	1.35
Ni-59	1.18	Pu-238	1.27
Ni-63	1.18	Pu-240	1.37
Zr-93	1.20	Pu-242	1.46
Nb-93m	1.61	Cm-242	1.46
Mo-93	1.61	Cm-244	1.48
Pd-107	1.52	Cm-246	1.52
Sm-151	1.21	Cm-248	1.46
Pb-205	1.61	Cf-248	1.55
Th-232	1.12	Cf-250	1.36
U-232	1.13	Cf-252	1.42
U-234	1.16		

Note: The ratios are the dose rate factor (DRF) at 10 cm above the soil surface divided by the dose rate factor at 1 meter above the soil.
Nuclides having DRFs within 10% at the two elevations are not shown. DRFs were computed using the EXTDF program, which is part of the GENII software package.

External dose rate factors for immersion in contaminated air are listed in Table 12 below. Values are from Federal Guidance Report Number 12 (EPA-402-R-93-081). The dose rate factors were computed assuming the individual is located at the center of a hemisphere of infinite extent. Hence these are also referred to as semi-infinite cloud dose rate factors. Values for Nb-91 and Po-209 are from the EXTDF program of the GENII software package. The columns labeled "Ratio" compare the external dose from submersion in contaminated air with the inhalation dose that accrues during the same period. The inhalation dose is computed as the product of the air concentration, the exposure time, the breathing rate, and the inhalation dose factor. The submersion dose is computed as the product of the air concentration, the exposure time, and the submersion dose rate factor. Thus the ratio of inhalation dose to submersion dose is the product of the breathing rate and the inhalation dose factor divided by the submersion dose factor. This ratio is shown in Table 12 for the daily average breathing rate (0.95 m^3/h) and EPA inhalation dose factors. The light activity breathing rate could also be used, but leads to larger ratios. For the nuclides used in this report (Table 5), the smallest ratio is 5.06 for Na-22. Nuclides notable for large inhalation doses, like insoluble transuranic (TRU) isotopes, have ratios greater than 1 million. Because the activity inhaled by the individual is considerably smaller than the activity ingested, the inhalation dose for non-TRU isotopes is a small part of the total. Therefore, the submersion dose will not be included in the dose calculation.

Table 12. External Dose Rate Factors for Air, mrem/h per pCi/m^3.

Nuclide	Air DRF	Ratio	Nuclide	Air DRF	Ratio
H-3	4.41E-12	1.38E+04	Re-187	0.0	
Be-10	1.49E-10	2.26E+06	Tl-204	7.45E-10	3.07E+03
C-14	2.98E-12	6.64E+05	Pb-205	6.74E-12	5.53E+05
Na-22	1.44E-06	5.06E+00	Pb-210+D	1.19E-09	1.10E+07
Si-32+D	1.33E-09	7.37E+05	Bi-207	1.00E-06	1.89E+01
Cl-36	2.97E-10	7.02E+04	Po-209	2.22E-09	5.04E+06
K-40	1.07E-07	1.10E+02	Po-210	5.54E-12	1.61E+09
Ti-44+D	1.47E-06	2.92E+02	Ra-226+D	1.18E-06	6.92E+03
V-49	0.0		Ra-228+D	6.37E-07	7.58E+03
Mn-54	5.45E-07	1.17E+01	Ac-227+D	2.47E-07	2.58E+07
Fe-55	0.0		Th-228+D	1.08E-06	3.05E+05

Table 12. External Dose Rate Factors for Air, mrem/h per pCi/m^3.

Nuclide	Air DRF	Ratio	Nuclide	Air DRF	Ratio
Co-60	1.68E-06	1.24E+02	Th-229+D	1.98E-07	1.04E+07
Ni-59	0.0		Th-230	2.32E-10	1.33E+09
Ni-63	0.0		Th-232	1.16E-10	1.34E+10
Se-79	4.04E-12	2.32E+06	Pa-231	2.29E-08	5.32E+07
Rb-87	2.42E-11	1.27E+05	U-232	1.89E-10	3.31E+09
Sr-90+D	2.63E-09	8.94E+04	U-233	2.17E-10	5.92E+08
Zr-93	0.0		U-234	1.02E-10	1.24E+09
Nb-91	1.23E-09	2.26E+04	U-235+D	1.03E-07	1.13E+06
Nb-93m	5.91E-11	4.70E+05	U-236	6.67E-11	1.79E+09
Nb-94	1.03E-06	3.84E+02	U-238+D	1.57E-08	7.15E+06
Mo-93	3.36E-10	8.04E+04	Np-237+D	1.38E-07	3.71E+06
Tc-99	2.16E-11	3.66E+05	Pu-236	8.46E-11	1.63E+09
Ru-106+D	1.39E-07	3.27E+03	Pu-238	6.50E-11	5.73E+09
Pd-107	0.0		Pu-239	5.65E-11	7.22E+09
Ag-108m+D	1.04E-06	2.59E+02	Pu-240	6.33E-11	6.44E+09
Cd-109	3.92E-09	2.77E+04	Pu-241+D	2.87E-12	2.73E+09
Cd-113m	9.24E-11	1.57E+07	Pu-242	5.34E-11	7.31E+09
In-115	5.99E-11	5.92E+07	Pu-244+D	2.17E-07	1.77E+06
Sn-121m+D	8.26E-10	1.37E+04	Am-241	1.09E-08	3.87E+07
Sn-126+D	1.28E-06	7.49E+01	Am-242m+D	1.02E-08	3.96E+07
Sb-125	2.69E-07	4.31E+01	Am-243+D	1.32E-07	3.18E+06
Te-125m	6.03E-09	1.15E+03	Cm-242	7.58E-11	2.17E+08
I-129	5.06E-09	3.26E+04	Cm-243	7.83E-08	3.73E+06
Cs-134	1.01E-06	4.36E+01	Cm-244	6.54E-11	3.60E+09
Cs-135	7.53E-12	5.74E+05	Cm-245	5.28E-08	8.20E+06
Cs-137+D	3.63E-07	8.36E+01	Cm-246	5.94E-11	7.22E+09
Ba-133	2.37E-07	3.13E+01	Cm-247+D	2.14E-07	1.84E+06
Pm-147	9.23E-12	4.04E+06	Cm-248	4.52E-11	3.48E+10
Sm-147	0.0		Cm-250+D	2.11E-07	4.23E+07

Table 12. External Dose Rate Factors for Air, mrem/h per pCi/m^3.

Nuclide	Air DRF	Ratio	Nuclide	Air DRF	Ratio
Sm-151	4.81E-13	5.92E+07	Bk-247	6.27E-08	8.68E+06
Eu-150	9.55E-07	2.67E+02	Cf-248	6.30E-11	7.64E+08
Eu-152	7.53E-07	2.79E+02	Cf-249	2.11E-07	2.60E+06
Eu-154	8.18E-07	3.32E+02	Cf-250	5.99E-11	4.15E+09
Eu-155	3.32E-08	1.19E+03	Cf-251	7.43E-08	7.52E+06
Gd-152	0.0		Cf-252	6.74E-11	2.21E+09
Ho-166m	1.13E-06	6.52E+02			

Notes:
(1) External DRF for submersion in contaminated air are from Federal Guidance Report Number 12, EPA 402-R-93-081 (Sept 1993). Because Nb-91 and Po-209 are not part of the EPA compilation, the GENII values were used. Short-lived radioactive progeny included in the "+D" nuclides are in secular equilibrium with their parent nuclide. The nuclide is dispersed uniformly in a hemisphere of infinite extent. The receptor is at the center of the hemisphere.
(2) The "Ratio" columns are computed as the inhalation dose factor times the daily average breathing rate (0.95 m^3/h) divided by the submersion dose rate factor.

2.2.3 Ingestion Rates for People

In this section the ingestion rates for all types of produce for all exposure scenarios are presented and compared. In addition, consumption rates for water and trace amounts of soil are given. Finally, garden size is discussed because the assumed garden size controls soil concentration in the garden of the post-intrusion resident.

The diets compiled by the EPA to represent averages in different parts of the United States have been used in prior Hanford Site disposal facility performance assessments. The consumption parameters for the "West" region in a national survey were used (Yang and Nelson 1986). These are listed in Table 13 below, under the column "g/d". In contrast, a somewhat different set of values has become established for Hanford dose assessments. These are found in DOE/RL-91-45 Revision 3, *Hanford Site Risk Assessment Methodology* (HSRAM). The consumption parameters listed in that document for the industrial, residential and agricultural scenarios are presented in Table 14.

In Table 13 the last two columns of numbers are computed from the first column using 365 days per year consumption. Note that the usual 365.25 d/y has been rounded to simplify calculations. The values shown in the second column under "Observed Intakes" are the same as the values in the first column, except that the units have been changed from grams per day to kilograms per year.

The last column gives the consumption rates used for an average individual in the residential and all-pathways farmer scenarios. These have been adjusted for the fraction of the individual's diet which is locally produced based on the fractions given in the EPA Exposure Factors Handbook (EPA/600/8-89/043). The adjustment for garden produce is that 25 percent of the vegetable diet actually comes from the garden, and is contaminated. The other 75 percent is assumed to be obtained from uncontaminated sources. For animal products, it is assumed that 50 percent of the animal products (except for fish) are locally produced and thus contaminated.

Table 13. Human Food Consumption: Traditional Models.

Item Consumed	Observed Intakes		Residential & Farmer Intakes kg/y
	g/d	kg/y	
Leafy produce	45.3	16.53	4.1
Other veg. (protected)	152.5	55.66	13.9
Fruit (exposed + misc)	105.3	38.43	9.6
Cereal (grain)	202.6	73.95	18.5
Meat (beef & pork)	115.0	41.98	21.0
Milk	283.5	103.48	51.7
Poultry	28.9	10.55	5.3
Eggs	29.1	10.62	5.3
Fish	18.5	6.75	6.75
Drinking Water	1480	540	540
Trace Soil Ingestion	0.1	0.0365	0.0365

Notes: Annual intakes are computed as 365 days of daily intakes. Values in the last column are adjusted for average diet fraction locally produced, namely, 25% for garden produce and 50% for animal products.

"Leafy" refers to vegetables whose leafy parts are normally eaten, such as lettuce, cabbage and spinach. "Other veg." are termed "protected" produce because the edible portion is underground or has some type of non-edible covering. Examples of protected produce are potatoes, onions, peanuts, and sweet corn. "Fruit" is termed "exposed" produce because airborne contaminants may deposit on the edible portion, but the surface area is small compared to leafy vegetables. Examples of exposed produce are apples, asparagus, cherries, grapes, snap beans,

squash, and tomatoes. "Grains" refers to cereals consumed by humans, such as corn (for meal), oats, soybeans, and wheat.

The next grouping of foods, namely, "Meat", "Milk", "Poultry", and "Eggs" refers to animal products that may be contaminated because the animals ingest contaminated feed and drink. The various animals raised for foods are separated into the two categories "Meat" and "Poultry". If the animal resembles a cow (e.g. goats or pigs), it is "Meat". If the animal resembles a bird (e.g. ducks and turkeys), it is "Poultry". The names simply refer to the most likely animal. In addition, no distinction is made between goat's milk and cow's milk. The method for estimating animal product concentrations is too coarse.

Other animal products can be postulated, such as wild animals or commercial food items (not grown locally). However, neither is contaminated by exhumed waste or ground water, so no dose accrues from them. Wild animals that are hunted for food, such as deer and waterfowl, would acquire some contamination once the ground water reaches the Columbia River. These are not explicitly included, because only the population dose is of interest from the Columbia River. Game animals are a small part of the total population dose.

The non-dairy beverage consumption rates measured by the EPA (Yang and Nelson 1986) for the western region is 1.48 liters per day (1480 g/d). The grouted waste performance assessment used 1.84 liters per day (Roseberry and Burmaster 1992). The traditional assumption commonly used in other performance assessments is 2 liters per day, which is 35 percent higher than the EPA average and 9 percent higher than the grouted waste PA. The EPA value (540 L/y) will be used for the residential and all-pathway farmer cases, while the 2 L/d value is considered the bounding value.

Inadvertent soil ingestion is assumed to occur at the rate of 100 mg per day for adults, and at twice this rate for children (EPA/600/8-89/043). This is a trace amount associated with hand-mouth contact, licking the lips, and similar motions. Deliberate soil ingestion is not considered. A survey of measurements of soil ingestion is presented in NUREG/CR-5512, Section 6.3.2.

In the drilling scenario, the worker is exposed for a period of 5 days. At 100 mg/d, the worker ingests 500 mg soil. Since 0.14 m^3 waste was spread over a 15 m^3 soil volume [(15 m^3)=(100 m^2)(0.15 m)], the amount of waste ingested is shown in the calculation below.

Driller soil ingestion = (100 mg/d)(5 d) = 500 mg soil

Driller waste ingestion = (500 mg)(0.14 m^3)/(15 m^3) = 4.7 mg waste

In the post-intrusion gardening scenario, the resident is exposed for a period of 365 days. At 100 mg/d, the resident ingests 36,500 mg soil. Since 0.14 m^3 waste was spread over a 30 m^3 soil volume [(30 m^3)=(200 m^2)(0.15 m)], the amount of waste ingested is shown in the calculation below.

Gardener soil ingestion = (100 mg/d)(365 d) = 36,500 mg soil

Gardener waste ingestion = (36,500 mg)(0.14 m^3)/(30 m^3) = 170 mg waste

Note that the amount ingested by the post-intrusion resident is substantially larger than the amount ingested by the driller. In addition, the ingestion amounts can be normalized to unitless fractions, the activity ingested per unit activity exhumed. This is illustrated below using an area density of 225 kg/m^2 based on a soil density of 1500 kg/m^3 and a tilling depth of 0.15 cm. This method of comparison avoids the need to know the waste thickness and well diameter.

Driller ingestion fraction = (500 mg)/(225 kg/m^2)/(100 m^2)
= 2.22 x 10^{-8} Ci ingested per Ci exhumed

Gardener ingestion fraction = (36,500 mg)/(225 kg/m^2)/(200 m^2)
= 8.11 x 10^{-7} Ci ingested per Ci exhumed

For exposure of the population along the Columbia River, parameters are scaled up by the assumed total population of 5 million. Two exceptions are water intake and fish consumption. The average drinking rate of 540 L/y per person (Yang and Nelson 1986) will be used. About half of this number is water, while the rest is various other beverages, most of which are derived from drinking water supplies.

The quantity of fish consumed by the population is limited by what the river is able to produce. The total mass of fish harvested from the Columbia River annually and consumed locally is approximately 15 metric tons (PNNL-9823). The average amount of fish consumed by 5 million people is thus 3 grams per year per person.

The range of consumption rates for a large population is small since the individual differences are averaged out. Thus the total food consumed by the population depends primarily on the size of the population. The one exception is fish consumption, which is assumed to remain constant at 15 metric tons per year.

The HSRAM ingestion rates are shown in Table 14 for the industrial and agricultural scenarios. The ingestion rates for the residential scenario are the same except that the meat and milk pathways are absent. Game meat (deer) and fish are listed even though they would not be contaminated by exhumed soil, or by the irrigation of a subsistence farm from a well. The game rate is based on one 45 kg deer per year. Half the mass is edible, and is divided among a family of four.

Estimated food intake rates are from DOE/RL-96-16 (April 1997 draft) for the Native American Subsistence Resident (NASR) (Table 5.7). The total vegetable intake rate was divided among the four types of produce using the same relative proportions as shown in Table 13. The animal protein intake rate (150 g/d) was assumed to be made of meat (120 g/d) and deer (30 g/d).

Note that the deer intake rate is assumed to be twice the game intake rate given in the HSRAM. In DOE/RL-96-16 a value for organ intake rate is given as 54 g/d. This has been added to the meat to give the total shown. Values for waterfowl (70 g/d), upland game birds (18 g/d), and wild bird eggs (45 g/d) have been added to the deer assumption to give the total game intake rate shown (163 g/d). These daily intake rates are converted to annual intake rates using 365 days per year.

Overall, the native american food intake rates are roughly twice the all-pathways farmer intake rates. Thus the resulting scenario dose factors will be roughly twice as great also.

Table 14. Human Food Consumption: New Models.

Item Consumed	Industrial	Agricultural	NASR
Leafy produce	0	3.7	20
Other veg. (protected), kg/y	0	11.0	67
Fruit (exposed + misc), kg/y	0	15.3	46
Cereal (grain), kg/y	0	14.6	108
Meat (beef & pork), kg/y	0	21.9	42
Milk, L/y	0	110	219
Poultry, kg/y	0	5.5	11
Eggs, kg/y	0	0	11
Fish, kg/y	0	9.9	197
Game (deer & birds), kg/y	0	5.5	59
Water, L/y	250	730	1095
Soil, kg/y	0.0125	0.0365	0.073

The industrial and agricultural are from HSRAM (DOE/RL-91-45). The HSRAM residential scenario has the same intake rates as the agricultural except that the meat, milk, poultry and egg intakes are zero. The HSRAM vegetable intake rate of 80 g/d has been separated into 10 g/d leafy, 30 g/d other vegetables, and 40 g/d grain. The HSRAM meat intake rate of 75 g/d has been separated into 60 g/d meat and 15 g/d poultry. The HSRAM daily intakes were converted to annual intakes using 365 days per year.

The native american subsistence resident (NASR) intakes are from DOE/RL-96-16 (April 1997). The daily vegetable intake rate of 660 g/d has been divided into 55 g/d leafy, 184 g/d other vegetables, 127 g/d fruit, and 295 g/d grains based on the distribution shown in Table 13. Similarly, the animal protein intake rate of 150 g/d has been separated into 135 g/d meat and 15 g/d deer. The organ intake of 54 g/d has been added to the meat intake for a total of 189 g/d. Daily intakes are converted to annual intakes using 365 days per year.

Garden Area Determination: From the estimated annual intakes of garden produce it is possible to estimate the minimum garden area needed to supply an individual. This area is needed for intruder calculations in which the exhumed waste is spread over a garden.

The quantity of food derived from the garden is proportional to the garden size. To estimate food production per unit garden area, two approaches were considered. The first is commercial food production in Washington State (WA Department of Agriculture 1994). Values for production per acre and per square meter are shown on Table 15. "cwt" means 100 pounds. Bushels of grain were assumed to have a density 70 percent that of water (700 kg/m^3). Thus a bushel of grain is assumed to weigh about 54 lb. The categories used for human consumption are from Table 13. The average person consumes the amount shown, in kg/y. Based on the average food production rate, the necessary garden area is 194 m^2. This total area is mostly needed for production of grains. This area also requires an efficient gardening operation to succeed.

The second approach to estimating garden size uses garden production estimates published by the Washington State University (WSU) Cooperative Extension (1980). Values are listed in Table 16. The document provides estimates of pounds of produce per 10 foot row in a garden. In addition, it gives recommended row spacings. The spacing was treated as the row width to compute production per unit area. The same average annual consumption rates from Table 13 were used to determine garden area needs. The WSU production estimates are higher than the commercial production averages hence the needed garden area is smaller (161 m^2). These were assumed to be optimum values under excellent growing conditions.

For performance assessment gardens, an efficiently planned and maintained garden of 200 m^2 will be assumed to supply 100% of the garden produce needs of a single adult over a year's time, or 25% of the garden produce needs of a family of four. Note that this represents a marked decrease from previous performance assessments. Ingestion doses from the post-intrusion garden are thus expected to increase due to the higher soil concentration.

Table 15. Commercial Food Production as a Basis for Garden Size.

Type of Produce	Yield per acre	Yield kg/m^2	Garden Area
Leafy Vegetables	**16.5 kg/y**	**2.35**	**7.0 m^2**
Cabbage			
Chard			
Lettuce	210 cwt	2.35	
Spinach			
Exposed Produce	**38.4 kg/y**	**1.79**	**21.5 m^2**

Table 15. Commercial Food Production as a Basis for Garden Size.

Type of Produce	Yield per acre	Yield kg/m²	Garden Area
Apple	17 tons	3.81	
Apricots	6.23 tons	1.40	
Asparagus	35 cwt	0.39	
Broccoli			
Brussel Sprouts			
Bushberries	7000 lb	0.78	
Cauliflower			
Cherry	6.93 tons	1.55	
Cucumber			
Eggplant			
Grape	10.83 tons	2.43	
Peach	10 tons	2.24	
Pear	15 tons	3.36	
Plums & Prunes	8.4 tons	1.88	
Rhubarb			
Snap Bean	90 cwt	1.01	
Strawberry	7000 lb	0.78	
Tomato			
Protected Produce	**55.7 kg/y**	**2.48**	**22.5 m²**
Bean (dry)	19 cwt	0.21	
Beet			
Carrot	580 cwt	6.50	
Kohlrabi			
Lentils	1340 lb	0.15	

Table 15. Commercial Food Production as a Basis for Garden Size.

Type of Produce	Yield per acre	Yield kg/m²	Garden Area
Muskmelon			
Onion	360 cwt	4.04	
Parsnip			
Peas	38 cwt	0.43	
Potato	590 cwt	6.61	
Radishes			
Squash			
Sweet Corn	150 cwt	1.68	
Tree Nuts	0.87 tons	0.20	
Turnip			
Watermelon			
Grains	**74.0 kg/y**	**0.52**	**143.3 m²**
Barley	67 bu	0.41	
Corn (for meal)	190 bu	1.16	
Hops	1884 lb	0.21	
Oats	68 bu	0.41	
Rye			
Wheat	63.6 bu	0.39	
		Total Garden Area:	**194 m²**

Notes: Food production data is from *Washington Agricultural Statistics 1993-1994*. Average consumption rates are from Yang and Nelson, 1986. A bushel of grain is assumed to have a density 70% of water, so that a bushel weighs 54 lb.

Table 16. Homeowner Food Production as a Basis for Garden Area.

Type of Produce	Yield lb/10'	Row Spacing inches	Yield kg/m²	Garden Area
Leafy Vegetables	**16.5 kg/y**		**4.48**	**3.7 m²**
Cabbage	10	24	2.44	
Chard	30	18	9.76	
Lettuce	10	18	3.25	
Spinach	5	12	2.44	
Exposed Produce	**38.4 kg/y**		**2.26**	**17.0 m²**
Apple		12		
Apricots		12		
Asparagus	5	24	1.22	
Broccoli	10	24	2.44	
Brussel Sprouts	10	24	2.44	
Bushberries		12		
Cauliflower	8	24	1.95	
Cherry		12		
Cucumber	12	24	2.93	
Eggplant	8	36	1.30	
Grape		12		
Peach		12		
Pear		12		
Plums & Prunes		12		
Rhubarb	15	36	2.44	
Snap Bean	6	18	1.95	
Strawberry		12		

Table 16. Homeowner Food Production as a Basis for Garden Area.

Type of Produce	Yield lb/10'	Row Spacing inches	Yield kg/m²	Garden Area
Tomato	30	48	3.66	
Protected Produce	**55.7 kg/y**		**3.85**	**14.4 m²**
Bean (dry)		12		
Beet	10	12	4.88	
Carrot	12	12	5.86	
Kohlrabi	7	18	2.28	
Lentils		12		
Muskmelon	30	72	2.44	
Onion	10	12	4.88	
Parsnip	10	18	3.25	
Peas	10	18	3.25	
Potato	20	24	4.88	
Radishes	4	6	3.91	
Squash	25	48	3.05	
Sweet Corn	10	24	2.44	
Tree Nuts		12		
Turnip	20	18	6.51	
Watermelon	40	96	2.44	
Grains	**74.0 kg/y**		**0.59**	**126.2 m²**
Barley	0.1	1	0.59	
Corn (for meal)	0.1	1	0.59	
Hops	0.1	1	0.59	
Oats	0.1	1	0.59	

Table 16. Homeowner Food Production as a Basis for Garden Area.

Type of Produce	Yield lb/10'	Row Spacing inches	Yield kg/m²	Garden Area
Rye	0.1	1	0.59	
Wheat	0.1	1	0.59	
			Total Garden Area:	**161 m²**

Notes: Food production data from *Home Gardens*, WSU Cooperative Extension Report EB-422. Average consumption rates are from Yang and Nelson, 1986.

2.2.4 Inhalation Rates for People

To determine the internal dose from the inhalation of resuspended particulate matter, one must be able to compute the total activity inhaled. Values are needed for the average air concentration, the time exposed at that concentration, and the average breathing rate during the exposure period.

A mass loading approach is used to estimate airborne concentrations of radionuclides for scenarios involving resuspension of contaminated soil as well as scenarios involving aerosolization of contaminated water. It is assumed that the air contains some average amount of contaminated soil or water per unit volume. This is then inhaled at a characteristic breathing rate for a length of time appropriate to the activity to calculate the total inhalation intake.

Radionuclides Dispersed in Soil: For scenarios with inhalation of radionuclides dispersed in soil, the average mass loading in air depends on what is happening to the contaminated soil. Active gardening produces the largest average mass loading, at 0.5 mg/m³. Routine activities outdoors are assume to take place at an average air concentration of 0.1 mg/m³. Indoor activities are assumed to take place at the lowest air concentration, 0.05 mg/m³. The basis for these air concentrations is presented very effectively in NUREG/CR-5512, Section 6.3.1.

In the well-drilling scenario, the individual is assumed to be exposed for 40 hours, spread over 5 days. This is the time needed to drill the well. During this time the individual breathes at the light activity rate for reference man (ICRP 23), 1.2 cubic meters per hour. The actual inhalation scenario is highly variable. The worker can be exposed to a high concentration when the waste material comes out of the hole. However, this material is soon buried by clean material coming from farther down the hole. In addition, the material is likely wetted as part of the drilling operation and to minimize fugitive dust emissions. Another modeling approach is to average the contamination over the assumed spreading area and compute the total inhaled over the 40 hour work period.

In the Grouted Waste performance assessment (WHC-SD-WM-EE-004) the well-drilling worker inhales resuspended dust at a concentration of 0.1 mg/m³ for one hour. However, the air concentration was not based on the waste concentration, but rather on the average soil concentration after spreading. In effect, the 0.64 m³ of exhumed waste is diluted to a total volume of 15 m³. These assumptions lead to the inhalation of 0.12 mg soil containing 0.0051 mg of waste, as shown in the calculations below.

Soil Inhaled (Grout PA) = (1 h)(1.2 m^3/h)(0.1 mg/m^3)
= 0.12 mg soil inhaled

Waste Inhaled (Grout PA) = (0.12 mg soil)(0.64 m^3)/(15 m^3)
= 0.0051 mg waste inhaled

If the well-driller's dust is undiluted waste, the worker would inhale 0.12 mg of waste. However, the actual inhalation time is probably greater than one hour. Since the waste layer is about 10% of the total well volume, and the well takes 40 h to drill, the time of exposure to the waste is (40 h)(0.10)=4 h. This would mean the worker inhales 4.8 mg of soil containing 0.48 mg of waste, as shown in the calculations below.

Soil Inhaled (ILAW PA) = (40 h)(1.2 m^3/h)(0.1 mg/m^3)
= 4.8 mg soil inhaled

Waste Inhaled (ILAW PA) = (4.8 mg soil)(0.14 m^3)/(1.4 m^3)
= 0.48 mg waste inhaled

For estimating inhalation exposure in the post-drilling residential scenario, the individual spends the entire year living in the contaminated area. The Grouted Waste performance assessment (WHC-SD-WM-EE-004) used an average inhalation rate of 8520 m³ per year and an average air concentration of 0.1 mg/m³. The annual amount of soil inhaled was 852 mg. The 200 West Area Burial Ground performance assessment (WHC-EP-0645) used more detailed inhalation assumptions based on PNNL-6312. The inhalation dose was based on an annual inhalation of 445 milligrams.

Inhalation dose for the ILAW PA will be based on a refinement of the model used for the 200 West Area Burial Ground. It is also very similar to the method discussed in NUREG/CR-5512.

The air concentrations shown in Table 17 are used to estimate the equivalent time of exposure to an average air concentration of 0.1 mg/m³. The actual air concentrations used in the table are discussed at length in NUREG/CR-5512, Section 6.3.1. The values chosen represent

conservative bounds on likely concentrations for the activities indicated. The exposure times are also based on the NUREG/CR-5512, although the document is not as explicit as to the assumptions behind the time periods used. It appears that NUREG/CR-5512 includes a vacation period of 2 weeks away from the residence. This is a minor (3%) reduction in the mass inhaled, and is not included in the ILAW PA. The combinations shown on Table 17 for the residential scenario lead to the annual inhalation of 573 milligrams of soil, which lies between the values used in the prior Hanford Site performance assessments. This value will also be used for the all-pathways farmer scenario.

The Columbia River population average is based on an exposure of 12 hours per day at the daily average breathing rate. This leads to an annual inhalation of 416 milligrams of soil, as shown below. In the 200 West Area Burial Ground PA (WHC-EP-0645) the annual inhalation was twice as great based on wide-spread irrigation leading to contaminated airborne material over a much larger region. This is unrealistically high, since the air concentration of contaminated material is bounding. There are other sources of airborne material that are not contaminated. Hence the lower estimate will be used in the ILAW PA for population dose.

(8766 h/y)(0.5)(0.95 m3/h)(0.1 mg/m3) = 416 mg/y

In Table 17 the 2920 hour period asleep is 8 hours per day, 365 days per year. For 180 days the individual works in or near his fields for 10 hours, making a total of 1800 hours outdoors. Of this 1800 hours, 100 hours is spent in dusty conditions. The remainder of the year (4046 hours) is spent indoors. The breathing rates shown on the table are from ICRP Report Number 23 on Reference Man (ICRP 23). No adjustment is made for the finite area of the contamination because the individual spends most of the year close to the emission source. Adjustment for a 4 week period away from home would reduce the annual inhalation intake by less than 10 percent. Therefore, the above value will be used for both the post-intrusion garden as well as the irrigated farm.

Table 17. Calculation of the Inhalation Time for the Residential Gardener.

Activity	Air Concentration (mg/m^3)	Exposure Time (h/y)	Breathing Rate (m^3/h)	Mass Inhaled (mg/y)
Asleep	0.05	2,920	0.45	65.7
Indoors	0.05	4,046	1.2	242.8
Outdoor	0.1	1,700	1.2	204.0
Gardening	0.5	100	1.2	60.0
Away		0		0.0
	Total Time:	8,766		572.5
	Averages:	6,030	0.95	573

Note: The individual spends 8 hours per day, 365 days per year asleep. For 180 days the individual spends 10 hours each day in the fields. Of this time, 100 hours are spent in relatively dusty conditions.

For routine exposure calculations, a daily average breathing rate (0.95 m^3/hr or 22.8 m^3/d) and air concentration (0.1 mg/m^3) must be used. Using these values, the annual intake of 573 mg requires an inhalation exposure time of 6030 hours, as shown in the last line of Table 17. Note also that the amount of waste actually inhaled depends on the garden size. If 0.14 m^3 of waste are exhumed and spread over a 200 m^2 garden that is tilled to a depth of 0.15 meter, then the 573 mg of soil contains 2.7 mg of waste. This assumes the densities of the waste and soil are nearly the same.

$$\text{Waste Inhaled} = (573 \text{ mg soil})(0.14 \text{ m}^3)/(200 \text{ m}^2)/(0.15 \text{ m}) = 2.7 \text{ mg}$$

The result for the post-intrusion resident is substantially larger than the amount inhaled by the driller. In addition, the inhaled masses can be normalized to a unitless fraction, the activity inhaled per unit activity exhumed. This is illustrated below using an area density of 225 kg/m^2 based on a soil density of 1500 kg/m^3 and a tilling depth of 0.15 cm. This method of comparison avoids the need to know the waste thickness and well diameter.

$$\text{Driller inhalation fraction} = (4.8 \text{ mg})/(225 \text{ kg/m}^2)/(100 \text{ m}^2)$$
$$= 2.13 \times 10^{-10} \text{ Ci inhaled per Ci exhumed}$$

Gardener inhalation fraction = (573 mg)/(225 kg/m^2)/(200 m^2)
= 1.27 x 10^{-8} Ci inhaled per Ci exhumed

In the HSRAM scenarios, the average air concentration is 50 μg/m^3. The daily inhalation rate is 20 m^3/d. Thus the individuals inhale 1.0 mg soil each day. In the industrial scenario, the annual inhalation time is 250 days so that the total annual inhalation is 250 mg soil. In the residential and agricultural scenarios the annual inhalation time is 365 days so that the total annual inhalation is 365 mg soil. The HSRAM inhalation intakes are therefore lower than the residential gardener commonly used in Hanford Site performance assessments.

The native american subsistence resident scenario (DOE/RL-96-16 Table 5.7) has the individual inhaling 30 m^3/d at an average concentration of 100 μg/m^3. Thus the daily intake rate is 3.0 mg/d, and the annual intake is 1095 mg soil. As with the food pathways, this is roughly twice the intake of the all-pathways farmer. Therefore, the inhalation dose from resuspended soil should be roughly twice as great also.

Radionuclides Suspended in Water: For scenarios with inhalation of radionuclides suspended in water, two situations are modeled. The first is the inhalation of spray created by a shower. The second is inhalation of steam in a wet sauna or "sweat lodge". A mass loading approach is used to estimate intakes for both cases.

The two parts of the mass loading approach are droplet suspension in air, and evaporation of water. The average water droplet concentration in air during these activities is about 10 mg liquid/m^3, a value characteristic of fogs (Hinds 1982). The evaporation of the contaminated water leads to partially saturated water vapor (a gas) in the shower or sauna. The assumed temperature and relative humidity determines the water vapor concentration. Note that only a small fraction of the radioactivity in the evaporating water becomes airborne. In *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1* (DOE-HDBK-3010-94) data for the sudden depressurization of superheated aqueous solutions is presented in Table 3-5 for various initial pressures and volumes. With a source volume of 0.35 L at a pressure of 60 psig, the respirable release fraction is 0.006. A somewhat larger value of 0.01 will be used to represent the resuspension from pouring water on hot rocks in the sweat lodge, and for the spray of a shower. (The only exception to this is tritium. Since it is assumed to be oxidized, 100% of the tritium becomes airborne.) From data cited in DOE-HDBK-3010-94, it will be assumed that 99% of the radioactive contaminants (except for tritium) are not aerosolized when the water evaporates. The assumed temperatures and relative humidities for the shower and sweat lodge are listed in Table 18 below. Values for ambient conditions at the irrigation site are calculated from the average temperature and relative humidity at the Hanford Site (PNNL-12087) during the irrigation months (April through September). The evaporative entrainment fraction is assumed to be an order of magnitude smaller, again based on data cited in DOE-HDBK-3010-94 for lower temperature conditions without spray sources.

Also shown in Table 18 are the vapor concentrations calculated from the vapor pressure and relative humidity for the assumed temperature. The percents are by volume. The row labeled "Evaporated Water" is the concentration of water in the air. It is calculated using the formula weight for water (18.0153 g/gmole) and the ideal gas law, as shown below. Note that the temperature is in degrees kelvin rather than celsius, and also that Table 18 uses cubic meters (m^3) as the unit for volume.

Mass of water vapor per unit volume =
(18.0153 g/gmole)(Vapor Conc)/(0.08057 L·atm/gmole/°K)/(Temperature)

The line labeled "Entrained Water" is 1% of the "Evaporated Water" line to reflect the fact that evaporation leaves most of the contaminants behind. The line labeled "Droplets" is the bounding droplet concentration of a fog. Under ambient conditions normally found at the irrigation site there is no fog. The fog is only found in the shower and sauna.

Table 18 shows the effective total concentration of ground water in the air in the line labeled "Total Water". This line is the sum of the "Entrained Water" and "Droplets" lines. The line labeled "Tritium Total" is the sum of the "Evaporated Water" and "Droplets" lines.

The "Dilution Adjustment" is for the ambient humidity exposure only. It divides the year into two halves: irrigation and no irrigation. During the irrigation season the ground water is diluted by natural precipitation. As discussed in Section 2.5, this leads to a factor of 94%. During the remainder of the year (without irrigation) the contaminated fraction of the humidity is assumed to be reduced to 50%. Activities such as cooking and cleaning supply the contaminated portion of the humidity. For ambient conditions, the adjustment is calculated as shown below.

Ambient Dilution Adjustment = (94%)(0.5) + (50%)(0.5) = 72%

The annual exposure times depend on the exposure scenario, and determine the annual inhalation intake. Parameters for the ILAW PA are listed in the lower half of Table 18. The last lines in the table are calculated as the product of the "Annual Count", the "Event Duration", the "Breathing Rate", the "Dilution Adjustment", and the total water intake. Values are given for both tritium and all other nuclides. The assumed density of the irrigation water is 1.0 kg/L.

Table 18. Airborne Ground Water Intakes.

Parameter	Ambient	Shower			Sauna
Temperature	19.3°C (66.8°F)	40°C (104°F)			50°C (122°F)
Relative Humidity	39.8%	80%			80%
Water Vapor Concentration	0.87%	5.82%			9.74%
Evaporated Water, g/m^3	6.5	41			66
Entrained Contaminants, g/m^3	0.0065	0.41			0.66
Droplets, g/m^3	0	0.01			0.01
Total Water, g/m^3	0.0065	0.42			0.67
Tritium Total, g/m^3	6.5	41			66
Dilution Adjustment	72%	100%			100%
Breathing Rate, m^3/h	0.95	1.2			1.2
Exposure Scenario	All-Pathways and NASR	All-Pathways	HSRAM Industrial	HSRAM Residential, Agricultural	NASR
Event Duration, h/d	24	0.25	0.167	0.167	1
Annual Count, d/y	365	365	250	365	180
Total Inhaled, L/y	0.039	0.046	0.021	0.031	0.14
Total Tritium, L/y	39	4.5	2.1	3.1	14

Notes:

Ambient conditions are those found at the irrigation site. The average temperature and relative humidity during the irrigation season (April through September) are from PNNL-12087. No aerosol droplets are present. The "Dilution Adjustment" is based on the presence of natural precipitation during the irrigation season and half the normal during the remainder of the year.

The shower temperature is based on typical hot water settings. The relative humidity during the shower is a value selected from the likely range of 60% to 100%.

The sauna or sweat lodge experience lasts one hour and is repeated approximately every other day during the year. The temperature and relative humidity are reasonable assumptions.

The evaporative entrainment from ambient sources is assumed to be 0.1%, while the entrainment during showers and saunas (sweat lodge) is assumed to be 1%.

The listed breathing rates are from ICRP 23. The assumed density of the ground water is 1.0 kg/L.

Because the total groundwater inhaled is considerably smaller than the total groundwater ingested during the year the moisture inhalation dose should be smaller also. These moisture inhalation pathways were not used in prior Hanford performance assessments.

The "Sauna" for the NASR is also the "Sweat Lodge" used in DOE/RL-96-16. The assumed exposure conditions for the ILAW PA scenario leads to an inhalation of 0.14 L/y. The exposure conditions in DOE/RL-96-16 lead to the much larger inhalation of about 57 L/y. The reason for the difference is the extreme exposure conditions found in DOE/RL-96-16. For example, the sweat lodge temperature is 60 °C (140 °F) with a relative humidity of 100%, which means the air in the sauna is 20% water vapor. The sudden 20% reduction in oxygen concentration would certainly result in labored breathing, possibly fainting. The exposure to high temperature at saturated conditions for one hour would lead to skin burns over most of the body. Most of the difference is due to the assumption that 100% of the dissolved impurities become airborne when the water evaporates.

2.2.5 External Exposure Times

During the drilling operation, the worker is exposed to varying dose rates. Until the waste is exhumed this dose rate is zero. While the waste comes from the hole, the dose rate is high. Since the radiation source is small (about 0.14 m^3), the dose rate varies inversely with the square of the worker's distance from the waste. The waste is soon covered with clean soil from deeper in the well, which reduces the dose rate. To represent the potential dose to the worker, the waste is assumed to be spread into a layer 15 cm thick over an area of 100 m^2. The external dose rate factors of Table 10 are used to estimate the dose from 40 hours of exposure. This is the same approach used in the Grouted Waste performance assessment.

It should be noted that this assumption for the drilling operation exaggerates the external dose to the worker. If a flattened mound is placed 2 meters to the side of the worker, the dose rates are actually less than those from a 100 m^2 slab, even though the nuclide concentration is higher. With a general area contamination, the worker is standing on a portion of the contamination and receives higher dose rates.

The external dose rate factors of Table 10 apply to the center of the contaminated area. As one moves away from the center the dose rate decreases sharply with distance, unlike the resuspended dust concentration in the air. The airborne dust concentration decreases by diffusion and turbulent mixing rather slowly with distance, falling to half the peak value at a distance of about 100 m. By contrast, external dose rates at the edge of the contaminated area are half the value at the center of the contaminated area. At a distance of 10 meters from the edge of the contamination the dose rates are less than 10 percent of the center value.

For the post-intrusion resident, only the garden is contaminated, while for the irrigation scenarios most of the area near the person's dwelling is contaminated. The extent of the contaminated areas will affect the calculation of external dose in the two exposure situations. The exposure to soil contamination is divided into two time periods during the year. The first

period is the time actually spent standing in the contamination. The second period is the total time near the contamination, or indoors.

In the post-intrusion garden scenario, the external exposure time is taken to be half the total time outdoors, or 900 hours. In other words, the individual spends a time equivalent to 900 hours during the year standing in the center of his garden. Since the dose rate decreases rapidly with distance from the small garden, the time away from the garden has zero exposure.

In the irrigation scenarios, it is assumed that the entire time outdoors (1800 hours) is spent in exposure conditions similar to the center of an irrigated field. However, the dose rate indoors is reduced by a factor of 3. This factor of 3 is discussed in detail in NUREG/CR-5512, Section 6.7.4. Therefore the effective time of exposure at the unshielded dose rate is 4120 hours, as shown below.

$$(1800 \text{ hr}) + (6966 \text{ hr})/3 = 4120 \text{ hours}$$

Prior Hanford Site performance assessments used different values. The Grouted Waste performance assessment used an effective time of 4383 hours for both the post-intrusion gardener, the all-pathways irrigator, and the populations. The 200 West Area Burial Ground performance assessment used an effective time of 3260 hours for individuals and 4383 hours for populations. The effective exposure times selected for the ILAW performance assessment differ from the values used in prior Hanford performance assessments. Note that the average exposure time for the Columbia River population is chosen to be 4383 hours to be consistent with prior calculations.

For the HSRAM scenarios, the external exposure in the industrial scenario is 8 h/d, 146 d/y for an annual total time of 1,168 h. The residential and agricultural scenarios use an exposure time of 24 h/d, 365 d/y for an annual total of 8760 h/y. All external doses are reduced using the factor 0.8 to account for shielding from building walls. Therefore, the annual exposure time for the industrial scenario is 934 hours, and for the residential/agricultural scenarios is 7008 hours. The NASR also uses 7008 h/y for the effective external annual exposure time.

Comparison of the Driller and Post-Intrusion Resident. To compare the driller and the post-intrusion resident, note that the intake parameters are directly proportional to the dose from each pathway. For a few nuclides there are additional differences due to removal processes such as radioactive decay or leaching from the surface layer. Ignoring these details, Table 19 summarizes the important parameters for comparing doses. The inhaled and ingested amounts are in terms of the grams of waste exhumed. (Waste density is assumed to be the same as surface soil density.) The external exposure time has been adjusted by the waste volume to garden volume ratio to correct for the different garden sizes. In each pathway, the intake by the Driller is significantly smaller than the intake by the Gardener. Thus the dose to the Driller will be less than the dose to the Gardener for all nuclides.

Table 19. Comparison of the Intake Parameters for the Intruders.

Pathway	Driller	Gardener	Ratio
Waste Ingested	4.7 mg	170 mg	0.03
Vegetables ingested	0.0	43 kg	0.00
Waste Inhaled	0.48 mg	2.7 mg	0.18
External factor	(40h)(0.14m³)/(15m³) = 0.37 h	(900h)(0.14m³)/(30m³) = 4.2 h	0.09

Note: The above values assume 0.14 m³ of waste are exhumed and spread over 100 m² for the Driller and 200 m² for the Gardener. In both scenarios the soil mixing depth is 0.15 meter.

Some of the external exposure pathways noted in Table 3 are much smaller than internal pathways that accompany the external exposure. For example, the external exposure to an individual whose livestock and household pets drink contaminated well water is much smaller than the internal dose resulting from the consumption of animal products (milk, meat, poultry, and eggs). This follows from the observation that the dose resulting from a given amount of radioactivity outside the body (leading to an external dose) is orders of magnitude lower than the dose resulting from the same amount of radioactivity ingested or inhaled (leading to an internal dose). Admittedly, the individual will not eat all of the radioactivity present in an animal, since the radioactivity will be present in organs and tissues that are not normally eaten. However, the use of all four animal pathways combined with the observation that the individual is in close proximity to the animal for only short periods during the day gives assurance that this external pathway can be ignored.

A more detailed evaluation of the external dose from submersion in contaminated air is needed in order to eliminate it from further consideration. Table 12 shows the submersion dose rate factor as well as the ratio between the inhalation dose and the submersion dose. The smallest ratio is 5.06 for Na-22. Hence the submersion dose can be ignored since it will never be a significant part of the total dose.

2.2.6 Absorption Through the Skin

Each exposure scenario includes dermal contact with the contaminated medium. The driller and post-intrusion resident get the contaminated soil on their skin. The ground water scenarios have contaminated water being used for showers and saunas. These two will be treated separately to demonstrate that the likely intake from contamination being absorbed through the skin into body fluids is negligible compared to other ingestion pathways.

An exception is for tritium as water vapor. The inhalation dose factor for tritium includes absorption through the skin in addition to the lungs by increasing the value by 50%. The ingestion dose factor is not modified.

Internal dose factors for radionuclides absorbed through the skin can be calculated from the numbers given in Table 7 by dividing the ingestion dose factor by the gut-to-body-fluid transfer fraction (f1). This is somewhat inexact because the material in the gut is wet and has a variety of chemicals secreted by the body to aid in the absorption of nutrients. In addition, the interior surface area of the small intestine is larger than the skin area of the entire body to aid in the absorption of nutrients.

For both soil and water in contact with the skin, the transfer from the skin to the body fluids is assumed to be proportional to the f1 parameter. The f1 transfer fraction thus cancels out of the calculation, and dermal contact becomes another ingestion dose.

Contaminated Soil. Soil adheres to the skin, which is one reason people take showers. Typical soil adherence values range from 0.1 mg/cm^2 to 5 mg/cm^2. The adult body has a skin area of about 20,000 cm^2. The hands and arms have about 20% of the total area. A small fraction of the contamination present on the skin will be absorbed into the body through the skin. This fraction is assumed to be one percent of the f1 value. Table 20 summarizes the affected skin areas, soil adherence, and annual contact events for each of the exposure scenarios. The product of these factors gives the effective soil ingestion due to dermal contact. The values shown are small compared to the values for direct ingestion of soil presented in Tables 13 and 14. Hence the approach taken in DOE/RL-91-45 to neglect dermal absorption of radionuclides will be adopted in the ILAW PA also.

Contaminated Irrigation Water. Waterborne contaminants in contact with the skin may potentially be absorbed through the skin into the body fluids. The leading dermal contact events are showers and the sauna or sweat lodge. Since these expose the entire skin surface, the potential for significant absorption exists. However, contact time is limited to 15 minutes for showers and 1 hour for the sauna or sweat lodge. Based on typical values for the dermal absorption constant (0.001 cm/h or less) and the dermal absorption method described in PNNL-10523 (Section 2.2), it is concluded that effective intakes per shower or sauna are less than 20 cm^3. With up to 180 saunas per year, the annual ingestion intake increases by less than 1 percent. Therefore, the dermal absorption of radionuclides in irrigation water will not be explicitly included in the calculations for the ILAW PA.

Table 20. Effective Soil Ingestion Due to Dermal Contact With Soil.

	Intruder	Post-Intrusion Resident and Irrigated Farm	HSRAM Industrial	HSRAM Residential and Agricultural	NASR
Skin Surface Fraction	0.25	0.2	0.25	0.25	0.25
Soil Adherence, mg/cm^2	0.25	0.25	0.20	0.20	1.0
Contact Frequency, d/y	5	100	146	180	365
Effective Annual Ingestion, g/y	0.063	1.0	1.5	1.8	18

Notes:

The total skin surface area for an adult is 20,000 cm^2. It is assumed that 1% of the soil adhering to the skin is available for absorption into the body.

The effective annual ingestion is the product of the total skin area, the skin surface fraction, 1% of the soil adherence, and the contact frequency. The NASR has the greatest intake.

HSRAM - Hanford Site Risk Assessment Methodology
NASR - Native American Subsistence Resident

2.3 Animal Parameters

The animal parameters discussed here are those pertaining to the eventual concentration of radioactivity in animal products consumed as food, such as fish, milk, meat, poultry, and eggs. The equilibrium model used to represent various animals assumes that they take in radioactivity by inhalation, ingestion, and dermal absorption at a rate which changes slowly during the year. The concentration in the animal reaches a steady-state maximum related to the concentration in its environment. Note that the radiation doses received by the animals are assumed to be low enough to not affect their health or metabolism. The contaminant concentration in food products is proportional to the level of contamination in the animal's environment, particularly in the food it consumes. The constants of proportionality are called bioaccumulation factors, or transfer factors.

Not all animals have transfer factors developed for them. It is assumed that other aquatic animals such as bottom-dwelling fish, crustaceans and mollusks are consumed in minimal amounts. If a group of people is identified who consume significant quantities of these creatures

then efforts will be made to quantify the transfer factors which would apply to them. Other land animals such as pigs or goats are assumed to have transfer factors which differ very little from cattle.

The contaminant concentration in cattle and poultry depends on the rate at which the contaminant is consumed. The cattle and poultry diets are discussed in the next section. The equilibrium transfer factors for these animals are discussed afterward.

2.3.1 General Animal Parameters

The daily intake rates assumed for cattle and poultry are listed in Table 21. These are from NUREG/CR-5512, Section 6.5.1. No distinction is made between the diets of poultry raised for food and egg-laying hens. For comparison with prior Hanford Site performance assessments, the default intake rates used by the GENII program (PNNL-6584) are also shown in Table 21. The water intake rates are the same for both. Note that the GENII program does not distinguish between the two types of stored feed (i.e. hay or grain), nor does it allow the animals to ingest soil directly.

To calculate the radionuclide concentrations in the animal foods, it is necessary to introduce a "dry-to-wet ratio". The "dry-to-wet ratio" is a unitless quantity measured as the ratio of the dry weight of the item to its wet weight. The "dry-to-wet ratio" for stored hay applies at the time of harvest. In practice the hay is dried before being fed to cattle. Thus the "dry-to-wet ratio" for sun-cured hay is reported as approximately 0.9, similar to stored grain. All of the wet weights shown on Table 21 are at the time of harvest or when the animal is grazing.

The intake rates found in NUREG/CR-5512 will be used in the current performance assessment. The principal reason for this change from prior Hanford performance assessments is the extra detail provided on the diet. Previous performance assessments relied on the GENII software, which is unable to accommodate this detail. The ILAW PA for the low-level waste glass form will utilize hand calculations that incorporate the added detail.

The exposure of special groups living near waste sites or near locations where the ground water enters the Columbia River would probably include the consumption of some type of native game animals. These animals could acquire radioactivity from drinking and grazing near locations were ground water enters the river. The larger examples of these, such as deer, would graze over a large area. Thus only a small portion of the deer would be contaminated. Similarly, the smaller animals might derive all of their nourishment from a contaminated area. However, such animals would have to be harvested from many locations over the course of a year. The average concentration from all such animals would be much lower due to the large forage area needed for hunting and gathering. It will be assumed that the game animals are contaminated at such a low level compared with the domesticated animals that the dose from game animals can be ignored.

Table 21. Animal Feed, Water, and Soil Intake Rates

Values from NUREG/CR-5512 for use in the ILAW PA							
Type of Feed	dry-to-wet ratio	Beef, kg/d		Milk, kg/d		Poultry, kg/d	
		dry	wet	dry	wet	dry	wet
Fresh Forage	0.22	3	14	8	36	0.0275	0.13
Stored Hay	0.22	6	27	6	29	0	0
Stored Grain	0.91	3	3	2	2	0.0825	0.09
Total Feed, kg/d:		12	44	16	67	0.110	0.22
Soil Ingestion Rate:		0.6 kg/d		0.8 kg/d		0.011 kg/d	
Drinking Water:		50 L/d		60 L/d		0.3 L/d	
Values from GENII (PNNL-6584) used in previous Hanford Site PAs							
Type of Feed	dry-to-wet ratio	Beef, kg/d		Milk, kg/d		Poultry, kg/d	
		dry	wet	dry	wet	dry	wet
Fresh Forage	0.20	10	51	8	41	0	0
Stored Hay	0.18	3	17	2	14	0.022	0.12
Stored Grain	NA	NA	NA	NA	NA	NA	NA
Total Feed, kg/d:		13	68	10	55	0.022	0.12
Soil Ingestion Rate:		NA		NA		NA	
Drinking Water:		50 L/d		60 L/d		0.3 L/d	

The wet weights are at the time of harvest or grazing. The GENII software does not distinguish between stored hay and stored grain. In addition, GENII does not consider ingestion of soil by grazing animals.

It should be noted that animals killed by native hunters would be more efficiently scavenged than common farm animals. Some of the internal organs would be eaten. The animal skins could be used for clothing, and larger bones could be used as tools or ceremonial items. The more extensive use of animal parts could increase the exposed person's radiation dose. Nevertheless, it will be assumed that this dose is small compared with that from farm animals.

2.3.2 Equilibrium Transfer Factors

The equilibrium transfer factors for cattle and poultry relate the rate of intake of a contaminant to the eventual steady-state concentration in meat or milk or eggs. These parameters are the ratio of the equilibrium concentration of a nuclide in the animal product to the daily intake by the animal. For beef, poultry and eggs the units are Ci/kg per Ci/d (equivlent to d/kg), while for milk the units are Ci/L(milk) per Ci/d (equivalent to d/L). Values obtained from NUREG/CR-5512 (1992) are listed in Table 22. Transfer factors for organs such as liver or brain are not available. Since some elements may be found in higher concentrations in these tissues, individuals who consume the organs would receive higher doses from the radioactive isotopes of the elements.

The concentration of waterborne contaminants in fish is assumed to be proportional to the concentration of the contaminant in the water environment of the fish. The constant of proportionality for fish is called a "bioaccumulation" factor. It is the average concentration of the contaminant in the edible portion of the fish divided by the concentration in the water. This parameter has units of L/kg. Values for fresh-water fish from NUREG/CR-5512 (1992) and PNWD-2023 (1994) are listed in Table 22 under the column labelled "Fish". The NUREG/CR-5512 values have been used in prior Hanford Site performance assessments. The Hanford Environmental Dose Reconstruction (HEDR) values are recently published and have not been used in prior performance assessments. There are only two bioaccumulation factors which are affected by the HEDR research. The first is for sodium (100 in NUREG/CR-5512 became 8) and neptunium (250 in NUREG/CR-5512 became 21). These are marked in Table 22.

Table 22. Transfer Factors for Cows, Chickens, and Fish

Element	Meat d/kg	Milk d/L	Poultry d/kg	Eggs d/kg	Fish L/kg	Atomic Number
H	0.010*	0.0082*	1.9*	2.1*	1	1
Be	0.001	9.0E-07	0.4	0.02	2	4
C	0.049*	0.0105*	4.2*	3.1*	4,600	6
Na	0.055	0.035	0.01	0.2	8*	11
Si	4.0E-05	0	0.2	0	1,000	14
Cl	0.08	0.015	0.03	2	50	17
K	0.02	0.007	0.4	0.7	1,000	19
Ti	0.03	0.01	0.004	0.003	100	22
V	0.0025	2.0E-05	0.2	0.8	200	23
Mn	0.0004	0.00035	0.05	0.065	400	25

Table 22. Transfer Factors for Cows, Chickens, and Fish

Element	Meat d/kg	Milk d/L	Poultry d/kg	Eggs d/kg	Fish L/kg	Atomic Number
Fe	0.02	0.00025	1.5	1.3	2,000	26
Co	0.02	0.002	0.5	0.1	330	27
Ni	0.006	0.001	0.001	0.1	100	28
Se	0.015	0.004	8.5	9.3	170	34
Rb	0.015	0.01	2	3	2,000	37
Sr	0.0003	0.0015	0.035	0.3	50	38
Y	0.0003	2.0E-05	0.01	0.002	25	39
Zr	0.0055	3.0E-05	0.000064	0.00019	200	40
Nb	0.25	0.02	0.00031	0.0013	200	41
Mo	0.006	0.0015	0.19	0.78	10	42
Tc	0.0085	0.01	0.03	3	15	43
Ru	0.002	6.0E-07	0.007	0.006	100	44
Pd	0.004	0.01	0.0003	0.004	10	46
Ag	0.003	0.02	0.5	0.5	2	47
Cd	0.00055	0.001	0.84	0.1	200	48
In	0.008	0.0001	0.3	0.8	100,000	49
Sn	0.08	0.001	0.2	0.8	3,000	50
Sb	0.001	0.0001	0.006	0.07	200	51
Te	0.015	0.0002	0.085	5.2	400	52
I	0.007	0.01	0.018	2.8	500	53
Cs	0.02	0.007	4.4	0.49	2,000	55
Ba	0.00015	0.00035	0.00081	1.5	200	56
Pm	0.005	2.0E-05	0.002	0.02	25	61
Sm	0.005	2.0E-05	0.004	0.007	25	62
Eu	0.005	2.0E-05	0.004	0.007	25	63
Gd	0.0035	2.0E-05	0.004	0.007	25	64
Ho	0.0045	2.0E-05	0.004	0.007	25	67

Table 22. Transfer Factors for Cows, Chickens, and Fish

Element	Meat d/kg	Milk d/L	Poultry d/kg	Eggs d/kg	Fish L/kg	Atomic Number
Re	0.008	0.0015	0.04	0.4	120	75
Tl	0.04	0.002	0.3	0.8	5,000	81
Pb	0.0003	0.00025	0.2	0.8	100	82
Bi	0.0004	0.0005	0.1	0.8	15	83
Po	0.0003	0.00035	0.9	7	500	84
Ra	0.00025	0.00045	0.03	2.0E-05	70	88
Ac	2.5E-05	2.0E-05	0.004	0.002	25	89
Th	6.0E-06	5.0E-06	0.004	0.002	100	90
Pa	1.0E-05	5.0E-06	0.004	0.002	11	91
U	0.0002	0.0006	1.2	0.99	50	92
Np	5.5E-05	5.0E-06	0.004	0.002	21*	93
Pu	5.0E-07	1.0E-07	0.00015	0.008	250	94
Am	3.5E-06	4.0E-07	0.0002	0.009	250	95
Cm	3.5E-06	2.0E-05	0.004	0.002	250	96
Bk	3.5E-06	4.0E-07	0.0002	0.009	50	97
Cf	0.005	7.5E-07	0.004	0.002	25	98

*Beef, milk, poultry, and egg transfer factors for H-3 and C-14 were computed from the equilibrium model described in the text. Fish bioaccumulation factors for sodium and neptunium are from PNWD-2023. Other transfer factors are from NUREG/CR-5512. Above transfer factors are based on the wet weights.

Transfer factors for tritium (H-3) and C-14 are computed from an equilibrium model. The ratio of radioactive H-3 (or C-14) to the non-radioactive hydrogen (or carbon) in the animal's diet is assumed to be reproduced in the food product. The equilibrium transfer factor is then the fraction of hydrogen (or carbon) in the food product divided by the daily intake of hydrogen (or carbon). The assumed element fractions are listed in Table 23 below. Values in this table were taken from NUREG/CR-5512.

Table 23. Hydrogen and Carbon Fractions for Equilibrium Models

Food Pathway Item	Hydrogen Fraction	Carbon Fraction
Garden Soil	0.022	0.03
Leafy Vegetables	0.10	0.09
Other Vegetables	0.10	0.09
Fruit	0.10	0.09
Grain	0.068	0.40
Fresh Forage	0.10	0.09
Stored Hay	0.10	0.09
Stored Grain	0.068	0.40
Beef	0.10	0.24
Milk	0.11	0.07
Poultry	0.10	0.20
Eggs	0.11	0.15

Notes: All fractions listed above are based on the wet weight of the item. All fractions are taken from NUREG/CR-5512, except for the hydrogen fraction in garden soil, which is calculated as the soil porosity (30%) times the density of water (1.0 kg/L) divided by the soil density (1.5 kg/L) times 9. Hydrogen fractions include organically bound hydrogen as well as water. The effective water fraction is the hydrogen fraction times 8.94, which is the ratio of molecular weights for water and hydrogen.

The bioaccumulation factors shown in Table 22 are used to estimate total population dose from fish consumption to people living near the Columbia River. The edible portion of fish is the muscle normally cooked and consumed. The rest of the fish is assumed to be discarded. If there are individuals who eat or otherwise use other parts of the fish they could receive additional dose.

Although not important for the ILAW PA, a subject requiring research is the equilibrium transfer factors for wild animals consuming native vegetation. These species may be "harvested" by humans for food. In addition, since standard uptake factors are for muscle tissue only, there would need to be organ-specific uptake factors for those internal organs which may be consumed by special groups of people.

2.4 Plant Parameters

Living plants supplying food for people fall into two broad categories, aquatic plants and terrestrial plants. It will be assumed that aquatic plants contribute very little to the typical human diet -- either directly or indirectly. If exceptions are identified then a suitable set of parameters and models for contaminant uptake by aquatic plants and subsequent consumptions by humans will be utilized. All plants eaten are assumed to be terrestrial rather than aquatic.

The calculation of radionuclide concentrations in living terrestrial plants uses three main routes, (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) direct deposition of irrigation water on foliage. Each of these will be considered separately below. The three uptake routes are then combined to obtain the total concentration in edible portions of plants.

2.4.1 Root Uptake

The model for root uptake of a contaminant into terrestrial plants assumes that the concentration in the edible portion is proportional to the concentration in the soil at the time of harvest. The constants of proportionality are known as the soil-to-plant concentration ratios. These concentration ratios are measured as the concentration of the dry produce item divided by the soil concentration. They have no units, since the soil and food items have the same mass-based concentration units, eg. pCi/kg.

Because the human consumption rates shown in Tables 13 and 14 are the wet weights, it is necessary to select suitable constants to convert from dry weight to wet weight. These constants are known as "dry-to-wet ratios". They are simply the dry weight of the food item divided by the wet weight of the item. The "dry-to-wet ratios" from three sources are listed in Table 24. The values chosen for the ILAW PA are from PNWD-2023 for leafy vegetables and NUREG/CR-5512 for the others. The chosen values for the ILAW PA appear in the last column of Table 24. The values under the "GENII" column have been used in prior Hanford Site performance assessments.

The GENII dry-to-wet ratios for grains differ greatly from the other collections. However, it has been assumed in prior performance assessments that grains would be unlikely to become contaminated in the intruder or irrigation scenarios. The intruder would probably not raise grains in his home garden, and the principal grain crop in this area (dry-land wheat) would not be irrigated. For the ILAW PA grains are included as contaminated vegetable intakes. The basis for this approach is that some grains (e.g. corn) are irrigated. In addition, the 25% contamination fraction incorporates the presence of non-irrigated grains (e.g. wheat) in the individual's diet.

Table 24. Dry-to-Wet Ratios for Vegetation Consumed by Humans

Type of Produce	GENII	ORNL-5786	ILAW PA
Leafy Vegetables	0.10	0.067	0.09
Other (protected)	0.25	0.222	0.25
Fruit (exposed)	0.18	0.126	0.18
Grains	0.18	0.888	0.91

ILAW PA values are from PNWD-2023 and NUREG/CR-5512.

Root uptake will be calculated using concentration ratios listed in Table 25. The ratios for four types of vegetables are given on this table. The definition of the four types were given in Section 2.2.3. Most of the values are from NUREG/CR-5512 (1992). The value for the iodine concentration ratio in leafy vegetables is from the more recent HEDR assessment (PNWD-2023 1994). The values for hydrogen were calculated using an equilibrium assumption. The ratio of tritium to hydrogen in the soil is assumed to be duplicated in the plant. Thus the effective soil-to-plant transfer factor is the hydrogen concentration in the plant divided by the hydrogen concentration in the soil and the dry-to-wet ratio for the plant.

Table 25. Transfer Factors for Garden Produce

Element	Plant/Soil Concentration Ratios				Atomic Number
	Leafy	Root	Fruit	Grain	
H	51*	18*	25*	3.4*	1
Be	0.01	0.0015	0.0015	0.0015	4
C	0.7	0.7	0.7	0.7	6
Na	0.075	0.055	0.055	0.055	11
Si	0.35	0.07	0.07	0.07	14
Cl	70	70	70	70	17
K	1.0	0.55	0.55	0.55	19
Ti	0.0055	0.003	0.003	0.003	22
V	0.0055	0.003	0.003	0.003	23
Mn	0.56	0.15	0.05	0.29	25
Fe	0.004	0.001	0.001	0.001	26

Table 25. Transfer Factors for Garden Produce

Element	Plant/Soil Concentration Ratios				Atomic Number
	Leafy	Root	Fruit	Grain	
Co	0.081	0.04	0.007	0.0037	27
Ni	0.28	0.06	0.06	0.03	28
Se	0.025	0.025	0.025	0.025	34
Rb	0.15	0.07	0.07	0.07	37
Sr	1.6	0.81	0.17	0.13	38
Y	0.015	0.006	0.006	0.006	39
Zr	0.002	0.0005	0.0005	0.0005	40
Nb	0.02	0.005	0.005	0.005	41
Mo	0.25	0.06	0.06	0.06	42
Tc	44	1.1	1.5	0.73	43
Ru	0.52	0.02	0.02	0.005	44
Pd	0.15	0.04	0.04	0.04	46
Ag	0.00027	0.0013	0.0008	0.1	47
Cd	0.55	0.15	0.15	0.15	48
In	0.004	0.0004	0.0004	0.0004	49
Sn	0.03	0.006	0.006	0.006	50
Sb	0.00013	0.00056	8.0E-05	0.03	51
Te	0.025	0.004	0.004	0.004	52
I	0.05*	0.05	0.05	0.05	53
Cs	0.13	0.049	0.22	0.026	55
Ba	0.15	0.015	0.015	0.015	56
Pm	0.01	0.004	0.004	0.004	61
Sm	0.01	0.004	0.004	0.004	62
Eu	0.01	0.004	0.004	0.004	63
Gd	0.01	0.004	0.004	0.004	64
Ho	0.01	0.004	0.004	0.004	67

Table 25. Transfer Factors for Garden Produce

Element	Plant/Soil Concentration Ratios				Atomic Number
	Leafy	Root	Fruit	Grain	
Re	1.5	0.35	0.35	0.35	75
Tl	0.004	0.0004	0.0004	0.0004	81
Pb	0.0058	0.0032	0.009	0.0047	82
Bi	0.035	0.005	0.005	0.005	83
Po	0.0025	0.009	0.0004	0.0004	84
Ra	0.075	0.0032	0.0061	0.0012	88
Ac	0.0035	0.00035	0.00035	0.00035	89
Th	0.0066	0.00012	0.000085	0.000034	90
Pa	0.0025	0.00025	0.00025	0.00025	91
U	0.017	0.014	0.004	0.0013	92
Np	0.013	0.0094	0.01	0.0027	93
Pu	0.00039	0.0002	0.000045	0.000026	94
Am	0.00058	0.00041	0.00025	0.000059	95
Cm	0.0003	0.00024	0.000015	0.000021	96
Bk	0.00058	0.00024	0.000015	0.000059	97
Cf	0.01	0.00024	0.000015	0.01	98

*Concentration ratios shown for hydrogen were calculated from the equilibrium model. The concentration ratio for iodine is from PNWD-2023. Other concentration ratios are from NUREG/CR-5512. The above transfer factors are based on the dry weights.

The Hanford Site is very dry and sandy, so that plant uptake factors would likely differ from the generic values used in literature reviews such as NUREG/CR-5512 and ORNL-5786. However, the preparation of the soil for a garden changes the properties of surface layer. The tilling, watering and addition of fertilizers and organic material produces soil which resembles the generic garden soil of NUREG/CR-5512 and ORNL-5786. It is therefore assumed that the concentration ratios found in these documents are adequate to describe plant uptakes in possible future gardens on the Hanford Site.

Groups of people gathering native vegetation for nourishment and other household needs may require special consideration. The soil-to-plant transfer factors could differ considerably

from the values shown on Table 25. Soils deficient in some mineral will have much higher uptake factors for radionuclides which are chemically similar to what is missing. The converse is also true. In addition, the distribution of the contaminant in the native vegetation during the growth of the plant is important. For example, Native American Indians use various parts of the cattail over its growth stages (CTUIR 1995). However, the ILAW PA deals with localized areas of contaminated soil resulting from intrusion or irrigation with contaminated ground water. The transfer factors for native plant species is not needed because the contaminated portion is an insignificant part of the overall diet.

2.4.2 Rain Splash

The term "rain splash" refers to all the processes which cause soil to deposit on the surfaces of plants. It includes the transport of soil by the irrigation water, rain drops, and the wind. The standard model (NRC 1977) then includes a "translocation" factor which is the fraction of activity deposited on plant surfaces which ends up in the edible portions of the plant. There are two basic approaches to estimating the concentration in plants due to resuspension of contaminated soil. The standard approach begins with an estimate of the average air concentration and then computes the activity deposition rate on the plant. The other approach (NUREG/CR-5512 1992) simply treats rain splash in a manner similar to root uptake.

In NUREG/CR-5512 the amount of rain splash is characterized by a "mass loading" factor which is the ratio of foliage contamination due to rain splash divided by the concentration in the soil nearby. It is similar to the root uptake concentration ratio described in the previous section. The value recommended in NUREG/CR-5512, Section 6.5.2 is 0.1 Ci/kg (dry produce) per Ci/kg soil for all plant types. In addition, this value "includes consideration of translocation of activity in soil from plant surfaces to edible parts of the plant." The only other parameter used to estimate the actual plant concentration from rain splash is the dry-to-wet ratio.

The more commonly used approach begins with an average air concentration due to rain splash and computes a deposition rate on plant surfaces. The RESRAD program (Yu et al. 1993) has a default mass loading air concentration of 0.1 mg/m^3. The default value in GENII is 0.225 mg/m^3. Both of these use a deposition speed of 0.001 m/sec which is suitable for respirable particles. However, both of these assumptions lead to rain splash transfers which are two or three orders of magnitude below the experimental data referenced in NUREG/CR-5512.

For the ILAW PA the standard transport model will be used rather than the effective mass loading approach of NUREG/CR-5512. However, the average air concentration for rain splash will be 1 mg/m^3 with a deposition speed of 0.01 m/sec. These parameters lead to mass loading values which are consistent with the data reported in NUREG/CR-5512.

Other parameters which are part of the standard model for foliar deposition are the interception fraction, the crop yield (biomass), the translocation factor, the weathering half-life, and the growing period.

The interception fraction is the portion of the airborne contamination depositing in a unit area which initially attaches to vegetation. It includes the fraction of the ground surface which is covered by vegetation. Values for interception fraction for various crops are given in ORNL-5786. More recent publications described in PNNL-6584 will be used as the basis of the interception fractions for this performance assessment. The empirical relationship between interception fraction and standing biomass (dry weight) is shown below.

$$\text{Interception Fraction} = 1.0 - \text{Exp}[-(P)(\text{Dry Yield})] \quad (3)$$

The parameter P depends on the type of vegetation. For leafy vegetables, grains, grass and hay the measured value for P is 2.9 m^2/kg, while for fruits and other plants the measured value for P is 3.6 m^2/kg. The "Dry Yield" is the mass per unit area of the standing biomass at the time of harvest, adjusted for water content. The "Dry Yield" is calculated as the product of the dry-to-wet ratio and the crop yield (wet). Values for biomass and interception fraction are shown on the Table 26.

Table 26. Various Crop-Specific Parameters

Type of Produce	Dry-to-wet Ratio	Crop Yield kg(wet)/m^2	Interception Fraction[2]	Translocation Factor	Growing Period
Leafy Vegetables	0.09[1]	2.0	0.407	1.0	45 d
Other (protected)	0.25	2.0	0.835	0.1	90 d
Fruit (exposed)	0.18	3.0	0.857	0.1	90 d
Grains	0.91	0.8	0.371	0.1	90 d
Fresh Forage - Cow	0.22	1.5	0.616	1.0	30 d
Stored Hay - Cow	0.22	1.0	0.472	1.0	45 d
Stored Grain - Cow	0.91	1.0	0.472	0.1	90 d
Forage - Poultry	0.22	1.0	0.472	1.0	30 d
Grain - Poultry	0.91	1.0	0.472	0.1	90 d

[1]Value shown is from PNWD-2023. All other values are from NUREG/CR-5512 Section 6.5.7.
[2]Interception fractions are calculated using the formula described in the text (PNNL-6584 Section 4.7.4).

The translocation factor is the fraction of what deposits on the foliage that reaches the edible parts of the plant. The values are shown on Table 26 are widely used in calculations of this type (NRC 1977; PNNL-6584 1988; NUREG/CR-5512 1992) and will be used in the ILAW PA.

The weathering half-life is the time required for half the contamination initially deposited on plant foliage to be removed by the action of wind, rain and irrigation. The value chosen for all nuclides is 14 days, based on the recommendations of NRC (1977) and the review given in ORNL-5786.

The growing period is the time that a plant is subject to the mechanical action of weathering prior to be harvested. The growing period varies with crop type. It is the time needed to produce one crop. During the growing season more than one crop may be harvested.

2.4.3 Direct Deposition

The models for root uptake and rain splash contributions to growing plants depend only on the soil concentration at the time of harvest. Direct deposition is unique to overhead irrigation. It refers to the transfer of contamination from irrigation water to the foliage intercepting the water as it falls.

A key parameter to model the contamination of foliage by direct deposition is the interception fraction. The value recommended for all plant types by the NRC (1977) will be used, 0.25. This value is not well documented, but is widely used in other reviews (PNNL-6584 1988; NUREG/CR-5512 1992).

The other parameters determining plant concentrations exposed to contaminated irrigation water are the translocation factors, the weathering half-life, and the growing periods. The same parameters used for describing rain splash will also be used for direct deposition. The translocation factors and growing periods are shown on Table 26, while the weathering half-life is 14 days.

If a special group of people were using overhead irrigation to increase growth density and crop yield, then the same parameters used for the standard group would apply to them also. No special modeling would be required unless the group were using the crop in some manner which could produce more dose than simply eating it.

2.5 Soil Parameters

The soil parameters of interest are those pertaining to the delivery of radiation exposure to someone living over, or growing food crops in contaminated soil. The two main types of exposure are from external and internal sources. In addition, the internal exposure can be divided into inhalation and ingestion intakes. Each of these routes of exposure will be discussed below.

The principal effect of the soil on the external exposure received by someone living nearby is through the soil density, chemical composition, and roughness. As described in Section 2.2.2, the surface soil density is assumed to be 1.5 g/cc. The contamination of interest is distributed through the top 15 cm. The assumed composition is primarily silicon dioxide, with various

additions, such as water. Over time the radioactive contaminants have been observed to migrate into deeper layers. The radioactive elements are affected by the average flow of water through the surface layer into deeper layers. Some elements, such as hydrogen and iodine are very soluble and leach from the surface layer in a few years. Other elements, such as cesium and plutonium hardly move at all.

The principal relationship between soil contamination and inhalation dose is through the ease with which contaminants in the soil become airborne. The presence of ground cover and moisture reduces the air concentration. Hand-tilling activities increase the air concentration. The gradual leaching of radioactive contamination to deeper layers of soil reduces the air concentration as well.

The principal relationship between soil contamination and ingestion dose is through the ease with which contaminants in the soil become incorporated in plant and animal produce. It is assumed that the effects of tilling and fertilizers lead to soils that are similar to those for which the concentration ratios shown in Table 25 were derived. The gradual leaching of radioactive contamination to deeper layers of soil (below the root zone) reduces the concentration in plant and animal products as well.

Soil-specific parameters related to leaching are the soil composition (sand, clay, silt and organic), the distribution coefficients, the density, porosity, and the water content. These parameters determine the rate at which radionuclides leach from the surface layer into deeper layers, the magnitude of the external dose rate factors, and the expected ratios of radioactive elements to non-radioactive elements in those cases where equilibrium models can be applied, namely, for tritium.

The composition of the surface layer is assumed to be sandy, where sandy is defined to have greater than 70 percent sand-sized particles. With few exceptions this is what lies near the surface of the entire Hanford Site. The soil-to-plant concentration ratios and distribution coefficients depend on this assumption. However, the preparation of the soil for a garden changes the properties of surface layer. The tilling, watering and addition of fertilizers and organic material produces soil which resembles the generic garden soil of NUREG/CR-5512. It is therefore assumed that the leaching coefficients found in this document is adequate to describe possible future gardens on the Hanford Site.

The distribution coefficients are taken from NUREG/CR-5512 (1992) and are listed in Table 27. The values in NUREG/CR-5512 were obtained from experiments using four different soil types (sand, loam, clay, and organic). The smallest distribution coefficients (representing the most mobile condition) was reported in NUREG/CR-5512. While this approach may underestimate soil concentrations, the effect of leaching from the surface layer during the growing season is small for most nuclides.

The thickness of the surface soil of interest in the dose calculations is the top 15 centimeters. This thickness represents typical cultivation depths for mechanical mixing of

deposited activity. In addition, it represents typical root depths. This thickness has been used in all prior Hanford Site performance assessments.

The density and thickness of the affected surface layer determine the external dose rate factors discussed in Section 2.2.2, as well as the leaching coefficients computed for the surface layer. Leaching is the process by which contaminants migrate from the surface layer of soil into deeper layers below. The driving force behind the leaching process is the application of water to the soil. Leaching is treated as a removal rate constant giving the fraction of the material in the surface layer which is removed per unit of time. It is calculated using equation (4) shown below.

$$\lambda_s = \frac{P + I - E}{\theta\, d\, (1 + \rho/\theta\, K_d)} \qquad (4)$$

where,

λ_s= average soil leaching coefficient, fraction removed from a soil layer of thickness "d" during the time that irrigation occurs.

P = total precipitation, in centimeters, during the irrigation period. Over the period 1961 to 1990, the precipitation during the 6 month irrigation season (April to September) has been 5.23 cm (PNNL-12087).

I = total irrigation, assumed to be 82.3 cm per year (32.4 inches/y). Nearly all of this is deposited during a 6 month period.

E = total evapo-transpiration, in centimeters per year. Assumed to be 77.5 cm per year so that the total over-irrigation (P+I-E) is 10 cm/y. This over-irrigation assumption is consistent with PNWD-2023, which assumed that farmers over-irrigate by 10 percent.

d = thickness of soil from which nuclides migrate, in centimeters. This is assumed to be 15 cm (5.9 inches).

ρ = bulk density of the surface soil, in grams per cubic centimeter. The value normally used at Hanford is 1.5 g/cc.

θ = volumetric water content of the surface soil, milliliters of water per cubic centimeter of soil. A value of 0.3 ml/cc is assumed. The irrigated soil is assumed to be nearly saturated with water.

K_d= distribution coefficient in surface soil for an element, in milliliters per gram. Values from NUREG/CR-5512 are shown on Table 27.

The values assigned to the variables in the above equation were used in prior Hanford performance assessments. The annual irrigation total (82.3 cm/y) is based on the Specific Information on the Terrestrial Environment (SITE) database referenced ORNL-5786. The SITE database reports that a large percentage of the drier western states falls into the range from 70 to 85 cm/y. The values chosen in NUREG/CR-5512 is 76 cm/y, while the value more appropriate to Hanford is 82.3 cm/y (WHC-SD-WM-EE-004). The Hanford value is based on irrigation rates in the counties surrounding the site. Note that the amount of irrigation is assumed to be the same for all plant types including grains.

Leaching coefficients computed from the equation (4) are listed in Table 27. The numerator represents the excess water added each year. It is taken to be about 10 cm during the irrigation season based on the discussion in PNWD-2023.

Table 27. Leaching Factors for Garden Soil

Element	Leach per year	Kd	Atomic Number	Element	Leach per year	Kd	Atomic Number
H	2.22E+00	0	1	Sb	9.83E-03	45	51
Be	1.85E-03	240	4	Te	3.17E-03	140	52
C	6.44E-02	6.7	6	I	3.70E-01	1	53
Na	5.83E-03	76	11	Cs	1.64E-03	270	55
Si	1.47E-02	30	14	Ba	8.51E-03	52	56
Cl	2.34E-01	1.7	17	Pm	1.85E-03	240	61
K	2.44E-02	18	19	Sm	1.85E-03	240	62
Ti	4.44E-04	1000	22	Eu	1.85E-03	240	63
V	4.44E-04	1000	23	Gd	1.85E-03	240	64
Mn	8.85E-03	50	25	Ho	1.85E-03	240	67
Fe	2.77E-03	160	26	Re	3.13E-02	14	75
Co	7.38E-03	60	27	Tl	1.14E-03	390	81
Ni	1.11E-03	400	28	Pb	1.64E-03	270	82
Se	3.17E-03	140	34	Bi	3.70E-03	120	83
Rb	8.51E-03	52	37	Po	2.96E-03	150	84
Sr	2.92E-02	15	38	Ra	8.89E-04	500	88
Y	2.34E-03	190	39	Ac	1.06E-03	420	89
Zr	7.66E-04	580	40	Th	1.39E-04	3200	90
Nb	2.77E-03	160	41	Pa	8.71E-04	510	91
Mo	4.36E-02	10	42	U	2.92E-02	15	92
Tc	1.48E+00	0.1	43	Np	8.55E-02	5	93
Ru	8.05E-03	55	44	Pu	8.08E-04	550	94
Pd	8.51E-03	52	46	Am	2.34E-04	1900	95

Element	Leach per year	Kd	Atomic Number	Element	Leach per year	Kd	Atomic Number
Ag	4.93E-03	90	47	Cm	1.11E-04	4000	96
Cd	1.11E-02	40	48	Bk	2.34E-04	1900	97
In	1.14E-03	390	49	Cf	8.71E-04	510	98
Sn	3.41E-03	130	50				

Soil distribution coefficients are from NUREG/CR-5512. The leaching factors were calculated using Equation (4).

The soil moisture is used in the special equilibrium model for tritium. The tritium is chemically bound in a water molecule and thus goes with the water. The transfer from soil or irrigation water to vegetation is best described with an equilibrium model. The concentration of tritium in irrigation water, for example, is similar to the concentration in the water in the soil or a plant or the cow's milk. The soil hydrogen fraction is 0.022 kg hydrogen per kg soil. Thus the effective moisture content of the soil is calculated as shown below. The density of water is 1.0 kg/L.

$$(8.94\ g\ H_2O/g\ H_2)(0.022\ kg\ H_2/kg\ soil)/(1.0\ kg/L)=0.197\ L\ H_2O/kg\ soil$$

This value is consistent with the assumed value for the volumetric water content of soil (0.3 ml/cc) and its density (1.5 kg/L). Note that the value reported in NUREG/CR-5512 is 0.1 L/kg. A higher value is therefore being used in the ILAW PA, which leads to higher tritium concentrations in irrigated soil.

In the exposure scenario where the glass waste matrix is brought to the surface, it will be assumed that the glass is still largely unchanged from the time of disposal. Most of the radionuclides are assumed to remain in the glass brought to the surface. Leaching from the surface layer for the nuclides trapped in the glass will not be considered.

Because the expected irrigation application rate of 82.3 cm/year (32.4 inches/year) is applied over a minimum area of 2 hectare (5 acres), the total annual water need for the farmer is at least 1.7×10^7 liters. This value was assumed in prior Hanford performance assessments. The ability of a well to supply water at this rate must be confirmed before dose calculations based on it are carried out.

The Hanford Environmental Dose Reconstruction Project (HEDR) found the irrigation rate in the counties surrounding the Hanford Site ranged from 61 cm/y to 98 cm/y (PNWD-2023, Rev 1). This range leads to leaching coefficients that range from 0 to 2.5 times the chosen values. This range has little effect on the resulting doses for most nuclides because the leaching coefficients are generally small.

A two-part removal rate from the soil has been adopted for use in the ILAW PA. It is assumed that significant irrigation occurs during 6 months of the year. The rest of the year has very little water infiltration. During the no-irrigation period there is no leaching from the surface layer. The one exception is tritium. Tritium is removed from the surface layer during this period by evaporation. Since the natural precipitation normally is 10.69 cm water during the no-irrigation period, this is also the evaporation rate. Evaporation of tritiated water thus leads to the effective leaching coefficient shown below.

$$\lambda_{s,H3} = (10.69 \text{ cm/y})/(0.3 \text{ ml/cc})/(15 \text{ cm}) = 2.38 \text{ per year}$$

Natural precipitation acts to dilute contaminated irrigation water slightly. It adds water that is not contaminated. The formula below shows the dilution factors [i.e., I/(I+P)] used in these calculations during the irrigation season.

$$\text{Dilution Adjustment (individual)} = (82.3 \text{ cm})/(82.3 + 5.23 \text{ cm}) = 0.940$$

$$\text{Dilution Adjustment (population)} = (63.5 \text{ cm})/(63.5 + 5.23 \text{ cm}) = 0.924$$

3.0 MATHEMATICAL MODELS AND DOSE CALCULATIONS

The mathematical models used for the ILAW PA unit dose factors are described in this section. The selection of the various pathway parameters discussed in the previous section can be best understood through the formulas that apply the parameters. The presence of radioactive decay chains complicates this discussion, and the subsequent calculations. But the use of decay chains is necessary because some progeny nuclides are more significant than the parent nuclide.

To facilitate calculations with the large number of nuclides that may be found at the Hanford Site, the hand calculations were automated using commercial spreadsheet software. Spreadsheet calculations have been verified by hand calculations presented in Appendix A and Appendix B.

Doses to humans exposed to exhumed contamination or irrigation water include both internal and external radiation exposures. The internal dose comes from the inhalation of resuspended dust and the ingestion of contaminated water, soil, and foodstuffs. The external dose comes primarily from being near the contaminated soil. The sections below describe how the human dose is computed from the parameters of Section 2 together with standard models for estimating this dose. First, the time dependence of soil concentrations are presented. Second, the external and inhalation doses received from contaminated soil are described. Third, the concentrations and doses for various plant types are described. Finally, the concentrations and doses for animal products are described. The role of radioactive decay and daughter ingrowth is discussed in each section.

3.1 Time Dependence of Soil Concentrations

The soil concentrations are of two types. The first type of soil contamination results from drilling a hole through the waste site and spreading the contamination in a garden. In this case there is some initial concentration of a nuclide in the surface layer that decreases with time due to radioactive decay and leaching from the surface layer. The second type of soil concentration results from irrigating with contaminated water. In this case the contamination increases with time due to the added radioactivity. However, this increase is offset by radioactive decay and leaching from the surface layer.

In the description of progeny ingrowth, it will be assumed that only the parent nuclide is present initially. Each nuclide in the chain must be treated independently. This enables the calculation of unit dose factors for each of the principal nuclides in a decay chain. In the case of irrigation water, it is also assumed that the progeny are not accumulating in the water prior to irrigation. Only the parent nuclide is coming from the well and being deposited on the soil. In addition, it is assumed that the water concentration is constant during the year of irrigation. As before, this enables the calculation of unit dose factors for each of the principal nuclides in a decay chain.

The discussion below is divided into three parts. The first describes the decay of a nuclide and progeny ingrowth with time due to nuclear decay alone, i.e., without leaching or additions from contaminated irrigation water. The second part adds decay in the presence of leaching from the surface layer. The third includes irrigation with contaminated water. In all cases, the decay chains shown in Table 6 are used. The longest decay chain has just four members because decay times less than 1000 years are assumed.

3.1.1 Decay Without Leaching or Irrigation Deposition

The radioactive decay constants will be represented as λ_{1r}, λ_{2r}, λ_{3r}, λ_{4r}, and so forth until λ_{nr}, which is the last member of the chain. The leaching coefficients describing removal from the surface layer by water infiltration will be represented as λ_{1s}, λ_{2s}, λ_{3s}, λ_{4s}, and so forth. The sum of these the radioactive and leaching constants for a given nuclide will be represented as λ_1, λ_2, λ_3, λ_4, and so forth. In other words, λ_2 is defined by the equation $\lambda_2 = \lambda_{2r} + \lambda_{2s}$. Radioactive decay constants are computed by dividing the half life of the nuclide (Table 5) into the logarithm of 2 (Ln 2 = 0.69314718). Leaching coefficients are listed in Table 27.

The following demonstrates the general form of the customary decay chain formula to describe the ingrowth of the "nth" progeny from the first member of the chain. In other words, the only member of the chain with any activity to begin with is the first nuclide. The equations below describe the ingrowth of a specific progeny nuclide, the "nth" member of the chain in the absence of leaching and irrigation with contaminated water. These equations also describe the activity in contaminated vegetables or animal products after they are harvested.

$$C_{sn} = C_{s1}^{0} \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^{n} \lambda_{kr} \right) DR_{1n} \tag{5}$$

$$DR_{1n} = \sum_{k=1}^{n} \frac{e^{-\lambda_{kr} t}}{PD_{1,kr,n}} \tag{6}$$

where

$$PD_{1,kr,n} = \prod_{\substack{i=1 \\ i \neq k}}^{n} \left(\lambda_{ir} - \lambda_{kr} \right) \tag{7}$$

C_{s1}^{0} is the initial soil concentration of the first member of the chain. C_{sn} is the concentration of the "nth" member of the chain after the time "t" has elapsed. C_{sn} is assumed to be zero initially, and to increase with time. Both concentrations have units of Ci/kg.

The term $B_{k,k+1}$ is the fraction of decays of nuclide number "k" which produce nuclide number "k+1". $B_{k,k+1}$ is also known as the branching ratio for nuclear transition from k to k+1. Most branching ratios are simply 1.0. Non-unit branching ratios are given in Table 6.

The term DR_{1n} contains the time dependent functions for each nuclide in the chain from nuclide "1" down to nuclide "n". For convenience in writing the denominator, the product of decay constant differences is defined as shown in Equation (7).

The decay equations are presented as Equation (8) for the first four nuclides. In a four-step decay chain, nuclide 1 (the parent) decays to nuclide 2, which then decays to nuclide 3, which then decays to nuclide 4.

$$C_{s1} = C_{s1}^{0} \, \mathrm{Exp}(-\lambda_{1r} T) \tag{8}$$

$$C_{s2} = C_{s1}^{0} \, \lambda_{2r} \left\{ \mathrm{Exp}(-\lambda_{1r} T)/(\lambda_{2r} - \lambda_{1r}) + \mathrm{Exp}(-\lambda_{2r} T)/(\lambda_{1r} - \lambda_{2r}) \right\}$$

$$\begin{aligned} C_{s3} = C_{s1}^{0} \, \lambda_{2r} \lambda_{3r} \{ & \mathrm{Exp}(-\lambda_{1r} T)/[(\lambda_{2r} - \lambda_{1r}/(\lambda_{3r} - \lambda_{1r})] \\ & + \mathrm{Exp}(-\lambda_{2r} T)/[(\lambda_{1r} - \lambda_{2r})(\lambda_{3r} - \lambda_{2r})] + \mathrm{Exp}(-\lambda_{3r} T)/[(\lambda_{1r} - \lambda_{3r})(\lambda_{2r} - \lambda_{3r})] \} \end{aligned}$$

$$\begin{aligned} C_{s4} = C_{s1}^{0} \, \lambda_{2r} \lambda_{3r} \lambda_{4r} \{ & \mathrm{Exp}(-\lambda_{1r} T)/[(\lambda_{2r} - \lambda_{1r})(\lambda_{3r} - \lambda_{1r})(\lambda_{4r} - \lambda_{1r})] \\ & + \mathrm{Exp}(-\lambda_{2r} T)/[(\lambda_{1r} - \lambda_{2r})(\lambda_{3r} - \lambda_{2r})(\lambda_{4r} - \lambda_{2r})] \\ & + \mathrm{Exp}(-\lambda_{3r} T)/[(\lambda_{1r} - \lambda_{3r})(\lambda_{2r} - \lambda_{3r})(\lambda_{4r} - \lambda_{3r})] \\ & + \mathrm{Exp}(-\lambda_{4r} T)/[(\lambda_{1r} - \lambda_{4r})(\lambda_{2r} - \lambda_{4r})(\lambda_{3r} - \lambda_{4r})] \} \end{aligned}$$

where,

C^0_{s1} = initial concentration of nuclide 1 (i.e. at T=0), in Ci/kg. The initial concentrations of all other members of the chain are assumed to be zero.

C_{s1},C_{s2}, C_{s3},C_{s4} = concentration of nuclides 1, 2, 3, and 4 at time T, in Ci/kg.

λ_{1r},λ_{2r}, λ_{3r},λ_{4r} = radioactive decay constants for nuclides 1, 2, 3, and 4. Note that the decay constant is the natural logarithm of 2 divided by the half-life of the nuclide. Note also that the decay constants in a decay chain are all different so the denominators will never be zero.

3.1.2 Decay With Leaching but Without Irrigation Deposition

For the case where leaching from the surface layer is allowed, there is an additional removal mechanism, which has the effect of increasing the size of the removal terms. Leaching coefficients were discussed in Section 2.5 and are listed in Table 27. The addition of leaching only changes Equations (6) and (7) by replacing λ_k for λ_{kr}. For these equations the radioactive decay constant, in effect, increases. The new equations for decay with leaching are shown below as Equations (9), (10), and (11). Note that the product of radioactive decay constants in Equation (9) is unchanged from Equation (5).

$$C_{sn} = C^0_{s1} \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^{n} \lambda_{kr} \right) DS_{1n} \tag{9}$$

$$DS_{1n} = \sum_{k=1}^{n} \frac{e^{-\lambda_k t}}{PD_{1,k,n}} \tag{10}$$

where

$$PD_{1,k,n} = \prod_{\substack{i=1 \\ i \neq k}}^{n} (\lambda_i - \lambda_k) \tag{11}$$

The term C^0_{s1} is the same as in Equation (5). It is the initial soil concentration of the parent nuclide in the chain. The $B_{k,k+1}$ terms are also the same as in Equation (5). The change in the definition of the time-dependent function DS_{1n} increases the exponents, so the decline in soil concentration is faster. Note that the subtractions in the $PD_{1,k,n}$ term do not eliminate the leaching factor. Therefore Equations (7) and (11) are not the same.

In the post-intrusion gardening scenario, the dose received during the first year is greatest for most nuclides. However, a few nuclides with long half lives, little leaching, and progeny with large unit dose factors, the dose in some later year may be the largest. This will be discussed when the post-intrusion unit dose factors are described. An additional consideration for the glass waste matrix is degradation of the glass leading to increased availability for plant uptake and resuspension into the air.

3.1.3 Decay With Leaching and Irrigation Deposition

The sources of contaminated irrigation water are either groundwater or Columbia River water. The instantaneous rate of addition of contamination to the soil is given by the equation below. The conversion factor shown in the equations changes centimeters of water applied to the soil to liters applied per square meter.

$$ID_p = C_w I (10 \text{ L m}^{-2} \text{ cm}^{-1}) / T_{irr}$$

where

ID_p = instantaneous activity deposition rate during the irrigation of areas growing plant type p, in curies per square meter per year (Ci y^{-1} m^{-2}).

C_w = irrigation water concentration, in curies per liter (Ci/L). This concentration is assumed to be constant (no decay) during the 6 month application period.

I = irrigation water applied to plants during the irrigation period. For the maximum individual cases, this value is 82.3 cm. For the population dose, this value was lowered to 63.5 cm due to less irrigation in humid areas along the Columbia River (Kincaid 1993).

T_{irr} = irrigation period in years. The value 0.5 yr is used since the irrigation is assumed to take place 6 months per year.

The instantaneous rate of increase in the soil concentration is computed from Equation (12) below.

$$ID^0_{s1} = ID_p / (\rho \, d) \qquad (12)$$

where

ID^0_{s1} = instantaneous rate of increase in the soil concentration during the irrigation season, in curies per kilogram per year.

ID_p = instantaneous activity deposition rate during the irrigation of soils growing plant type p, in curies per square meter per year (Ci y^{-1} m^{-2}).

ρ = bulk density of the surface soil, in grams per cubic centimeter. The value normally used in Hanford Site PA work is 1.5 g/cc.

d = thickness of soil from which nuclides migrate, in centimeters. This is assumed to be 15 cm (5.9 inches).

Using contaminated irrigation water, the concentration of radioactivity in the surface layer of soil increases with time. The equations to represent this turn out to be the time integral of Equations (9), (10), and (11). This activity accumulation is shown in Equations (13) and (14), below. Equation (11), which defines $PD_{1,k,n}$, is not affected by the integration. The term ID^0_{s1} is the rate at which the concentration of the parent nuclide increases due to irrigation deposition. Note that irrigation is assumed for a 6 month period, followed by 6 months in which the precipitation essentially matches the evapo-transpiration, so that the leaching coefficients during the last 6 months are zero. Note the addition of the irrigation time (t) to the equation to make the DI decay term a unitless fraction representing accumulation in the soil of contaminants that decay or are leached from the surface layer. At the end of the irrigation period, $t=T_{irr}$.

$$C_{sn} = t \cdot ID^0_{s1} \left(\prod_{k=1}^{n-1} B_{k,k+1} \right) \left(\prod_{k=2}^{n} \lambda_{kr} \right) DI_{1n} \tag{13}$$

$$DI_{1n} = \sum_{k=1}^{n} \frac{1 - e^{-\lambda_k t}}{\lambda_k t \, PD_{1,k,n}} \tag{14}$$

Equations (5), (6), and (7) apply to soil with no leaching at all. Whatever water falls on the soil evaporates without forcing contamination through the surface layer into deeper layers. The key to represent this ordinary decay is the term DR_{1n}. Equations (9), (10), and (11) apply to soil with some leaching taking place. This might be due to excess natural precipitation or irrigation with uncontaminated water. The key to represent this decay with leaching is the term DS_{1n}. Equations (13) and (14) apply to soil being irrigated with contaminated water. Leaching from the surface layer is also occurring. The key to represent this combination of decay, leaching, and accumulation is the term DI_{1n}. These key terms will be used in the next section to describe the soil concentration after many years of irrigation with contaminated water. The soil concentration after 50 years of irrigation with a constant nuclide concentration can be computed for evaluation purposes.

One exception to the above is for tritium in the irrigation water applied to the soil. An equilibrium approach is used. The tritium concentration in the soil moisture is assumed to equal the tritium concentration in the applied irrigation water, adjusted for natural precipitation. This is calculated using the formula below.

$$C_{s,H3} = 8.94\ F_{Hs}\ C_{w,H3}\ I/(I+P) \quad (15)$$

where

$C_{s,H3}$ = concentration of tritium in the surface soil, in curies per kilogram.

8.94 = factor to convert the hydrogen weight fraction into a water fraction. It comes from the ratio of molecular weights for hydrogen (2.0159 g/gmole) and water (18.0153 g/gmole).

F_{Hs} = fraction of hydrogen in garden soil, 0.022 g hydrogen per gram of soil (from Table 23).

$C_{w,H3}$ = concentration of tritium in the irrigation water, in pCi/L.

I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 cm/y for the population).

P = total natural precipitation water reaching the soil during the irrigation period, 5.23 cm/y (PNNL-12087).

The ratio I/(I+P) incorporates the dilution of contaminated irrigation water with natural precipitation. The values chosen for "I" and "P"lead to dilution ratio of 94%.

3.1.4 Activity Concentration at the End of the First Year

To describe the concentration of a nuclide in the soil at the end of the first year, one must combine the equations of the previous section into the physically allowable sequences. During the first 6 months of the year irrigation takes place. The leaching coefficients are as shown in Table 27. Then the irrigation ceases and the precipitation rate is assumed to match the evapo-transpiration rate, so that the leaching factors are all zero. During the second half of the year there is only radioactive decay.

Initial Soil Contamination. In the post-intrusion garden scenario, for the first member of a decay chain, the soil concentration at the end of the year is the initial concentration multiplied by factors for decay and leaching during the irrigation season followed by simple decay during the remainder of the year. This is shown in Equation (16) below. The Y_{11} term is introduced to simplify later equations.

$$C_{s1}(1) = C^0_{s1} \cdot DS_{11} \cdot DR_{11} = C^0_{s1} \cdot Y_{11} \quad (16)$$

In general, the term $C_{sn}(Ti)$ is the soil concentration of the "nth" member of the decay chain after Ti years. As before, C^0_{s1} is the initial soil concentration of the first member of the chain. The DS_{11} factor applies for the first 6 months. The DR_{11} factor controls the second 6 months. The DS_{11} and DR_{11} terms are normally preceded by factors for branching ratios and products of decay constants. However, for the first member of the chain, these terms are 1.

The first daughter of nuclide "1" is produced during the irrigation period and then decays during the rest of the year. It also is produced from the decay of the parent nuclide that is present at the end of the irrigation season. This is shown in Equation (17) below. The term BP_{12} contains the branching ratio and product of decay constants found in Equations 5 and 9.

$$C_{s2}(1) = C_{s1}^{0} \cdot BP_{12} \cdot (DS_{12} \cdot DR_{22} + DS_{11} \cdot DR_{12}) = C_{s1}^{0} \cdot BP_{12} \cdot Y_{12} \tag{17}$$

The concentration of the third and fourth nuclides in the chain at the end of the first year is calculated using Equation (18) below. Longer chains are computed in a similar fashion. Note that all possible decay paths must be considered. This leads to as many terms as there are members in the decay chain.

$$\begin{aligned} C_{s3}(1) &= C_{s1}^{0} \cdot BP_{13} \cdot (DS_{13} \cdot DR_{33} + DS_{12} \cdot DR_{23} + DS_{11} \cdot DR_{13}) \\ &= C_{s1}^{0} \cdot BP_{13} \cdot Y_{13} \\ C_{s4}(1) &= C_{s1}^{0} \cdot BP_{14} \cdot (DS_{14} \cdot DR_{44} + DS_{13} \cdot DR_{34} + DS_{12} \cdot DR_{24} + DS_{11} \cdot DR_{14}) \\ &= C_{s1}^{0} \cdot BP_{14} \cdot Y_{14} \end{aligned} \tag{18}$$

Irrigation. In the irrigation scenarios, for the first member of the chain, the concentration at the end of the year is the product of the accumulated activity at the end of the irrigation season and the decay factor resulting from decay without irrigation or leaching for the remainder of the year. This is shown in Equation (19) below. Note the similarity between Equations (16) and (19). This will be seen again in the next few equations.

$$C_{s1}(1) = T_{irr} \cdot ID_{s1}^{0} \cdot DI_{11} \cdot DR_{11} \tag{19}$$

In general, the term $C_{sn}(Ti)$ is the soil concentration of the "nth" member of the decay chain after Ti years. As before, ID_{s1}^{0} is the instantaneous rate of increase in the soil concentration for the first member of the chain. The DI and DR terms are normally preceded by factors for branching ratios and products of decay constants. However, for the first member of the chain, these terms are 1.

The first daughter of nuclide "1" is produced during the irrigation period and then decays during the rest of the year. It also is produced from the decay of the parent nuclide that is present at the end of the irrigation season. This is shown in Equation (20) below. Note that the assumed amount of the daughter in the irrigation water is zero. The term BP_{12} contains the branching ratio and product of decay constants found in Equations (9) and (13).

$$C_{s2}(1) = T_{irr} \cdot ID^0_{s1} \cdot BP_{12} \cdot (DI_{12} \cdot DR_{22} + DI_{11} \cdot DR_{12}) \quad (20)$$

The concentration of the third and fourth nuclides in the chain at the end of the first year is calculated using Equation (21) below. Longer chains are computed in a similar fashion. Note that all possible decay paths must be considered. This leads to as many terms as there are members in the decay chain, as shown below.

$$\begin{aligned} C_{s3}(1) &= T_{irr} \cdot ID^0_{s1} \cdot BP_{13} \cdot (DI_{13} \cdot DR_{33} + DI_{12} \cdot DR_{23} + DI_{11} \cdot DR_{13}) \\ C_{s4}(1) &= T_{irr} \cdot ID^0_{s1} \cdot BP_{14} \cdot (DI_{14} \cdot DR_{44} + DI_{13} \cdot DR_{34} + DI_{12} \cdot DR_{24} + DI_{11} \cdot DR_{14}) \end{aligned} \quad (21)$$

In practice, it is better to calculate the decay factors for each nuclide, since these are unitless fractions whose value is near 1.0 for nuclides with long half lives. The calculation of media concentrations and dose can be carried out ignoring decay. A decay factor can then be added.

3.1.5 Soil Concentration after Many Years of Irrigation

After the first year of irrigation, there is residual contamination which must be taken into account when computing the total activity at the end of the year under consideration. The activity after N years is the sum of (1) the activity after (N-1) years decaying for 1 year, plus (2) the activity which normally accumulates during the year. Note that the residual activity from (N-1) years of prior irrigation is first subjected to decay with leaching during the first portion of the year and then decay without leaching for the remainder (Y_{11}). As a reminder, it is assumed that the water concentration of the parent nuclide remains constant and that none of the progeny nuclides accumulate in the water. This permits separate unit dose factors for each of the principal nuclides in a decay chain. The concentration of progeny nuclides in the irrigation water will be determined by the release and transport codes.

For the first member of the decay chain, the soil concentration at the end of N years is shown in Equation (22). The Y and Z terms are introduced to simplify later equations. The Z term is analogous to an exponential term in the usual decay equations. Equation (22) applies to scenarios in which irrigation with contaminated water occurs.

$$\begin{aligned} C_{s1}(N) &= C_{s1}(N\text{-}1) \cdot Y_{11} + C_{s1}(1) \\ &= C_{s1}(1) \cdot (1 - Y_{11}^N)/(1 - Y_{11}) = C_{s1}(1) \cdot Z_1 \end{aligned} \quad (22)$$

where, $Z_1 = (1 - Y_{11}^N)/(1 - Y_{11})$

The activity concentration of the first daughter after N years of accumulation and decay is shown below. The soil concentration after N years is the sum of (1) the activity added during the

Nth year and the activity present at the end of N-1 years after one more year of leaching and decay.

The YZ combination term shown in Equation (23) is introduced to simplify later equations. The YZ term has a form similar to that of the standard decay equations. The product of decay constants represented as the PD term in Equations (6), (10) and (14) has a reversed order compared to these equations.

$$\begin{aligned} C_{s2}(N) &= C_{s1}(N\text{-}1)\cdot BP_{12}\cdot Y_{12} + C_{s2}(N\text{-}1)\cdot Y_{22} + C_{s2}(1) \\ &= C_{s2}(1)\cdot Z_2 + C_{s1}(1)\cdot BP_{12}\cdot Y_{12}\cdot(Z_1 - Z_2)/(Y_{11} - Y_{22}) \\ &= C_{s2}(1)\cdot Z_2 + C_{s1}(1)\cdot BP_{12}\cdot YZ_{12} \end{aligned} \tag{23}$$

The activity concentration of the third member of the decay chain after N years of accumulation and decay is shown below.

$$\begin{aligned} C_{s3}(N) &= C_{s1}(N\text{-}1)\cdot BP_{13}\cdot Y_{13} + C_{s2}(N\text{-}1)\cdot BP_{23}\cdot Y_{23} + C_{s3}(N\text{-}1)\cdot Y_{33} + C_{s3}(1) \\ &= C_{s3}(1)\cdot Z_3 + C_{s2}(1)\cdot BP_{23}\cdot Y_{23}\cdot(Z_2 - Z_3)/(Y_{22} - Y_{33}) + \\ &\qquad C_{s1}(1)\cdot BP_{13}\cdot Y_{13}\cdot(Z_1 - Z_3)/(Y_{11} - Y_{33}) + \\ &\qquad C_{s1}(1)\cdot BP_{13}\cdot Y_{12}\cdot Y_{23}\cdot\{Z_1/[(Y_{11} - Y_{22})(Y_{11} - Y_{33})] + \\ &\qquad Z_2/[(Y_{22} - Y_{11})(Y_{22} - Y_{33})] + Z_3/[(Y_{33} - Y_{11})(Y_{33} - Y_{22})]\} \\ &= C_{s3}(1)\cdot Z_3 + C_{s2}(1)\cdot BP_{23}\cdot YZ_{23} + C_{s1}(1)\cdot BP_{13}\cdot[YZ_{13} + YZ_{123}] \end{aligned} \tag{24}$$

The activity concentration of the fourth member of the decay chain after N years of accumulation and decay is shown below.

$$\begin{aligned} C_{s4}(N) &= C_{s1}(N\text{-}1)\cdot BP_{14}\cdot Y_{14} + C_{s2}(N\text{-}1)\cdot BP_{24}\cdot Y_{24} + C_{s3}(N\text{-}1)\cdot BP_{34}\cdot Y_{34} + \\ &\qquad C_{s4}(N\text{-}1)\cdot Y_{44} + C_{s4}(1) \\ &= C_{s4}(1)\cdot Z_4 + C_{s3}(1)\cdot BP_{34}\cdot YZ_{34} + C_{s2}(1)\cdot BP_{24}\cdot[YZ_{24} + YZ_{234}] \\ &\qquad C_{s1}(1)\cdot BP_{14}\cdot[YZ_{14} + YZ_{124} + YZ_{134} + YZ_{1234}] \end{aligned} \tag{25}$$

where

$$\begin{aligned} YZ_{1234} = Y_{12}\cdot Y_{23}\cdot Y_{34}\cdot\{&Z_1/[(Y_{11} - Y_{22})(Y_{11} - Y_{33})(Y_{11} - Y_{44})] + \\ &Z_2/[(Y_{22} - Y_{11})(Y_{22} - Y_{33})(Y_{22} - Y_{44})] + \\ &Z_3/[(Y_{33} - Y_{11})(Y_{33} - Y_{22})(Y_{33} - Y_{44})] + \\ &Z_4/[(Y_{44} - Y_{11})(Y_{44} - Y_{22})(Y_{44} - Y_{33})]\} \end{aligned}$$

Fortunately, chains with more than 4 members do not need to be considered because the accumulation time is 50 years. For the nuclides of interest, four member chains will be adequate for 1000 years. There is a similarity between the above equations for decay and leaching of an initial soil contamination over time and the ordinary decay equations.

The initial soil contamination may be due to well-drilling or to irrigation with contaminated water in prior years. Thus irrigation calculations involving prior irrigation with contaminated water are calculated as the sum of an initial soil concentration case and an irrigation case. The initial soil concentration is computed according to the method shown in equations (22) through (25).

3.2 Emanation of Gaseous Nuclides from the Soil Surface

Two cases are described in the "No Infiltration Scenarios" of Table 2. The first is the "Offsite Farmer" who is downwind of the disposal site. The second is the "Onsite Resident" who lives in a dwelling affected by the gaseous emission. These scenarios are presented in more detail below. In addition, the two are compared to show that the offsite dose is always lower than the onsite dose.

The nuclides of concern for these emissions are H-3, C-14, Rn-220, and Rn-222. The H-3 is normally found as water and would be released as water vapor. The C-14 has been assumed to be bound to an organic compound. Presumably the organic compound could be volatile as well. The most likely carbon compound to be emitted is carbon dioxide. However, the inhalation dose factor for carbon dioxide is about 90 time smaller than for organically bound C-14. Finally, the inhalation dose from radon compounds depends on the ease with which the particulate progeny of the inert gas become attached to dust particles in the air, as well as the relative amounts of the short half life progeny. For this reason, the radon emission is limited to 20 pCi m^{-2} s^{-1} (HNF-EP-0826).

3.2.1 Effect on the Offsite Farmer

Radioactivity released into the air is carried by the wind to locations some distance from the emission source. As the airborne material travels it is diluted, so that the potential doses are lessened. However, the radioactive material may settle on crops and pastures, leading to ingestion pathway doses as well as the initial inhalation dose as the plume passes the receptor location. The inhalation dose to an individual downwind is calculated using the formula shown below.

$$H_{bt} = Q_{emit}\, X/Q'\, BR\, DF_{inh} \qquad (26)$$

where,

H_{bt} = inhalation dose at a downwind location, mrem

Q_{emit} = activity released into the air as a gas or respirable particles, Ci

X/Q' = air transport factor, 1.0E-4 s/m^3

BR = breathing rate, 2.64E-4 m^3/s

DF_{inh} = inhalation dose factor for a nuclide emanating from the ground surface, in mrem per pCi inhaled. Values are given in Table 8.

Because the emission from the ground surface is assumed to take place over the course of a year, the parameters in Equation (26) are chosen to represent the annual average. Thus the annual average breathing rate is 0.95 m^3/h, or 2.64E-4 m^3/s. In addition, the activity released into the air is the total released over the course of one year. Finally, the air transport factor (1.0E-4 s/m^3) is a bounding value for an annual emission (WHC-SD-WM-TI-616). It includes the normal variation in wind direction, wind speed, and atmospheric stability.

Inserting values for inhalation dose factor, and assuming a 1 Ci emission over the course of a year, leads to unit dose factors of 0.0025 mrem per Ci H-3, and 0.055 mrem per Ci C-14.

An additional method for estimating the offsite dose, that takes into account the ingestion pathways is the CAP88-PC software from EPA (402-B-92-001). The software predicts that the total doses are 0.0237 mrem per Ci H-3, and 1.32 mrem per Ci C-14. The program output is listed in Appendix C. Note that the air transport factors used by CAP88-PC was 7.98E-6 s/m^3 because a distance of 1000 m was input. The doses reported by CAP88-PC were then adjusted upward by the ratio of air transport factors, namely, (1.0E-4)/(7.98E-6)=12.5 to give the values reported above. An additional difference with the simple inhalation dose method is the assumed chemical form of the carbon. In CAP88-PC the carbon is in the form of carbon dioxide, while in the simple inhalation calculation, the organic form is used. Although the organic form of carbon leads to larger inhalation doses, the ingestion pathways in CAP88-PC give most of the dose. It should be noted that the various consumption parameters in CAP88-PC are larger. For example the fraction of contaminated vegetables is 100% in CAP88-PC. The value of CAP88-PC is that is can be used to demonstrate compliance with the 10 mrem/y performance objective for airborne emissions.

3.2.2 Effect on the Onsite Resident

For modeling the effect of contaminants emanating from the soil into a ventilated building, the equilibrium air concentration is the product of the emanation rate (activity per unit area per unit time) and the floor area divided by the building ventilation rate (volume per unit time). The ratio of ventilation rate to floor area is characteristic of classes of building construction. Typical ratios are less than 0.003 m/s. The individual exposed to gaseous emanations from the disposal site is located in a ventilated dwelling. For a constant emanation rate with a constant ventilation rate, the concentration starts at zero and rises according to the formula shown below.

$$C = (C_{eq})\cdot\{1-\mathrm{Exp}[-(F)(t)/(V)]\}$$

$$C_{eq} = (E)/(F/A) \qquad (27)$$

where,

C = time-dependent air concentration inside the building, Ci/m³

C_{eq} = steady-state (or equilibrium) air concentration, Ci/m³

E = contaminant emanation rate, Ci m^{-2} s^{-1}

A = building floor area, m²

F = building ventilation rate, m³/s

V = building volume, m³

The ratio F/A is characteristic of certain dwellings. Two examples are listed below. Typical values will need to be established for dose calculation purposes. For radon, the DOE uses an emanation limit. For gases such as tritium (as water vapor) and carbon-14, a dose calculation can be performed.

house: F/A = (10 cfm)/(100 ft²) = 1/600 ft/s = 5.08E-4 m/s

office: F/A = (100 cfm)/(200 ft²) = 1/120 ft/s = 2.54E-3 m/s

Using the smaller value to maximize the equilibrium air concentration, and assuming a unit emanation rate (1 pCi m^{-2} s^{-1}) leads to an equilibrium air concentration of 2000 pCi/m³, or 2 pCi/L in the dirt-floor house.

The inhalation dose received by exposure to radionuclides emanating from the soil into a dwelling is the product of the steady-state air concentration, the volume of air inhaled during the year, and the inhalation dose factor as shown in Equation (28). Any decay factor is expected to be nearly one, since the nuclides that contribute to this pathway (tritium, C-14, Rn-220 and Rn-222) are expected to see very little change in the emanation rate due to radioactive decay.

$$H_{be} = Q_{ab}\, C_{eq}\, D_{inh}\, T_{inh} \qquad (28)$$

where

H_{be} = inhalation dose from the emanation of gaseous nuclides during one year, in mrem.

Q_{ab} = quantity of air inhaled by the person while in the dwelling, in m³/y. The value used is 6170 m³/y based on the sleeping and indoor data in Table 17.

C_{eq} = steady-state concentration of gaseous nuclides in the dwelling, in pCi/L.

D_{inh} = inhalation dose factor for a nuclide, in mrem per pCi inhaled. Values are given in Table 8.

T_{inh} = inhalation exposure time of the individual, 1 y.

For H-3 and C-14, the inhalation doses are calculated as shown below. They are based on a unit emanation rate, 1 pCi m^{-2} s^{-1}.

H-3: (6170 m^3/y)(2000 pCi/m^3)(9.60E-8 mrem/pCi)(1 y) = 1.18 mrem

C-14: (6170 m^3/y)(2000 pCi/m^3)(2.09E-6 mrem/pCi)(1 y) = 25.8 mrem

3.2.3 Comparison of Offsite and Onsite Doses

A basic difference between the two dose calculations is the input radioactivity. For the offsite dose calculation, the total released into the air during one year must be estimated. For the onsite dose calculation, the rate at which activity enters the air per unit area of floor space is needed. To put the two on a comparable level, assume the ground surface directly above the waste site has a surface area of 31,690 m^2. A uniform emanation rate of 1 pCi m^{-2} s^{-1} for one year will release 1 Ci of activity into the air.

(1 pCi m^{-2} s^{-1})(31,690 m^2)(3.156x10^7 s/y)(1 y) = 1 Ci

Because the offsite dose is smaller than the onsite dose for unit emission rates (Table 28), the waste site area needs to be increased to raise the offsite dose, which depends on the total emitted during the year. Table 28 shows the calculated doses and required disposal site area for the two doses to be equal. Because the disposal site surface area will be significantly less than a square kilometer (1.0E+6 m^2), the onsite dose will always be greater than the offsite dose.

Table 28. Comparison of Onsite and Offsite Doses.

Volatile Nuclide	Onsite Resident (per pCi m^{-2} s^{-1})	Offsite Farmer (per Ci released)	Disposal Facility Surface Area
H-3	1.18 mrem	0.0237 mrem	1.58E+6 m^2
C-14	25.8 mrem	1.32 mrem	1.08E+6 m^2

Disposal Site Area is calculated as the Onsite dose multiplied by 31,690 m^2 and divided by the Offsite dose.

3.3 External and Inhalation Dose

The inhalation dose that is received by exposure to airborne water during showering or a sauna or under ambient conditions is simply the product of the volume of water inhaled during

the year, the water concentration, and the inhalation dose factor as shown in equation (29). No consideration of radioactive decay or progeny ingrowth is needed, because the water concentration is assumed to be constant during the year, and no progeny are allowed to accumulate in the water.

$$H_{bw} = Q_{wb}\, C_w\, D_{inh}\, T_{inh} \tag{29}$$

where

H_{bw} = inhalation dose from airborne moisture during one year, in mrem.

Q_{wb} = quantity of contaminated water inhaled by the person while in the shower or sauna, in L/y. Values are given in Table 18.

C_w = concentration of a nuclide in the contaminated water, in pCi/L.

D_{inh} = inhalation dose factor for a nuclide, in mrem per pCi inhaled. Values are given in Table 8.

T_{inh} = inhalation exposure time of the individual, 1 y.

The external and inhalation dose due to exposure to contaminated soil are accumulated over the course of a year for all exposure scenarios except the waste intruder (driller). The amount accumulated per day depends on the soil concentration on that day. The external dose rate and the inhalation dose rate are proportional to the soil concentration. The total accumulated over the year is proportional to the time integral of the soil concentration. The external dose and inhalation doses are shown in equation (30). To obtain the total dose from the parent nuclide it is necessary to include the contributions from each progeny nuclide. Hence the sum over nuclides in a decay chain. Note that radioactive decay is not considered for the waste intruder because the exposure time is so brief (5 days) compared to the half lives of the nuclides selected for analysis.

$$H_{xs} = \sum_{i=1}^{n} \int_0^{1y} \rho\, d\, C_{si}\, D_{ext,i}\, dT$$

$$H_{bs} = \sum_{i=1}^{n} \int_0^{1y} M_{sb}\, C_{si}\, D_{inh,i}\, dT \tag{30}$$

where

H_{xs} = external dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem

H_{bs} = inhalation dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem

I = index over the decay chain. I=1 refers to the first member, or parent nuclide; I=2 refers to the second member of the decay chain; I=3 refers to the third member; I=4 refers to the fourth member.

ρ = bulk density of the surface soil, in grams per cubic centimeter. The value normally used in Hanford Site PA work is 1.5 g/cc.

d = thickness of soil from which nuclides migrate, in centimeters. This is assumed to be 15 cm (5.9 inches).

C_{si} = time-dependent soil concentration of the ith nuclide during the year, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil.

$D_{ext,i}$ = external dose rate factor for exposure to radiation from nuclide "I" in contaminated soil, in mrem/h per Ci/m^2. Values are given in Table 10.

M_{sb} = mass of soil inhaled annually by the individual, in mg/y. Values are discussed in Section 2.2.4.

$D_{inh,i}$ = inhalation dose factor for nuclide "I", in mrem per pCi inhaled. Values are given in Table 8.

The only term in the integrals with any time dependence is the soil concentration. Thus the accumulated dose at time T is the time integral of the activity equations. These integrations are simply the integral of each exponential. Each of the exponential terms in the decay equations (6) and (10), namely, Exp(-λT), are replaced with the time integral shown in Equation (31). Note that the integral of the DS term in equation (10) is the same as the DI term in equation (14).

$$\text{Time Integral} = \int_0^T \text{Exp}(-\lambda t)\, dt = [1 - \text{Exp}(-\lambda T)]/\lambda \qquad (31)$$

If the product λT is less than 0.0002, a loss of numeric accuracy is experienced. To overcome this, the integral in equation (31) is replaced with the equivalent polynomial to improve the numeric precision of the calculation. The polynomial used is shown in equation (32).

$$[1 - \text{Exp}(-\lambda T)]/\lambda = T\cdot[1 - \lambda T/2 + (\lambda T)^2/6 - (\lambda T)^3/24] \qquad (32)$$

Notice that if the product λT is very small, the time integral approaches the decay period. For this reason, the time integral of the decay equation is sometimes referred to as an effective time period. In effect, it is a particular time period adjusted for radioactive decay. To consistently work with unitless decay periods, all time integrals are divided by the integration period. Thus the integration period must be made a factor in the calculation.

For the irrigated farm scenario, the concentration of nuclides in the soil increases with time due to the activity accumulating in the soil as shown in equation (14). The soil concentration follows the time integral formula of equations (31) and (32). The accumulated intake or dose at time T is the time integral of the equation (14). In other words, each exponential term in the decay equation (10), namely, $\text{Exp}(-\lambda T)$ is replaced with its second integral, shown in equation (33).

$$\text{Second Integral} = [\lambda T - 1 + \text{Exp}(-\lambda T)]/\lambda^2 \tag{33}$$

If the product λT is less than 0.001, a loss of numeric accuracy is experienced. To overcome this, the integral in equation (33) is replaced with the equivalent polynomial to improve the numeric precision of the calculation. The polynomial used is shown in equation (34).

$$[\lambda T - 1 + \text{Exp}(-\lambda T)]/\lambda^2 = T^2 \cdot [1 - \lambda T/3 + (\lambda T)^2/12 - (\lambda T)^3/60]/2 \tag{34}$$

Notice that if the product λT is very small, the time integral in equations (33) and (34) approaches the decay period squared. Again, to only work with unitless decay factors, the second integral is divided by the integration period squared. This time must then be made a factor in the dose equation.

Using the two-part irrigation model, the dose accumulated during the first 6 months depends only on the DS or DI integration. The dose during the second 6 months (without irrigation) depends only on the DR integration. This idea is summarized in the equations below. Equation (35) shows the time integral of equations (16) through (18) for an initial soil contamination (e.g. the post-intrusion garden), while equation (36) shows the time integral of equations (19) through (21) for irrigation with contaminated water. Constant factors have been omitted to simplify the equations. In both equations the first integral represents the dose from the nth member of the decay chain during the first 6 months. During the first 6 months the only source of this nuclide is the decay of the parent nuclide. After 6 months of decay and ingrowth, each member of the decay chain will be present in the soil. Thus the second time integral on the right has contributions from decay of the parent as well as decay of the other members of the chain.

Initial Soil Contamination: (from Equation 16)

$$\int_0^{1y} Y_{1n}(T)\,dT = \int_0^{T_{irr}} DS_{1n}(T)\,dT + \sum_{k=1}^{n} DS_{1k}(T_{irr}) \int_0^{T_{no}} DR_{kn}(T)\,dT$$

$$\int_0^{1y} Y_{1n}(T)\,dT = T_{irr}\, IDS_{1n}(T_{irr}) + T_{no} \sum_{k=1}^{n} DS_{1k}(T_{irr})\, IDR_{kn}(T_{no}) \tag{35}$$

Irrigation with Contaminated Water: (from Equation 19)

$$\int_0^{1y} C_{s1}\,dT = \int_0^{T_{irr}} DI_{1n}(T)\,dT + \sum_{k=1}^{n} DI_{1k}(T_{irr}) \int_0^{T_{no}} DR_{kn}(T)\,dT$$

$$\int_0^{1y} C_{s1}\,dT = T_{irr}\, IDI_{1n}(T_{irr}) + T_{no} \sum_{k=1}^{n} DI_{1k}(T_{irr})\, IDR_{kn}(T_{no}) \qquad (36)$$

The above equations show the decay factors that represent each integral. Additional terms needed in later calculations are defined below. Note that the integration period becomes a factor in the equation because the decay factors are designed to be unitless quantities between 0 and 1.

$$\int_0^{T_{irr}} DS(T)\,dT = T_{irr}\, IDS(T_{irr}) \qquad \int_0^{T_{no}} DR(T)\,dT = T_{no}\, IDR(T_{no})$$

$$\int_0^{T_{irr}} DI(T)\,dT = T_{irr}\, IDI(T_{irr}) \qquad T_{no} = 1y - T_{irr} \qquad (37)$$

$$\int_0^{T_{veg}} DR(T)\,dT = T_{veg}\, IDR(T_{veg}) \qquad \int_0^{T_{beef}} DR(T)\,dT = T_{beef}\, IDR(T_{beef})$$

note that

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

T_{no} = interval during which no irrigation takes place, $T_{no} = 1y - T_{irr}$

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{beef} = consumption period for beef after slaughter, assumed to be 120 days.

3.4 Ingestion Dose

Human ingestion dose comes from the pathways discussed earlier, such as contaminated drinking water, trace intakes of soil, vegetables grown on contaminated soil, and animal products. Each of these is discussed below. The basic dose calculation is the product of three factors, (1) the quantity consumed, (2) the radionuclide concentration in what is consumed, and (3) the ingestion dose factor. The addition of radioactive decay and progeny ingrowth is discussed with each pathway.

3.4.1 Soil and Water Ingestion

The ingestion dose from drinking water is shown in equation (38). The drinking water has no progeny. The concentration of each nuclide in a chain is treated separately.

$$H_{ew} = Q_{we}\, C_w\, D_{ing}\, T_{ing} \tag{38}$$

where

H_{ew} = ingestion dose from drinking water, in mrem.

Q_{we} = quantity of contaminated drinking water ingested by the person, in L/y. See Tables 13 and 14 for values.

C_w = concentration of a nuclide in the contaminated water, in pCi/L.

D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table 7.

T_{ing} = ingestion exposure time of the individual, 1 y.

The ingestion dose from the intake of trace amounts of soil is shown in equation (39). The soil concentration does include leaching, decay and progeny ingrowth. Because the soil is consumed in small amounts during the year, the total dose is represented as the time integral of the daily intake. As before, the time integral must accommodate the change in infiltration rates during the year, just as was done for the inhalation and external doses using equations (35) and (36).

$$H_{es} = \sum_{i=1}^{n} \int_{0}^{1y} M_{se}\, C_{si}\, D_{ing,i}\, dT \tag{39}$$

where

H_{es} = ingestion dose accumulated during the year from one radionuclide and its progeny due to radioactivity in the soil, mrem

I = index over the decay chain. I=1 refers to the first member, or parent nuclide; I=2 refers to the second member of the decay chain; I=3 refers to the third member; I=4 refers to the fourth member.

M_{se} = mass of soil ingested annually by the individual, in mg/y.

C_{si} = time-dependent soil concentration of the ith nuclide during the year, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil.

$D_{ing,i}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table 7.

3.4.2 Garden Produce

The ingestion dose from garden produce grown in contaminated soil is the product of the quantity of vegetables eaten, the concentration of radioactivity in the vegetables, and the ingestion dose factor. The ingestion dose factors are given in Table 7. Quantities eaten are given in Tables 13 and 14. The calculation of radionuclide concentrations in living plants uses three main routes, (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) direct deposition of irrigation water on foliage. Each of these will be considered separately below. The three uptake routes are then combined to obtain the total ingestion dose from the garden produce.

The equations presented below apply to both garden produce and cattle feed in the sense that the quantity eaten and the ingestion dose factor can be removed to give the nuclide concentration in the cattle feed. These concentrations are needed to calculate dose from ingestion of contaminated animal products.

The garden produce intakes are based on the two situations. The first applies to leafy vegetables. It is assumed that leafy vegetables are produced more-or-less continuously during the growing season. They are consumed shortly after being collected. Thus the continuous model uses a time integral to represent the accumulated dose from leafy vegetables during the growing season. It is further assumed that leafy vegetables are not raised after the growing season has ended. Any leafy vegetables consumed after the growing seasons ends are assumed to have been imported from uncontaminated areas. The 25% of a person's diet that comes from contaminated sources is then assumed to be 50% during the irrigation period and 0% during the remainder of the year.

The second garden produce model applies to the other types of garden produce. These foods are assumed to be grown and harvested twice during the growing season. The plant concentration depends on the soil concentration at the time of harvest. For an initial soil contamination (e.g. post-intrusion garden or prior irrigation) this time is taken to be midway through the irrigation season. For the irrigation scenarios harvest is assumed to occur at the end of the irrigation season. Because these foods may be stored and eaten over a period of time, radioactive decay during the storage and consumption periods needs to be taken into account. The amount of radioactive contamination eaten during the consumption period is the time integral of the ordinary decay equations (5) through (7). The average consumption period for non-leafy vegetables is taken to be 90 days. Some products do not keep well, and have shorter consumption periods. Others keep very well and have longer consumption periods. The value selected for the ILAW PA (90 days) simplifies the calculations in that all non-leafy vegetables have the same period. Note that for long half life nuclides the actual value has no effect on the final doses.

Root uptake is calculated using concentration ratios. These ratios are listed in Table 25. The ingestion dose from garden produce due to root uptake into the various types of vegetation is described with equation (40). The first equation shows the continuous model for leafy

vegetables. Note that the integral is over half the year so the assumed annual intake from garden must be adjusted upward to compensate. Hence the ratio (1 y)/(T_{irr}). The second equation shows the harvest model for the other vegetables. In both equations the sum over radionuclides in a decay chain is needed to obtain the total dose from the parent nuclide.

$$H_{epr}(\text{leafy}) = \sum_{i=1}^{n} \frac{1\,y}{T_{irr}} \int_{0}^{T_{irr}} R_p\, B_{pi}\, Q_{vp}\, C_{si}\, D_{ing,i}\, dT$$

$$H_{epr}(\text{others}) = \sum_{i=1}^{n} R_p\, B_{pi}\, Q_{vp}\, C_{si}\, IDR_i(T_{veg})\, D_{ing,i}\, T_{ing} \qquad (40)$$

where

H_{epr} = ingestion dose from plant type p due to root uptake, in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

R^p = dry to wet ratio for plant type p. See Table 24 for values.

B_{pi} = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table 25 for values.

Q_{vp} = quantity of plant type p eaten by the person, in kg/y. See Tables 13 and 14 for values.

C_{si} = soil concentration of the ith nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season. In the second equation it is the soil concentration at the time of harvest.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

IDR_i = decay factor that accounts for radioactive decay of the ith nuclide during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,i}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table 7.

The resuspension of dust by wind, or water drops splashing soil onto the foliage leads to some contamination of the edible portion of the plant. The ingestion dose from this source of contamination is calculated using equation (41). The first equation shows the continuous model for leafy vegetables. Note that the integral is over half the year so the assumed annual intake from garden must be adjusted upward to compensate. Hence the ratio (1 y)/(T_{irr}). The second

equation shows the harvest model for the other vegetables. Note the sum over radionuclides in a decay chain to obtain the total dose from the parent nuclide.

$$H_{epf}(\text{leafy}) = \sum_{i=1}^{n} \frac{1\,y}{T_{irr}} \int_{0}^{T_{irr}} R^{a} V_{d} \frac{F_{fp} F_{tp} T_{w}}{Y_{p}} Q_{vp} C_{si} D_{ing,i}\, dT$$

$$H_{epf}(\text{others}) = \sum_{i=1}^{n} R^{a} V_{d} \frac{F_{fp} F_{tp} T_{w}}{Y_{p}} Q_{vp} C_{si} IDR_{i}(T_{veg}) D_{ing,i} T_{ing} \quad (41)$$

where

H_{epf} = ingestion dose from plant type p due to resuspension of contaminated soil onto plant surfaces (rain splash), in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

R^{a} = average concentration of soil in the air near the foliage due to rain splash, 1.0 mg/m³. See Section 2.4.2 for further discussion.

V_{d} = diffusion attachment speed, or ground deposition speed that represents rain splash soil, 0.01 m/s or 864 m/d. See Section 2.4.2 for further discussion.

F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed using equation (3). Values are listed in Table 26.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table 26.

T_{w} = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table 29.

Y_{p} = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table 26.

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Tables 13 and 14 for values.

C_{si} = time-dependent soil concentration of the ith nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season. In the second equation it is the soil concentration at the time of harvest.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

IDR_{i} = decay factor that accounts for radioactive decay of the ith nuclide during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,i}$ = ingestion dose factor for nuclide "I", in mrem per pCi ingested. Values are given in Table 7.

One effect of wind, rain, and irrigation is to remove deposited contamination from plant surfaces. This effect is included using a weathering term shown in equation (42). Values for the effective growing period are only slightly affected by the radioactive half life of the isotope for the long half lives shown in Table 5. Therefore, the decay effects were not considered (λ_w=0). Values for T_w are given in Table 29 for the growing periods shown in Table 26.

$$T_w = \{ 1 - Exp[-(\lambda_w + \lambda_r)T_p^f] \} / (\lambda_w + \lambda_r) \quad (42)$$

where

T_w = effective exposure period for foliar deposition, in days. Values are shown in Table 29.

λ_w = weathering removal coefficient, 0.0495105 per day, or 18.0713 per year, which corresponds to a 14 day half time.

λ_r = radioactive decay constant, namely, the natural logarithm of 2 divided by the radioactive decay half life in days. Values are listed in Table 5.

T_p^f = exposure time of the plant type p to the airborne contamination depositing on the foliage, in days (also called growing period). Values are shown in Table 26.

The previous two avenues by which contamination reaches the edible portions of the plants apply only to activity which is present in the soil. This section discusses direct deposition of contaminants in irrigation water onto the foliage. The ingestion dose due to radioactivity in the edible portion of the plants due to direct deposition on foliage is given in equation (43).

Table 29. Effective Exposure Times for Foliar Deposition

Growing Period	T_w
30 days	15.6 days
45 days	18.0 days
90 days	20.0 days

The effective exposure times are computed assuming radioactive decay is negligible for the nuclides of Table 5.

$$H_{epd}(leafy) = ID_p \frac{0.25\, F_{tp}\, T_w}{Y_p} Q_{vp}\, D_{ing}\, T_{ing}$$

(43)

$$H_{epd}(others) = \sum_{i=1}^{n} ID_p \frac{0.25\, F_{tp}\, T_w}{Y_p} Q_{vp}\, IDR_i(T_{veg})\, D_{ing,i}\, T_{ing}$$

where

H_{epd} = ingestion dose from plant type p due to deposition of a nuclide in contaminated irrigation water onto plant surfaces, in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m^2. Only the parent nuclide is present. Any progeny nuclides are assumed to be absent.

0.25 = interception fraction for contaminants in irrigation water. The fraction of what falls to the earth that lands on the plant.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table 26.

T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table 29.

Y_p = harvest yield of crop type p, in kg/m^2 (wet weight). Also called the standing biomass. Values are listed in Table 26.

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Tables 13 and 14 for values.

IDR_i = decay factor that accounts for radioactive decay during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,i}$ = ingestion dose factor for the ith nuclide, in mrem per pCi ingested. Values are given in Table 7.

The ingestion dose from garden produce due to direct deposition depends on the rate at which water is applied. In the previous two pathways, root uptake and rain splash, the determining factor is the total amount of water (and thus activity) applied to the soil. A summary of the essential calculation and the decay corrections is presented in Table 30.

Table 30. Summary of Ingestion Dose from Garden Produce

Essential Dose Calculation for an Initial Soil Contamination	
Root Uptake:	$R_p B_p C_s Q_{vp} D_{ing} T_{ing}$
Rain Splash:	$R^a V_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{vp} D_{ing} T_{ing}$
Correction for Radioactive Decay and Progeny Ingrowth	
Leafy Vegetables:	$IDS(T_{irr})$
Other Vegetables, Fruit, and Grain:	$DS(T_h) \cdot IDR(T_{veg})$
Essential Dose Calculation for Irrigation with Contaminated Water	
Root Uptake:	$R_p B_p C_s Q_{vp} D_{ing} T_{ing}$
Rain Splash:	$R^a V_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{vp} D_{ing} T_{ing}$
Direct Deposition:	$ID_p (0.25) (F_{tp} T_w / Y_p) Q_{vp} D_{ing} T_{ing}$
Correction for Radioactive Decay and Progeny Ingrowth	
Leafy Vegetables:	Root Uptake & Splash: $IDI(T_{irr})$ Direct Deposition: no decay
Other Vegetables, Fruit, and Grain:	Root Uptake & Splash: $DI(T_{irr}) \cdot IDR(T_{veg})$ Direct Deposition: $IDR(T_{veg})$

Notes: Leafy vegetables are consumed continuously during growing season (T_{irr}) only. Other produce is harvested and consumed over a period of time (T_{veg}). The decay factors are unitless fractions shown in Equation (37). Progeny ingrowth is computed using the method shown in Section 3.1.4.

Explanation of Symbols Used in Table 30.

B_p = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table 25 for values.

C_s = soil concentration of a nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season.

D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table 7.

F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed using equation (3). Values are listed in Table 26.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table 26.

ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m².

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Tables 13 and 14 for values.

R^a = average concentration of soil in the air near the foliage due to rain splash, 1.0 mg/m³. See Section 2.4.2 for further discussion.

R_p = dry to wet ratio for plant type p. See Table 24 for values.

T_h = time at which harvest occurs. For initial soil contaminations, harvest is assumed to occur halfway through the growing season, $T_h=T_{irr}/2$. For irrigation with contaminated water, the harvest occurs at the end of the irrigation season to maximize the soil contamination.

T_{ing} = ingestion exposure time of the individual, 1 y.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site.

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table 29.

V_d = diffusion attachment speed, or ground deposition speed that represents rain splash soil, 0.01 m/s or 864 m/d. See Section 2.4.2 for further discussion.

Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table 26.

The one special case nuclide is tritium in contaminated irrigation water. Tritium present in an initial soil contamination is handled using the same method as any other nuclide. The soil-to-plant concentration ratio shown in Table 25 is used. Tritium in irrigation water leads to an equilibrium situation in which the concentration of tritium in the water is reproduced throughout the plant. Since the equilibrium is established rather quickly, the decay corrections are simpler than for other nuclides. The calculation of dose from tritium in irrigation water is shown in Equation (44) below. Note that the tritium model assumes that loss of tritium by evaporation of water from soil or plants is not important.

$$H_{epH}(\text{leafy}) = \frac{I\,C_{w,H3}}{I + P}(8.94\,F_{Hp})\,Q_{vp}\,D_{ing,H3}\,T_{ing}$$

(44)

$$H_{epH}(\text{others}) = \frac{I\,C_{w,H3}}{I + P}(8.94\,F_{Hp})\,Q_{vp}\,IDR(T_{veg})\,D_{ing,H3}\,T_{ing}$$

where

H_{epH} = ingestion dose from plant type p due to tritium (H-3) in the irrigation water, in mrem.

p = type of plant. There are 4 types of garden produce. The first equation covers leafy vegetables (p=1). The second equation covers other vegetables, fruit, and grain (p=2,3,4).

I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 cm/y for populations).

$C_{w,H3}$ = concentration of tritium in the irrigation water, in pCi/L.

P = total natural precipitation water applied to the soil during the irrigation period, 5.23 cm/y (PNNL-12087).

F_{Hp} = fraction of hydrogen in plant type p. Values are listed in Table 23. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.

Q_{vp} = quantity of plant type p eaten by the person during the year, in kg/y. See Tables 13 and 14 for values.

IDR = decay factor that accounts for radioactive decay during the consumption of garden produce

T_{veg} = consumption period for garden produce, assumed to be 90 days

T_{ing} = ingestion exposure time of the individual, 1 y.

$D_{ing,H3}$ = ingestion dose factor for tritium, in mrem per pCi ingested. Value is given in Table 7.

3.4.3 Animal Products Eaten

The simplest animal product to evaluate is fish. The dose from fish consumption is shown in equation (45). It is the product of the quantity of fish consumed during the year, the concentration in the fish, and the ingestion dose factor. The fish harvested is consumed over the next few days, so there is no need to correct for radioactive decay and progeny ingrowth.

$$H_{ef} = Q_{fe}\,C_w\,B_f\,D_{ing}\,T_{ing} \quad (45)$$

where

H_{ef} = ingestion dose from contaminated fish, in mrem.

Q_{fe} = quantity of contaminated fish consumed by the person during the year, in kg/y. See Tables 13 and 14 for values.

C_w = concentration of a nuclide in the contaminated water, in pCi/L.

B_f = bioaccumulation factor in fish, in L/kg. It is the ratio of the contamination in the edible parts of the fish to the concentration in the water. Values are shown in Table 22.

T_{ing} = ingestion exposure time of the individual, 1 y

D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table 7.

The ingestion dose from foods obtained from land animals is computed using equilibrium transfer factors shown in Table 22. These relate the total radioactive material ingested by the animal each day to the concentration in the animal product consumed by a person. The total diet of the animal must be taken into account. The animal may drink contaminated water, ingest contaminated soil, graze on contaminated grass and be fed stored material that is also contaminated. Each of these will be presented in turn. The total ingestion dose from animal products is the sum of these.

Just as with garden produce there is a continuous production model and a harvest model in which the animal is slaughtered for later consumption. The beef cattle model illustrates the latter, while the milk cow illustrates the former. The chicken (meat) and egg are treated as continuous because these are produced at regular intervals during the year and then consumed shortly thereafter.

The ingestion dose from contaminated water consumed by the animal is shown in equation (46). Because the progeny nuclides are not allowed to form in the water supply, the dose from each nuclide in a chain will be calculated separately. When the beef cattle is slaughtered (i.e. harvested), there is a large quantity of beef available. This food is then consumed over a period of time during which radioactive decay and progeny ingrowth occurs. The quantity of contaminated beef consumed during the year is from Tables 13 and 14. These values have already been adjusted for the fraction of the year that contaminated beef is consumed. Hence, the factor (T_{ing}/T_{beef}) is included.

$$H_{eqw}(\text{beef}) = \sum_{i=1}^{n} \int_{0}^{T_{beef}} Q_{wq}\, C_w\, F_{qi}\, Q_{aq} \left(\frac{T_{ing}}{T_{beef}} \right) D_{ing,i}\, DR_i\, dT$$

$$H_{eqw}(\text{others}) = Q_{wq}\, C_w\, F_q\, Q_{aq}\, D_{ing}\, T_{ing} \qquad (46)$$

where

H_{eqw} = ingestion dose from animal product q due to contaminated drinking water, in mrem.

q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.

Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table 21 for values.

C_w = concentration of the parent nuclide in a decay chain in the contaminated water, in pCi/L. The progeny nuclide concentrations are assumed to be zero in the water.

F_{qi} = equilibrium transfer factor for animal product q for the ith nuclide in a decay chain, in d/kg (or d/L for milk). Values are given in Table 22. F_q is the transfer factor of the first nuclide.

Q_{aq} = quantity of animal product q consumed by the person during the year, in kg/y (or L/y for milk). See Tables 13 and 14 for values.

T_{beef} = consumption period for beef cattle, assumed to be 120 days

T_{ing} = ingestion exposure time of the individual, 1 y

$D_{ing,i}$ = ingestion dose factor for the ith nuclide in a decay chain, in mrem per pCi ingested. Values are given in Table 7. D_{ing} is the ingestion dose factor of the first nuclide in the chain.

The other contributors to the overall contamination of an animal product are summarized in Table 31. For the case of an initial soil contamination, the two components are vegetable foods consumed by the animal and the soil ingestion shown in Table 21. The animal foods are contaminated by root uptake and rain splash. There are three main kinds of food: fresh fodder (grass), stored hay (grass that is harvested and stored), and stored feed (grain that is harvested and stored). For the case of irrigation with contaminated water, additional components are direct deposition on the animal foods, and direct ingestion of the irrigation water.

Table 31. Summary of Ingestion Dose from Animal Products

Essential Dose Calculation for an Initial Soil Contamination. The activity intake rates are computed using the formulas below. These are converted to annual dose equivalent by means of the factor, $F_q Q_{aq} D_{ing} T_{ing}$.	
Trace Soil Ingestion:	$C_s Q_{sq}$
Fodder -- Root Uptake:	$R_p B_p C_s Q_{pq}$
Fodder -- Rain Splash:	$R^a V_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{pq}$

Correction for Radioactive Decay and Progeny Ingrowth -- Beef	
Soil Ingestion and Fresh Grass:	$DS(T_h)\cdot IDR(T_{beef})$
Stored Hay (grass) and Stored Grain:	$DS(T_h)\cdot DR(T_s)\cdot IDR(T_{beef})$
Correction for Radioactive Decay and Progeny Ingrowth -- Milk, Poultry, Eggs	
Soil Ingestion and Fresh Grass:	$[T_{irr}\cdot IDS(T_{irr}) + T_{no}\cdot DS(T_{irr})\cdot IDR(T_{no})]/T_{ing}$
Stored Hay (grass) and Stored Grain:	$DS(T_h)\cdot DR(T_s)\cdot IDR(T_{an})$
Essential Dose Calculation for Irrigation with Contaminated Water. The activity intake rates are computed using the formulas below. These are converted to annual dose equivalent by means of the factor, $F_q Q_{aq} D_{ing} T_{ing}$.	
Trace Soil Ingestion:	$C_s Q_{sq}$
Fodder -- Root Uptake:	$R_p B_p C_s Q_{pq}$
Fodder -- Rain Splash:	$R^a V_d F_{fp} (F_{tp} T_w / Y_p) C_s Q_{pq}$
Fodder -- Direct Deposition:	$ID_p (0.25) (F_{tp} T_w / Y_p) Q_{pq}$
Drinking Water Ingestion:	$C_w Q_{wq}$
Correction for Radioactive Decay and Progeny Ingrowth -- Beef	
Trace Soil Ingestion:	$DI(T_{irr})\cdot IDR(T_{beef})$
Fresh Grass:	Root & Splash: $DI(T_{irr})\cdot IDR(T_{beef})$ Direct Deposition: $IDR(T_{beef})$
Stored Hay and Grain:	Root & Splash: $DI(T_{irr})\cdot DR(T_s)\cdot IDR(T_{beef})$ Direct Deposition: $DR(T_s)\cdot IDR(T_{beef})$
Drinking Water:	$IDR(T_{beef})$
Correction for Radioactive Decay and Progeny Ingrowth -- Milk, Poultry, Eggs	
Trace Soil Ingestion:	$[T_{irr}\cdot IDI(T_{irr}) + T_{no}\cdot DI(T_{irr})\cdot IDR(T_{no})]/T_{ing}$

Fresh Grass:	Root Uptake & Rain Splash: $[T_{irr} \cdot IDI(T_{irr}) + T_{no} \cdot DI(T_{irr}) \cdot IDR(T_{no})]/T_{ing}$ Direct Deposition: no decay
Stored Hay and Grain:	Root & Splash: $DI(T_{irr}) \cdot DR(T_s) \cdot IDR(T_{an})$ Direct Deposition: $DR(T_s) \cdot IDR(T_{an})$
Drinking Water:	no decay

Notes: Beef is harvested and consumed over a period of time. Milk, poultry, and eggs are consumed continuously during the year. The decay factors are unitless fractions shown in Equation (37). Progeny ingrowth is computed using the method shown in Section 3.1.4.

Explanation of Symbols Used in Table 31.

B_p = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table 25 for values.

C_s = soil concentration of a nuclide, in Ci/kg. It is affected by radioactive decay and leaching from the surface layer of soil during the irrigation season.

C_w = concentration of a nuclide in the contaminated water, in pCi/L. Any progeny nuclide concentrations are assumed to be zero.

D_{ing} = ingestion dose factor for a nuclide, in mrem per pCi ingested. Values are given in Table 7.

F_q = equilibrium transfer factor for animal product q for a nuclide, in d/kg (or d/L for milk). Values are given in Table 22.

F_{fp} = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. Computed using equation (3). Values are listed in Table 26.

F_{tp} = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant. Values are listed in Table 26.

ID_p = instantaneous activity deposition rate due to irrigation of soils growing plant type p, in Ci/yr/m^2.

p = index for animal fodder. There are 3 types of animal fodder, fresh grass, stored hay, and stored grain.

q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.

Q_{aq} = quantity of animal product q eaten by the person during the year, in kg/y (or L/y for milk). See Tables 13 and 14 for values.

Q_{pq} = quantity of fodder type p eaten by the animal during the year, in kg/y. See Table 21 for values.

Q_{sq} = quantity of contaminated soil ingested by the animal associated with animal product q each day, in kg/d. See Table 21 for values.

Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table 21 for values.

R^a = average concentration of soil in the air near the foliage due to rain splash, 1.0 mg/m³. See Section 2.4.2 for further discussion.

R_p = dry to wet ratio for plant type p. See Table 23 for values.

T_{an} = time period over which stored hay and grain are consumed by the milk cow and chickens. Assumed to be the same as T_{veg}, 90 d.

T_{beef} = consumption period for beef cattle, assumed to be 120 days.

T_h = time at which harvest occurs. For initial soil contaminations, harvest is assumed to occur halfway through the growing season, $T_h=T_{irr}/2$. For irrigation with contaminated water, the harvest occurs at the end of the irrigation season to maximize the soil contamination.

T_{ing} = ingestion exposure time of the individual, 1 y.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site. $T_{no} = 1y - T_{irr}$

T_s = storage time for the stored feed (hay and grain), 90 d.

T_w = effective exposure period for foliar deposition, in days. The values are computed using a foliage weathering time of 14 days. Values are shown in Table 29.

V_d = diffusion attachment speed, or ground deposition speed that represents rain splash soil, 0.01 m/s or 864 m/d. See Section 2.4.2 for further discussion.

Y_p = harvest yield of crop type p, in kg/m² (wet weight). Also called the standing biomass. Values are listed in Table 25.

The one special case nuclide is tritium in contaminated irrigation water. Tritium present in an initial soil contamination is handled using the same method as any other nuclide. The equilibrium transfer factors shown in Table 22 are used. Tritium in irrigation water leads to an equilibrium situation in which the concentration of tritium in the water is reproduced throughout the animal product. Since the equilibrium is established rather quickly, the decay corrections are simpler than for other nuclides. The calculation of dose from tritium in irrigation water is shown in Table 32 below. Note that the tritium model assumes that loss of tritium by evaporation of water from soil or plants is not important.

Table 32. Ingestion Dose from Animal Products from Tritium

Essential Dose Calculation for Irrigation with Contaminated Water. The activity intake rates are computed using the formulas below. These are converted to annual dose equivalent by means of the factor, $C_{w,H3} F_q Q_{aq} D_{ing,H3} T_{ing}$.	
Trace Soil Ingestion:	$8.94 F_{Hs} I/(I+P) Q_{sq}$
Fodder -- Root Uptake:	$8.94 F_{Hp} I/(I+P) Q_{pq}$
Drinking Water Ingestion:	Q_{wq}
Correction for Radioactive Decay and Progeny Ingrowth -- Beef	
Trace Soil Ingestion:	$IDR(T_{beef})$
Fresh Grass:	$IDR(T_{beef})$
Stored Hay and Grain:	$DR(T_s) \cdot IDR(T_{beef})$
Drinking Water:	$IDR(T_{beef})$
Correction for Radioactive Decay and Progeny Ingrowth -- Milk, Poultry, Eggs	
Trace Soil Ingestion:	$[T_{irr} + T_{no} \cdot IDR(T_{no})]/T_{ing}$
Fresh Grass:	$[T_{irr} + T_{no} \cdot IDR(T_{no})]/T_{ing}$
Stored Hay and Grain:	$DR(T_s) \cdot IDR(T_{an})$
Drinking Water:	no decay

Notes: Beef is harvested and consumed over a period of time. Milk, poultry, and eggs are consumed continuously during the year. The decay factors are unitless fractions shown in Equation (37). Progeny ingrowth is computed using the method shown in Section 3.1.4.

Explanation of Symbols Used in Table 32.

$C_{w,H3}$ = concentration of tritium (H-3) in the irrigation water, in pCi/L.

$D_{ing,H3}$ = ingestion dose factor for tritium, in mrem per pCi ingested. Value is given in Table 7.

F_q = equilibrium transfer factor for animal product q for tritium, in d/kg (or d/L for milk). Value is given in Table 22.

F_{Hs} = fraction of hydrogen in garden soil. The value used is listed in Table 23. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.

F_{Hp} = fraction of hydrogen in plant type p. Values are listed in Table 23. The factor of 8.94 converts the hydrogen fraction to an effective water fraction that includes organically bound hydrogen.

I = total irrigation water applied to the soil during the irrigation season, 82.3 cm/y (63.5 for populations).

p = index for animal fodder. There are 3 types of animal fodder, fresh grass, stored hay, and stored grain.

P = total natural precipitation water reaching the surface soil during the irrigation period, 5.23 cm/y (PNNL-12087).

q = index for animal products. There are 4 types of animal products, beef, milk, poultry, and eggs.

Q_{aq} = quantity of animal product q eaten by the person during the year, in kg/y (or L/y for milk). See Tables 13 and 14 for values.

Q_{pq} = quantity of fodder type p eaten by the animal during the year, in kg/y. See Table 21 for values.

Q_{sq} = quantity of contaminated soil ingested by the animal associated with animal product q each day, in kg/d. See Table 21 for values.

Q_{wq} = quantity of contaminated drinking water ingested by the animal associated with animal product q each day, in L/d. See Table 21 for values.

T_{an} = time period over which stored hay and grain are consumed by the milk cow and chickens. Assumed to be the same as T_{veg}, 90 d.

T_{beef} = consumption period for beef cattle, assumed to be 120 days.

T_{ing} = ingestion exposure time of the individual, 1 y.

T_{irr} = irrigation period in years. The value of 0.5 yr is assumed based on current practices near the Hanford Site. $T_{no} = 1y - T_{irr}$

T_s = storage time for the stored feed (hay and grain), 90 d.

4.0 SCENARIO DOSE FACTORS

The tables in this section provide unit dose factors for each exposure scenario. The intrusion scenarios (no water infiltration) are given in Tables 33 and 34. The ground water scenarios are given in Tables 35 to 39. The population dose from use of contaminated drinking water is given in Table 40. Finally, Table 41 provides a comparison of the total dose to the drinking water dose for each scenario. The dose from the drinking water is the largest contributor for most nuclides.

The intrusion scenarios separate the external and internal doses to facilitate calculation of doses for an exhumed waste matrix that retains a portion of the radioactivity in a form that is not able to produce inhalation or ingestion doses (i.e., pieces of glass). The external dose depends only the amount exhumed. The internal dose also depends on the fraction that has decomposed and is available to produce inhalation and ingestion doses.

The irrigation scenarios are bounded by the NASR (Table 39). The next largest dose factors are for the HSRAM Agricultural and All Pathways Farmer (Tables 37 and 38). The traditional All Pathways Farmer doses are generally lower than those for the HSRAM Agricultural. Exceptions are for Gd-152, Ac-227, Th-229, Th-230, Th-232, and U-232, largely due to the strong inhalation dose component.

The comparison ratios in Table 41 are the total dose divided by the drinking water dose for each of the irrigation scenarios. The HSRAM Industrial scenario is not listed in Table 41 because the largest ratio was for Gd-152 (1.13). All other nuclide ratios were less than 1.06.

As indicated in DOE M 435.1-1 Chapter IV, the use of representative exposure scenarios is desired to avoid overly conservative assumptions. Thus the Post-Intrusion Resident (Table 34) should be used for evaluating compliance with the performance objectives for intruders. In addition, the All Pathways Farmer (Table 38) should be used for the groundwater performance objectives.

To bound the uncertainties associated with the various scenario parameters, the Native American Subsistence Residence case was created. Unit dose factors for this individual should be used to indicate an upper bound on the potential doses resulting from ground water contamination.

Table 33. No Water Infiltration Case: Intruder

Nuclide	External	Internal	Ingest	Inhale
H-3	0.00	1.44E-03	1.42E-03	2.05E-05
Be-10	2.15E-01	1.79E-01	1.04E-01	7.55E-02
C-14	2.73E-03	4.69E-02	4.64E-02	4.46E-04
Na-22	2.39E+03	2.57E-01	2.56E-01	1.63E-03
Si-32+D	2.28E+00	4.64E-01	2.44E-01	2.20E-01
Cl-36	4.64E-01	7.20E-02	6.73E-02	4.67E-03
K-40	1.73E+02	4.16E-01	4.13E-01	2.65E-03
Ti-44+D	2.40E+03	6.43E-01	5.47E-01	9.64E-02
V-49	0.00	1.44E-03	1.36E-03	7.36E-05

Table 33. No Water Infiltration Case: Intruder

Nuclide	External	Internal	Ingest	Inhale
Mn-54	9.08E+02	6.30E-02	6.16E-02	1.43E-03
Fe-55	0.00	1.41E-02	1.35E-02	5.74E-04
Co-60	2.75E+03	6.44E-01	5.98E-01	4.67E-02
Ni-59	0.00	4.95E-03	4.67E-03	2.82E-04
Ni-63	0.00	1.35E-02	1.28E-02	6.61E-04
Se-79	3.78E-03	1.95E-01	1.93E-01	2.10E-03
Rb-87	2.85E-02	1.10E-01	1.09E-01	6.89E-04
Sr-90+D	4.68E+00	3.45E+00	3.40E+00	5.29E-02
Zr-93	0.00	1.05E-01	3.69E-02	6.85E-02
Nb-91	2.30E+00	1.78E-02	1.16E-02	6.23E-03
Nb-93m	2.11E-02	1.78E-02	1.16E-02	6.23E-03
Nb-94	1.72E+03	2.47E-01	1.59E-01	8.83E-02
Mo-93	1.20E-01	3.61E-02	3.00E-02	6.06E-03
Tc-99	2.54E-02	3.42E-02	3.24E-02	1.78E-03
Ru-106+D	2.33E+02	7.11E-01	6.09E-01	1.02E-01
Pd-107	0.00	6.04E-03	3.31E-03	2.73E-03
Ag-108m+D	1.75E+03	2.30E-01	1.69E-01	6.04E-02
Cd-109	2.99E+00	3.15E-01	2.91E-01	2.43E-02
Cd-113m	1.30E-01	3.90E+00	3.58E+00	3.26E-01
In-115	8.04E-02	4.31E+00	3.51E+00	7.98E-01
Sn-121m+D	4.28E-01	5.25E-02	5.00E-02	2.54E-03
Sn-126+D	2.14E+03	4.90E-01	4.69E-01	2.15E-02
Sb-125	4.48E+02	6.50E-02	6.24E-02	2.60E-03
Te-125m	3.07E+00	8.31E-02	8.16E-02	1.56E-03
I-129	2.63E+00	6.17E+00	6.13E+00	3.71E-02
Cs-134	1.70E+03	1.64E+00	1.63E+00	9.88E-03
Cs-135	7.76E-03	1.58E-01	1.57E-01	9.71E-04
Cs-137+D	6.12E+02	1.12E+00	1.11E+00	6.81E-03
Ba-133	3.74E+02	7.72E-02	7.56E-02	1.67E-03

Table 33. No Water Infiltration Case: Intruder

Nuclide	External	Internal	Ingest	Inhale
Pm-147	1.01E-02	3.17E-02	2.33E-02	8.36E-03
Sm-147	0.00	2.00E+01	4.11E+00	1.59E+01
Sm-151	2.00E-04	1.50E-02	8.64E-03	6.40E-03
Eu-150	1.58E+03	1.99E-01	1.41E-01	5.72E-02
Eu-152	1.22E+03	1.91E-01	1.44E-01	4.71E-02
Eu-154	1.34E+03	2.73E-01	2.12E-01	6.10E-02
Eu-155	3.70E+01	4.28E-02	3.40E-02	8.83E-03
Gd-152	0.00	5.54E+01	3.58E+00	5.18E+01
Ho-166m	1.86E+03	3.44E-01	1.79E-01	1.65E-01
Re-187	0.00	2.23E-04	2.11E-04	1.16E-05
Tl-204	8.16E-01	7.52E-02	7.47E-02	5.14E-04
Pb-205	1.43E-03	3.71E-02	3.62E-02	8.36E-04
Pb-210+D	1.20E+00	1.22E+02	1.19E+02	2.94E+00
Bi-207	1.64E+03	1.26E-01	1.22E-01	4.27E-03
Po-209	3.58E+00	5.54E+01	5.29E+01	2.52E+00
Po-210	9.28E-03	4.42E+01	4.22E+01	2.01E+00
Ra-226+D	1.91E+03	3.14E+01	2.96E+01	1.83E+00
Ra-228+D	1.05E+03	3.31E+01	3.20E+01	1.08E+00
Ac-227+D	3.84E+02	1.76E+03	3.29E+02	1.43E+03
Th-228+D	1.68E+03	9.16E+01	1.80E+01	7.36E+01
Th-229+D	2.99E+02	5.50E+02	8.96E+01	4.61E+02
Th-230	2.42E-01	8.17E+01	1.22E+01	6.95E+01
Th-232	1.05E-01	4.11E+02	6.07E+01	3.50E+02
Pa-231	3.64E+01	5.09E+02	2.36E+02	2.73E+02
U-232	1.81E-01	1.70E+02	2.91E+01	1.41E+02
U-233	2.74E-01	3.52E+01	6.42E+00	2.88E+01
U-234	8.12E-02	3.44E+01	6.29E+00	2.82E+01
U-235+D	1.50E+02	3.22E+01	5.93E+00	2.62E+01
U-236	4.32E-02	3.26E+01	5.98E+00	2.67E+01

Table 33. No Water Infiltration Case: Intruder

Nuclide	External	Internal	Ingest	Inhale
U-238+D	2.41E+01	3.11E+01	5.96E+00	2.52E+01
Np-237+D	2.11E+02	2.14E+02	9.87E+01	1.15E+02
Pu-236	4.56E-02	5.69E+01	2.60E+01	3.09E+01
Pu-238	3.06E-02	1.55E+02	7.11E+01	8.36E+01
Pu-239	5.76E-02	1.70E+02	7.87E+01	9.15E+01
Pu-240	2.97E-02	1.70E+02	7.87E+01	9.15E+01
Pu-241+D	3.78E-03	3.28E+00	1.52E+00	1.76E+00
Pu-242	2.60E-02	1.62E+02	7.47E+01	8.77E+01
Pu-244+D	3.62E+02	1.60E+02	7.38E+01	8.60E+01
Am-241	8.88E+00	1.76E+02	8.09E+01	9.47E+01
Am-242m+D	1.33E+01	1.69E+02	7.82E+01	9.09E+01
Am-243+D	1.77E+02	1.75E+02	8.07E+01	9.39E+01
Cm-242	3.44E-02	6.25E+00	2.56E+00	3.69E+00
Cm-243	1.14E+02	1.21E+02	5.58E+01	6.55E+01
Cm-244	2.56E-02	9.78E+01	4.49E+01	5.29E+01
Cm-245	6.84E+01	1.80E+02	8.31E+01	9.71E+01
Cm-246	2.36E-02	1.78E+02	8.22E+01	9.62E+01
Cm-247+D	3.50E+02	1.64E+02	7.60E+01	8.83E+01
Cm-248	1.78E-02	6.54E+02	3.02E+02	3.52E+02
Cm-250+D	3.42E+02	3.73E+03	1.73E+03	2.01E+03
Bk-247	8.56E+01	2.27E+02	1.04E+02	1.22E+02
Cf-248	2.53E-02	1.82E+01	7.42E+00	1.08E+01
Cf-249	3.48E+02	2.28E+02	1.05E+02	1.23E+02
Cf-250	2.40E-02	1.03E+02	4.73E+01	5.59E+01
Cf-251	1.05E+02	2.33E+02	1.08E+02	1.25E+02
Cf-252	3.56E-02	5.75E+01	2.40E+01	3.35E+01

Units are mrem per Ci exhumed.
The "Internal" column is the sum of the "Inhale" and "Ingest" columns. External and internal doses are separated because the glass waste matrix will prevent a portion of the exhumed activity from contributing to the internal dose.

Table 34. No Water Infiltration Case: Post-Intrusion Resident

Nuclide	External	Internal	Garden	Ingest	Inhale
H-3	0.00	1.46E+02	1.46E+02	2.37E-02	5.58E-04
Be-10	2.41E+00	1.65E+01	8.21E+00	3.78E+00	4.50E+00
C-14	3.00E-02	7.20E+02	7.19E+02	1.65E+00	2.60E-02
Na-22	2.36E+04	3.05E+02	2.97E+02	8.17E+00	8.54E-02
Si-32+D	2.55E+01	4.39E+02	4.17E+02	8.86E+00	1.30E+01
Cl-36	4.78E+00	9.96E+04	9.96E+04	2.25E+00	2.56E-01
K-40	1.93E+03	5.16E+03	5.15E+03	1.49E+01	1.56E-01
Ti-44+D	2.68E+04	8.57E+01	6.02E+01	1.98E+01	5.71E+00
V-49	0.00	1.54E-01	1.16E-01	3.50E-02	3.09E-03
Mn-54	6.98E+03	2.64E+02	2.62E+02	1.54E+00	5.83E-02
Fe-55	0.00	1.28E+00	8.15E-01	4.34E-01	3.02E-02
Co-60	2.89E+04	1.86E+02	1.63E+02	2.04E+01	2.61E+00
Ni-59	0.00	4.68E+00	4.49E+00	1.70E-01	1.68E-02
Ni-63	0.00	1.28E+01	1.23E+01	4.66E-01	3.93E-02
Se-79	4.24E-02	1.24E+02	1.16E+02	7.05E+00	1.25E-01
Rb-87	3.20E-01	1.83E+02	1.79E+02	3.98E+00	4.10E-02
Sr-90+D	5.15E+01	2.00E+04	1.98E+04	1.21E+02	3.09E+00
Zr-93	5.03E-03	7.48E+00	2.03E+00	1.36E+00	4.09E+00
Nb-91	2.58E+01	2.65E+00	1.86E+00	4.23E-01	3.71E-01
Nb-93m	2.32E-01	2.61E+00	1.83E+00	4.14E-01	3.64E-01
Nb-94	1.93E+04	3.64E+01	2.54E+01	5.79E+00	5.27E+00
Mo-93	1.33E+00	4.47E+01	4.33E+01	1.09E+00	3.64E-01
Tc-99	1.69E-01	7.93E+02	7.92E+02	7.01E-01	6.28E-02
Ru-106+D	1.90E+03	2.29E+02	2.08E+02	1.61E+01	4.39E+00
Pd-107	0.00	3.52E+00	3.24E+00	1.20E-01	1.62E-01
Ag-108m+D	1.96E+04	3.02E+02	2.92E+02	6.15E+00	3.59E+00
Cd-109	2.58E+01	8.55E+02	8.45E+02	8.16E+00	1.11E+00
Cd-113m	1.42E+00	1.26E+04	1.24E+04	1.27E+02	1.89E+01

Table 34. No Water Infiltration Case: Post-Intrusion Resident

Nuclide	External	Internal	Garden	Ingest	Inhale
In-115	9.04E-01	3.61E+02	1.85E+02	1.28E+02	4.76E+01
Sn-121m+D	4.78E+00	1.12E+01	9.24E+00	1.81E+00	1.50E-01
Sn-126+D	2.41E+04	1.05E+02	8.71E+01	1.71E+01	1.28E+00
Sb-125	4.44E+03	3.57E+01	3.31E+01	2.48E+00	1.52E-01
Te-125m	7.80E+00	3.40E+00	2.71E+00	6.73E-01	2.10E-02
I-129	2.58E+01	6.70E+03	6.50E+03	1.95E+02	1.93E+00
Cs-134	1.62E+04	1.60E+03	1.55E+03	5.05E+01	5.00E-01
Cs-135	8.72E-02	1.75E+02	1.69E+02	5.73E+00	5.79E-02
Cs-137+D	6.80E+03	1.23E+03	1.19E+03	4.01E+01	4.01E-01
Ba-133	4.06E+03	3.43E+01	3.16E+01	2.66E+00	9.59E-02
Pm-147	1.00E-01	4.04E+00	2.85E+00	7.48E-01	4.38E-01
Sm-147	0.00	1.65E+03	5.52E+02	1.50E+02	9.51E+02
Sm-151	2.24E-03	1.85E+00	1.16E+00	3.14E-01	3.80E-01
Eu-150	1.76E+04	2.73E+01	1.89E+01	5.11E+00	3.38E+00
Eu-152	1.34E+04	2.69E+01	1.90E+01	5.12E+00	2.74E+00
Eu-154	1.44E+04	3.87E+01	2.77E+01	7.44E+00	3.50E+00
Eu-155	3.86E+02	5.97E+00	4.33E+00	1.15E+00	4.90E-01
Gd-152	0.00	3.70E+03	4.81E+02	1.30E+02	3.09E+03
Ho-166m	2.09E+04	4.05E+01	2.41E+01	6.54E+00	9.83E+00
Re-187	0.00	1.75E+00	1.74E+00	7.62E-03	6.85E-04
Tl-204	8.38E+00	6.22E+00	3.71E+00	2.49E+00	2.80E-02
Pb-205	1.61E-02	6.82E+00	5.45E+00	1.32E+00	4.99E-02
Pb-210+D	1.33E+01	2.47E+04	1.94E+04	5.11E+03	2.37E+02
Bi-207	1.83E+04	2.46E+01	2.00E+01	4.39E+00	2.52E-01
Po-209	4.01E+01	6.40E+03	4.33E+03	1.92E+03	1.50E+02
Po-210	4.79E-02	2.61E+03	1.85E+03	7.07E+02	5.49E+01
Ra-226+D	2.15E+04	4.79E+03	3.52E+03	1.15E+03	1.13E+02
Ra-228+D	1.40E+04	5.48E+03	3.54E+03	1.20E+03	7.40E+02
Ac-227+D	4.25E+03	1.13E+05	1.68E+04	1.18E+04	8.42E+04

Table 34. No Water Infiltration Case: Post-Intrusion Resident

Nuclide	External	Internal	Garden	Ingest	Inhale
Th-228+D	1.59E+04	4.97E+03	7.37E+02	5.52E+02	3.69E+03
Th-229+D	3.35E+03	3.49E+04	4.13E+03	3.27E+03	2.75E+04
Th-230	7.38E+00	5.16E+03	5.62E+02	4.45E+02	4.15E+03
Th-232	8.06E+02	2.61E+04	2.94E+03	2.29E+03	2.09E+04
Pa-231	4.78E+02	3.81E+04	1.17E+04	8.78E+03	1.76E+04
U-232	3.01E+03	1.38E+04	3.73E+03	1.15E+03	8.96E+03
U-233	3.21E+00	2.74E+03	8.05E+02	2.32E+02	1.70E+03
U-234	9.04E-01	2.68E+03	7.88E+02	2.27E+02	1.66E+03
U-235+D	1.66E+03	2.51E+03	7.44E+02	2.14E+02	1.55E+03
U-236	4.81E-01	2.54E+03	7.49E+02	2.16E+02	1.57E+03
U-238+D	2.61E+02	2.45E+03	7.46E+02	2.15E+02	1.49E+03
Np-237+D	2.30E+03	2.39E+04	1.38E+04	3.49E+03	6.66E+03
Pu-236	1.02E+01	3.60E+03	1.07E+03	8.49E+02	1.68E+03
Pu-238	3.43E-01	1.07E+04	3.11E+03	2.58E+03	4.97E+03
Pu-239	6.48E-01	1.18E+04	3.45E+03	2.87E+03	5.46E+03
Pu-240	3.34E-01	1.18E+04	3.45E+03	2.87E+03	5.46E+03
Pu-241+D	1.19E-01	2.31E+02	6.77E+01	5.66E+01	1.07E+02
Pu-242	2.92E-01	1.12E+04	3.28E+03	2.72E+03	5.23E+03
Pu-244+D	4.07E+03	1.11E+04	3.24E+03	2.69E+03	5.13E+03
Am-241	9.98E+01	1.23E+04	3.69E+03	2.95E+03	5.65E+03
Am-242m+D	1.47E+02	1.20E+04	3.60E+03	2.89E+03	5.51E+03
Am-243+D	1.99E+03	1.22E+04	3.68E+03	2.94E+03	5.60E+03
Cm-242	1.97E-01	2.52E+02	7.39E+01	5.39E+01	1.24E+02
Cm-243	1.27E+03	8.30E+03	2.43E+03	2.01E+03	3.86E+03
Cm-244	2.82E-01	6.65E+03	1.94E+03	1.61E+03	3.10E+03
Cm-245	7.69E+02	1.25E+04	3.65E+03	3.03E+03	5.80E+03
Cm-246	2.65E-01	1.23E+04	3.60E+03	3.00E+03	5.74E+03
Cm-247+D	3.93E+03	1.14E+04	3.33E+03	2.77E+03	5.27E+03
Cm-248	2.00E-01	4.53E+04	1.33E+04	1.10E+04	2.10E+04

Table 34. No Water Infiltration Case: Post-Intrusion Resident

Nuclide	External	Internal	Garden	Ingest	Inhale
Cm-250+D	3.85E+03	2.58E+05	7.57E+04	6.30E+04	1.20E+05
Bk-247	9.63E+02	1.58E+04	4.66E+03	3.81E+03	7.31E+03
Cf-248	2.04E-01	1.95E+03	1.24E+03	2.14E+02	4.99E+02
Cf-249	3.91E+03	3.38E+04	2.27E+04	3.84E+03	7.34E+03
Cf-250	2.63E-01	1.49E+04	1.00E+04	1.68E+03	3.25E+03
Cf-251	1.18E+03	3.46E+04	2.32E+04	3.93E+03	7.48E+03
Cf-252	3.53E-01	7.23E+03	4.70E+03	7.70E+02	1.76E+03

Units are mrem per Ci exhumed.
The "Internal" column is the sum of the "Garden", "Inhale", and "Ingest" columns. External and internal doses are separated because the glass waste matrix will prevent a portion of the exhumed activity from contributing to the internal dose.

Table 35. Low Water Infiltration Case: HSRAM Industrial

Nuclide	Total	Ingest	Inhale
H-3	1.62E-05	1.60E-05	2.02E-07
Be-10	1.17E-03	1.17E-03	7.43E-06
C-14	5.23E-04	5.23E-04	4.39E-08
Na-22	2.88E-03	2.88E-03	1.61E-07
Si-32+D	2.77E-03	2.75E-03	2.16E-05
Cl-36	7.58E-04	7.58E-04	4.60E-07
K-40	4.65E-03	4.65E-03	2.60E-07
Ti-44+D	6.16E-03	6.15E-03	9.49E-06
V-49	1.54E-05	1.54E-05	7.25E-09
Mn-54	6.93E-04	6.93E-04	1.41E-07
Fe-55	1.52E-04	1.52E-04	5.65E-08
Co-60	6.73E-03	6.73E-03	4.60E-06
Ni-59	5.25E-05	5.25E-05	2.77E-08
Ni-63	1.44E-04	1.44E-04	6.51E-08
Se-79	2.18E-03	2.18E-03	2.07E-07
Rb-87	1.23E-03	1.23E-03	6.78E-08
Sr-90+D	3.83E-02	3.83E-02	5.21E-06
Zr-93	4.22E-04	4.15E-04	6.74E-06
Nb-91	1.31E-04	1.31E-04	6.13E-07
Nb-93m	1.31E-04	1.31E-04	6.13E-07
Nb-94	1.79E-03	1.79E-03	8.69E-06
Mo-93	3.38E-04	3.38E-04	5.96E-07
Tc-99	3.65E-04	3.65E-04	1.75E-07
Ru-106+D	6.86E-03	6.85E-03	1.00E-05
Pd-107	3.75E-05	3.73E-05	2.69E-07
Ag-108m+D	1.91E-03	1.91E-03	5.94E-06
Cd-109	3.28E-03	3.28E-03	2.39E-06
Cd-113m	4.03E-02	4.03E-02	3.21E-05

Table 35. Low Water Infiltration Case: HSRAM Industrial

Nuclide	Total	Ingest	Inhale
In-115	3.96E-02	3.95E-02	7.85E-05
Sn-121m+D	5.63E-04	5.63E-04	2.50E-07
Sn-126+D	5.28E-03	5.28E-03	2.12E-06
Sb-125	7.03E-04	7.03E-04	2.56E-07
Te-125m	9.18E-04	9.18E-04	1.53E-07
I-129	6.90E-02	6.90E-02	3.65E-06
Cs-134	1.83E-02	1.83E-02	9.72E-07
Cs-135	1.77E-03	1.77E-03	9.56E-08
Cs-137+D	1.25E-02	1.25E-02	6.70E-07
Ba-133	8.50E-04	8.50E-04	1.64E-07
Pm-147	2.63E-04	2.63E-04	8.23E-07
Sm-147	4.78E-02	4.63E-02	1.57E-03
Sm-151	9.79E-05	9.73E-05	6.30E-07
Eu-150	1.60E-03	1.59E-03	5.63E-06
Eu-152	1.62E-03	1.62E-03	4.64E-06
Eu-154	2.39E-03	2.39E-03	6.01E-06
Eu-155	3.83E-04	3.83E-04	8.69E-07
Gd-152	4.54E-02	4.03E-02	5.10E-03
Ho-166m	2.03E-03	2.02E-03	1.62E-05
Re-187	2.38E-06	2.38E-06	1.14E-09
Tl-204	8.40E-04	8.40E-04	5.06E-08
Pb-205	4.08E-04	4.08E-04	8.23E-08
Pb-210+D	1.34E+00	1.34E+00	2.90E-04
Bi-207	1.37E-03	1.37E-03	4.20E-07
Po-209	5.95E-01	5.95E-01	2.48E-04
Po-210	4.75E-01	4.75E-01	1.97E-04
Ra-226+D	3.33E-01	3.33E-01	1.81E-04
Ra-228+D	3.60E-01	3.60E-01	1.07E-04
Ac-227+D	3.84E+00	3.70E+00	1.41E-01

Table 35. Low Water Infiltration Case: HSRAM Industrial

Nuclide	Total	Ingest	Inhale
Th-228+D	2.10E-01	2.03E-01	7.25E-03
Th-229+D	1.05E+00	1.01E+00	4.54E-02
Th-230	1.44E-01	1.37E-01	6.85E-03
Th-232	7.17E-01	6.83E-01	3.44E-02
Pa-231	2.68E+00	2.65E+00	2.69E-02
U-232	3.41E-01	3.28E-01	1.38E-02
U-233	7.51E-02	7.23E-02	2.84E-03
U-234	7.35E-02	7.08E-02	2.77E-03
U-235+D	6.93E-02	6.68E-02	2.58E-03
U-236	6.99E-02	6.73E-02	2.63E-03
U-238+D	6.95E-02	6.70E-02	2.48E-03
Np-237+D	1.12E+00	1.11E+00	1.13E-02
Pu-236	2.96E-01	2.93E-01	3.05E-03
Pu-238	8.08E-01	8.00E-01	8.23E-03
Pu-239	8.94E-01	8.85E-01	9.01E-03
Pu-240	8.94E-01	8.85E-01	9.01E-03
Pu-241+D	1.73E-02	1.71E-02	1.73E-04
Pu-242	8.49E-01	8.40E-01	8.63E-03
Pu-244+D	8.38E-01	8.30E-01	8.46E-03
Am-241	9.19E-01	9.10E-01	9.32E-03
Am-242m+D	8.89E-01	8.80E-01	8.95E-03
Am-243+D	9.17E-01	9.08E-01	9.24E-03
Cm-242	2.91E-02	2.88E-02	3.63E-04
Cm-243	6.34E-01	6.28E-01	6.45E-03
Cm-244	5.10E-01	5.05E-01	5.21E-03
Cm-245	9.45E-01	9.35E-01	9.56E-03
Cm-246	9.34E-01	9.25E-01	9.47E-03
Cm-247+D	8.64E-01	8.55E-01	8.69E-03
Cm-248	3.43E+00	3.40E+00	3.47E-02

Table 35. Low Water Infiltration Case: HSRAM Industrial

Nuclide	Total	Ingest	Inhale
Cm-250+D	1.96E+01	1.94E+01	1.97E-01
Bk-247	1.19E+00	1.18E+00	1.21E-02
Cf-248	8.46E-02	8.35E-02	1.06E-03
Cf-249	1.20E+00	1.19E+00	1.21E-02
Cf-250	5.38E-01	5.33E-01	5.50E-03
Cf-251	1.22E+00	1.21E+00	1.23E-02
Cf-252	2.73E-01	2.70E-01	3.30E-03

Units are mrem per pCi/L in the ground water.
The "Total" column is the sum of the "Ingest" and "Inhale" columns.

Table 36. Low Water Infiltration Case: HSRAM Residential

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
H-3	4.92E-05	4.67E-05	2.13E-06	2.98E-07	0.00
Be-10	3.89E-03	3.40E-03	4.79E-04	1.13E-05	2.32E-06
C-14	1.84E-03	1.53E-03	3.14E-04	6.69E-08	2.91E-08
Na-22	3.29E-02	8.40E-03	1.20E-03	2.44E-07	2.33E-02
Si-32+D	9.27E-03	8.03E-03	1.18E-03	3.30E-05	2.46E-05
Cl-36	1.64E-02	2.21E-03	1.42E-02	7.00E-07	4.77E-06
K-40	1.81E-02	1.36E-02	2.62E-03	3.97E-07	1.86E-03
Ti-44+D	4.63E-02	1.80E-02	2.53E-03	1.45E-05	2.58E-02
V-49	5.08E-05	4.48E-05	5.96E-06	1.10E-08	0.00
Mn-54	9.61E-03	2.02E-03	3.01E-04	2.13E-07	7.29E-03
Fe-55	5.04E-04	4.43E-04	6.11E-05	8.58E-08	0.00
Co-60	5.06E-02	1.96E-02	2.75E-03	7.00E-06	2.82E-02
Ni-59	1.75E-04	1.53E-04	2.22E-05	4.22E-08	0.00
Ni-63	4.82E-04	4.21E-04	6.08E-05	9.92E-08	0.00
Se-79	7.26E-03	6.35E-03	9.08E-04	3.15E-07	4.08E-08
Rb-87	4.12E-03	3.59E-03	5.29E-04	1.03E-07	3.08E-07
Sr-90+D	1.30E-01	1.12E-01	1.83E-02	7.93E-06	4.98E-05
Zr-93	1.39E-03	1.21E-03	1.71E-04	1.03E-05	3.77E-09
Nb-91	4.61E-04	3.81E-04	5.38E-05	9.34E-07	2.48E-05
Nb-93m	4.36E-04	3.81E-04	5.36E-05	9.34E-07	2.24E-07
Nb-94	2.45E-02	5.21E-03	7.36E-04	1.32E-05	1.85E-02
Mo-93	1.13E-03	9.86E-04	1.45E-04	9.09E-07	1.28E-06
Tc-99	1.31E-03	1.07E-03	2.44E-04	2.64E-07	2.02E-07
Ru-106+D	2.47E-02	2.00E-02	2.69E-03	1.52E-05	1.96E-03
Pd-107	1.25E-04	1.09E-04	1.57E-05	4.10E-07	0.00
Ag-108m+D	2.52E-02	5.56E-03	8.19E-04	9.06E-06	1.88E-02
Cd-109	1.10E-02	9.56E-03	1.40E-03	3.63E-06	2.63E-05

Table 36. Low Water Infiltration Case: HSRAM Residential

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cd-113m	1.36E-01	1.18E-01	1.81E-02	4.89E-05	1.37E-06
In-115	1.32E-01	1.15E-01	1.62E-02	1.20E-04	8.69E-07
Sn-121m+D	1.88E-03	1.64E-03	2.32E-04	3.81E-07	4.60E-06
Sn-126+D	4.07E-02	1.54E-02	2.18E-03	3.23E-06	2.32E-02
Sb-125	6.76E-03	2.05E-03	3.08E-04	3.90E-07	4.40E-03
Te-125m	2.97E-03	2.68E-03	2.84E-04	2.28E-07	9.67E-06
I-129	2.31E-01	2.01E-01	2.92E-02	5.55E-06	2.62E-05
Cs-134	7.72E-02	5.35E-02	7.59E-03	1.48E-06	1.61E-02
Cs-135	5.92E-03	5.16E-03	7.54E-04	1.46E-07	8.39E-08
Cs-137+D	4.84E-02	3.65E-02	5.32E-03	1.02E-06	6.56E-03
Ba-133	6.77E-03	2.48E-03	3.51E-04	2.50E-07	3.94E-03
Pm-147	8.74E-04	7.67E-04	1.06E-04	1.25E-06	9.89E-08
Sm-147	1.56E-01	1.35E-01	1.90E-02	2.39E-03	0.00
Sm-151	3.25E-04	2.84E-04	4.00E-05	9.60E-07	2.15E-09
Eu-150	2.23E-02	4.64E-03	6.54E-04	8.57E-06	1.70E-02
Eu-152	1.83E-02	4.73E-03	6.64E-04	7.07E-06	1.29E-02
Eu-154	2.20E-02	6.97E-03	9.77E-04	9.14E-06	1.40E-02
Eu-155	1.65E-03	1.12E-03	1.56E-04	1.32E-06	3.77E-04
Gd-152	1.42E-01	1.18E-01	1.66E-02	7.78E-03	0.00
Ho-166m	2.68E-02	5.89E-03	8.31E-04	2.47E-05	2.01E-02
Re-187	8.16E-06	6.94E-06	1.21E-06	1.74E-09	0.00
Tl-204	2.80E-03	2.45E-03	3.40E-04	7.70E-08	8.22E-06
Pb-205	1.36E-03	1.19E-03	1.68E-04	1.25E-07	1.55E-08
Pb-210+D	4.50E+00	3.92E+00	5.76E-01	4.46E-04	1.29E-05
Bi-207	2.22E-02	4.00E-03	5.64E-04	6.40E-07	1.76E-02
Po-209	1.98E+00	1.74E+00	2.44E-01	3.78E-04	3.86E-05
Po-210	1.56E+00	1.39E+00	1.71E-01	2.96E-04	5.39E-08
Ra-226+D	1.13E+00	9.71E-01	1.38E-01	2.75E-04	2.07E-02

Table 36. Low Water Infiltration Case: HSRAM Residential

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Ra-228+D	1.21E+00	1.05E+00	1.49E-01	2.05E-04	1.31E-02
Ac-227+D	1.25E+01	1.08E+01	1.52E+00	2.15E-01	4.10E-03
Th-228+D	7.00E-01	5.92E-01	8.10E-02	1.10E-02	1.58E-02
Th-229+D	3.43E+00	2.94E+00	4.14E-01	6.91E-02	3.22E-03
Th-230	4.67E-01	4.00E-01	5.63E-02	1.04E-02	6.10E-06
Th-232	2.33E+00	1.99E+00	2.82E-01	5.25E-02	5.91E-04
Pa-231	8.87E+00	7.74E+00	1.09E+00	4.10E-02	4.45E-04
U-232	1.12E+00	9.56E-01	1.37E-01	2.11E-02	2.31E-03
U-233	2.45E-01	2.11E-01	2.97E-02	4.32E-03	3.07E-06
U-234	2.40E-01	2.07E-01	2.91E-02	4.22E-03	8.72E-07
U-235+D	2.28E-01	1.95E-01	2.75E-02	3.94E-03	1.61E-03
U-236	2.28E-01	1.96E-01	2.77E-02	4.00E-03	4.64E-07
U-238+D	2.27E-01	1.96E-01	2.76E-02	3.78E-03	2.52E-04
Np-237+D	3.72E+00	3.24E+00	4.57E-01	1.73E-02	2.24E-03
Pu-236	9.77E-01	8.54E-01	1.18E-01	4.63E-03	6.45E-06
Pu-238	2.68E+00	2.34E+00	3.28E-01	1.25E-02	3.30E-07
Pu-239	2.96E+00	2.58E+00	3.63E-01	1.37E-02	6.23E-07
Pu-240	2.96E+00	2.58E+00	3.63E-01	1.37E-02	3.21E-07
Pu-241+D	5.73E-02	5.00E-02	7.05E-03	2.64E-04	9.84E-08
Pu-242	2.81E+00	2.45E+00	3.45E-01	1.32E-02	2.81E-07
Pu-244+D	2.78E+00	2.42E+00	3.41E-01	1.29E-02	3.91E-03
Am-241	3.05E+00	2.66E+00	3.74E-01	1.42E-02	9.60E-05
Am-242m+D	2.95E+00	2.57E+00	3.62E-01	1.36E-02	1.42E-04
Am-243+D	3.04E+00	2.65E+00	3.73E-01	1.41E-02	1.91E-03
Cm-242	9.52E-02	8.40E-02	1.07E-02	5.47E-04	2.18E-07
Cm-243	2.10E+00	1.83E+00	2.57E-01	9.82E-03	1.23E-03
Cm-244	1.69E+00	1.47E+00	2.07E-01	7.93E-03	2.72E-07
Cm-245	3.13E+00	2.73E+00	3.84E-01	1.46E-02	7.40E-04

Table 36. Low Water Infiltration Case: HSRAM Residential

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cm-246	3.10E+00	2.70E+00	3.80E-01	1.44E-02	2.55E-07
Cm-247+D	2.86E+00	2.50E+00	3.51E-01	1.32E-02	3.78E-03
Cm-248	1.14E+01	9.93E+00	1.40E+00	5.28E-02	1.92E-07
Cm-250+D	6.50E+01	5.67E+01	7.98E+00	3.01E-01	3.70E-03
Bk-247	3.93E+00	3.43E+00	4.83E-01	1.84E-02	9.25E-04
Cf-248	2.79E-01	2.44E-01	3.31E-02	1.61E-03	2.10E-07
Cf-249	3.97E+00	3.46E+00	4.89E-01	1.85E-02	3.76E-03
Cf-250	1.78E+00	1.55E+00	2.19E-01	8.38E-03	2.55E-07
Cf-251	4.06E+00	3.54E+00	5.00E-01	1.88E-02	1.13E-03
Cf-252	9.03E-01	7.88E-01	1.09E-01	5.01E-03	3.49E-07

Units are mrem per pCi/L in the ground water.

Table 37. Low Water Infiltration Case: HSRAM Agricultural

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
H-3	5.73E-05	4.67E-05	1.03E-05	2.98E-07	0.00
Be-10	3.99E-03	3.40E-03	5.79E-04	1.13E-05	2.32E-06
C-14	6.44E-03	1.53E-03	4.92E-03	6.69E-08	2.91E-08
Na-22	8.82E-02	8.40E-03	5.65E-02	2.44E-07	2.33E-02
Si-32+D	9.30E-03	8.03E-03	1.22E-03	3.30E-05	2.46E-05
Cl-36	5.81E-02	2.21E-03	5.59E-02	7.00E-07	4.77E-06
K-40	4.09E-02	1.36E-02	2.55E-02	3.97E-07	1.86E-03
Ti-44+D	8.79E-02	1.80E-02	4.41E-02	1.45E-05	2.58E-02
V-49	5.31E-05	4.48E-05	8.25E-06	1.10E-08	0.00
Mn-54	9.73E-03	2.02E-03	4.18E-04	2.13E-07	7.29E-03
Fe-55	7.20E-04	4.43E-04	2.77E-04	8.58E-08	0.00
Co-60	6.57E-02	1.96E-02	1.79E-02	7.00E-06	2.82E-02
Ni-59	2.22E-04	1.53E-04	6.90E-05	4.22E-08	0.00
Ni-63	6.11E-04	4.21E-04	1.89E-04	9.92E-08	0.00
Se-79	1.44E-02	6.35E-03	8.10E-03	3.15E-07	4.08E-08
Rb-87	1.14E-02	3.59E-03	7.78E-03	1.03E-07	3.08E-07
Sr-90+D	1.60E-01	1.12E-01	4.81E-02	7.93E-06	4.98E-05
Zr-93	1.60E-03	1.21E-03	3.74E-04	1.03E-05	3.77E-09
Nb-91	3.91E-03	3.81E-04	3.50E-03	9.34E-07	2.48E-05
Nb-93m	3.84E-03	3.81E-04	3.46E-03	9.34E-07	2.24E-07
Nb-94	7.17E-02	5.21E-03	4.79E-02	1.32E-05	1.85E-02
Mo-93	1.56E-03	9.86E-04	5.72E-04	9.09E-07	1.28E-06
Tc-99	5.83E-03	1.07E-03	4.77E-03	2.64E-07	2.02E-07
Ru-106+D	2.54E-02	2.00E-02	3.44E-03	1.52E-05	1.95E-03
Pd-107	3.13E-04	1.09E-04	2.04E-04	4.10E-07	0.00
Ag-108m+D	4.37E-02	5.56E-03	1.93E-02	9.06E-06	1.88E-02
Cd-109	1.27E-02	9.56E-03	3.06E-03	3.63E-06	2.63E-05

Table 37. Low Water Infiltration Case: HSRAM Agricultural

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cd-113m	1.58E-01	1.18E-01	4.06E-02	4.89E-05	1.37E-06
In-115	1.55E-01	1.15E-01	4.00E-02	1.20E-04	8.69E-07
Sn-121m+D	5.19E-03	1.64E-03	3.54E-03	3.81E-07	4.60E-06
Sn-126+D	7.19E-02	1.54E-02	3.33E-02	3.23E-06	2.32E-02
Sb-125	6.99E-03	2.05E-03	5.35E-04	3.90E-07	4.40E-03
Te-125m	3.28E-03	2.68E-03	5.96E-04	2.28E-07	9.67E-06
I-129	5.92E-01	2.01E-01	3.90E-01	5.55E-06	2.62E-05
Cs-134	1.60E-01	5.35E-02	9.07E-02	1.48E-06	1.61E-02
Cs-135	1.46E-02	5.16E-03	9.42E-03	1.46E-07	8.39E-08
Cs-137+D	1.09E-01	3.65E-02	6.63E-02	1.02E-06	6.56E-03
Ba-133	6.92E-03	2.48E-03	5.00E-04	2.50E-07	3.94E-03
Pm-147	9.57E-04	7.67E-04	1.89E-04	1.25E-06	9.89E-08
Sm-147	1.73E-01	1.35E-01	3.51E-02	2.39E-03	0.00
Sm-151	3.59E-04	2.84E-04	7.38E-05	9.60E-07	2.15E-09
Eu-150	2.28E-02	4.64E-03	1.20E-03	8.57E-06	1.70E-02
Eu-152	1.89E-02	4.73E-03	1.22E-03	7.07E-06	1.29E-02
Eu-154	2.28E-02	6.97E-03	1.79E-03	9.14E-06	1.40E-02
Eu-155	1.78E-03	1.12E-03	2.84E-04	1.32E-06	3.77E-04
Gd-152	1.52E-01	1.18E-01	2.65E-02	7.78E-03	0.00
Ho-166m	2.74E-02	5.89E-03	1.46E-03	2.47E-05	2.01E-02
Re-187	1.13E-05	6.94E-06	4.39E-06	1.74E-09	0.00
Tl-204	5.72E-03	2.45E-03	3.26E-03	7.70E-08	8.22E-06
Pb-205	1.42E-03	1.19E-03	2.28E-04	1.25E-07	1.55E-08
Pb-210+D	4.72E+00	3.92E+00	8.00E-01	4.46E-04	1.29E-05
Bi-207	2.26E-02	4.00E-03	9.31E-04	6.40E-07	1.76E-02
Po-209	2.12E+00	1.74E+00	3.80E-01	3.78E-04	3.86E-05
Po-210	1.64E+00	1.39E+00	2.52E-01	2.96E-04	5.39E-08
Ra-226+D	1.21E+00	9.71E-01	2.17E-01	2.75E-04	2.07E-02

Table 37. Low Water Infiltration Case: HSRAM Agricultural

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Ra-228+D	1.30E+00	1.05E+00	2.31E-01	2.05E-04	1.31E-02
Ac-227+D	1.26E+01	1.08E+01	1.56E+00	2.15E-01	4.10E-03
Th-228+D	7.00E-01	5.92E-01	8.15E-02	1.10E-02	1.58E-02
Th-229+D	3.43E+00	2.94E+00	4.17E-01	6.91E-02	3.22E-03
Th-230	4.67E-01	4.00E-01	5.67E-02	1.04E-02	6.10E-06
Th-232	2.33E+00	1.99E+00	2.86E-01	5.25E-02	5.91E-04
Pa-231	8.88E+00	7.74E+00	1.10E+00	4.10E-02	4.45E-04
U-232	1.23E+00	9.56E-01	2.52E-01	2.11E-02	2.31E-03
U-233	2.71E-01	2.11E-01	5.53E-02	4.32E-03	3.07E-06
U-234	2.65E-01	2.07E-01	5.41E-02	4.22E-03	8.72E-07
U-235+D	2.52E-01	1.95E-01	5.10E-02	3.94E-03	1.61E-03
U-236	2.52E-01	1.96E-01	5.14E-02	4.00E-03	4.64E-07
U-238+D	2.51E-01	1.96E-01	5.12E-02	3.78E-03	2.52E-04
Np-237+D	3.72E+00	3.24E+00	4.64E-01	1.73E-02	2.24E-03
Pu-236	9.77E-01	8.54E-01	1.18E-01	4.63E-03	6.45E-06
Pu-238	2.68E+00	2.34E+00	3.28E-01	1.25E-02	3.30E-07
Pu-239	2.96E+00	2.58E+00	3.64E-01	1.37E-02	6.23E-07
Pu-240	2.96E+00	2.58E+00	3.64E-01	1.37E-02	3.21E-07
Pu-241+D	5.73E-02	5.00E-02	7.05E-03	2.64E-04	9.84E-08
Pu-242	2.81E+00	2.45E+00	3.45E-01	1.32E-02	2.81E-07
Pu-244+D	2.78E+00	2.42E+00	3.41E-01	1.29E-02	3.91E-03
Am-241	3.05E+00	2.66E+00	3.74E-01	1.42E-02	9.60E-05
Am-242m+D	2.95E+00	2.57E+00	3.63E-01	1.36E-02	1.42E-04
Am-243+D	3.04E+00	2.65E+00	3.73E-01	1.41E-02	1.91E-03
Cm-242	9.54E-02	8.40E-02	1.09E-02	5.47E-04	2.18E-07
Cm-243	2.11E+00	1.83E+00	2.63E-01	9.82E-03	1.23E-03
Cm-244	1.69E+00	1.47E+00	2.12E-01	7.93E-03	2.72E-07
Cm-245	3.14E+00	2.73E+00	3.93E-01	1.46E-02	7.40E-04

Table 37. Low Water Infiltration Case: HSRAM Agricultural

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cm-246	3.10E+00	2.70E+00	3.89E-01	1.44E-02	2.55E-07
Cm-247+D	2.87E+00	2.50E+00	3.60E-01	1.32E-02	3.78E-03
Cm-248	1.14E+01	9.93E+00	1.43E+00	5.28E-02	1.92E-07
Cm-250+D	6.52E+01	5.67E+01	8.17E+00	3.01E-01	3.70E-03
Bk-247	3.93E+00	3.43E+00	4.83E-01	1.84E-02	9.25E-04
Cf-248	3.01E-01	2.44E-01	5.51E-02	1.61E-03	2.10E-07
Cf-249	4.37E+00	3.46E+00	8.90E-01	1.85E-02	3.76E-03
Cf-250	1.96E+00	1.55E+00	3.96E-01	8.38E-03	2.55E-07
Cf-251	4.47E+00	3.54E+00	9.11E-01	1.88E-02	1.13E-03
Cf-252	9.86E-01	7.88E-01	1.93E-01	5.01E-03	3.49E-07

Units are mrem per pCi/L in the ground water.

Table 38. Low Water Infiltration Case: All Pathways Farmer

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
H-3	4.58E-05	3.46E-05	7.04E-06	4.18E-06	0.00
Be-10	3.19E-03	2.52E-03	6.42E-04	3.03E-05	1.37E-06
C-14	4.67E-03	1.13E-03	3.54E-03	1.79E-07	1.71E-08
Na-22	5.21E-02	6.21E-03	3.22E-02	6.54E-07	1.37E-02
Si-32+D	7.42E-03	5.94E-03	1.38E-03	8.81E-05	1.44E-05
Cl-36	4.81E-02	1.64E-03	4.65E-02	1.87E-06	2.80E-06
K-40	2.83E-02	1.00E-02	1.72E-02	1.06E-06	1.10E-03
Ti-44+D	5.70E-02	1.33E-02	2.85E-02	3.87E-05	1.52E-02
V-49	4.26E-05	3.32E-05	9.42E-06	2.94E-08	0.00
Mn-54	6.19E-03	1.50E-03	4.11E-04	5.71E-07	4.28E-03
Fe-55	6.05E-04	3.28E-04	2.77E-04	2.30E-07	0.00
Co-60	4.57E-02	1.45E-02	1.46E-02	1.87E-05	1.66E-02
Ni-59	1.71E-04	1.13E-04	5.80E-05	1.13E-07	0.00
Ni-63	4.71E-04	3.12E-04	1.59E-04	2.65E-07	0.00
Se-79	1.15E-02	4.70E-03	6.80E-03	8.42E-07	2.40E-08
Rb-87	7.50E-03	2.66E-03	4.84E-03	2.76E-07	1.81E-07
Sr-90+D	1.19E-01	8.26E-02	3.59E-02	2.12E-05	2.93E-05
Zr-93	1.30E-03	8.96E-04	3.81E-04	2.75E-05	2.22E-09
Nb-91	3.06E-03	2.82E-04	2.76E-03	2.50E-06	1.46E-05
Nb-93m	3.01E-03	2.82E-04	2.73E-03	2.50E-06	1.32E-07
Nb-94	5.26E-02	3.86E-03	3.78E-02	3.54E-05	1.09E-02
Mo-93	1.19E-03	7.29E-04	4.62E-04	2.43E-06	7.55E-07
Tc-99	3.54E-03	7.88E-04	2.75E-03	7.09E-07	1.19E-07
Ru-106+D	1.98E-02	1.48E-02	3.78E-03	4.06E-05	1.15E-03
Pd-107	1.93E-04	8.05E-05	1.11E-04	1.10E-06	0.00
Ag-108m+D	2.51E-02	4.11E-03	9.89E-03	2.42E-05	1.11E-02
Cd-109	9.60E-03	7.07E-03	2.50E-03	9.72E-06	1.54E-05

Table 38. Low Water Infiltration Case: All Pathways Farmer

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cd-113m	1.20E-01	8.69E-02	3.29E-02	1.31E-04	8.06E-07
In-115	1.27E-01	8.53E-02	4.17E-02	3.20E-04	5.11E-07
Sn-121m+D	4.54E-03	1.22E-03	3.32E-03	1.02E-06	2.71E-06
Sn-126+D	5.63E-02	1.14E-02	3.13E-02	8.64E-06	1.36E-02
Sb-125	4.66E-03	1.52E-03	5.55E-04	1.04E-06	2.58E-03
Te-125m	2.77E-03	1.98E-03	7.86E-04	6.16E-07	5.68E-06
I-129	3.77E-01	1.49E-01	2.27E-01	1.49E-05	1.54E-05
Cs-134	1.10E-01	3.96E-02	6.07E-02	3.95E-06	9.49E-03
Cs-135	1.01E-02	3.82E-03	6.32E-03	3.89E-07	4.93E-08
Cs-137+D	7.53E-02	2.70E-02	4.44E-02	2.73E-06	3.85E-03
Ba-133	4.68E-03	1.84E-03	5.29E-04	6.68E-07	2.32E-03
Pm-147	7.70E-04	5.67E-04	2.00E-04	3.35E-06	5.81E-08
Sm-147	1.43E-01	9.99E-02	3.69E-02	6.39E-03	0.00
Sm-151	2.90E-04	2.10E-04	7.75E-05	2.57E-06	1.26E-09
Eu-150	1.47E-02	3.43E-03	1.26E-03	2.29E-05	9.99E-03
Eu-152	1.24E-02	3.50E-03	1.28E-03	1.89E-05	7.60E-03
Eu-154	1.53E-02	5.16E-03	1.88E-03	2.45E-05	8.23E-03
Eu-155	1.35E-03	8.26E-04	2.97E-04	3.54E-06	2.22E-04
Gd-152	1.36E-01	8.69E-02	2.82E-02	2.08E-02	0.00
Ho-166m	1.78E-02	4.36E-03	1.54E-03	6.61E-05	1.18E-02
Re-187	8.74E-06	5.14E-06	3.60E-06	4.65E-09	0.00
Tl-204	4.66E-03	1.81E-03	2.84E-03	2.06E-07	4.83E-06
Pb-205	1.12E-03	8.80E-04	2.39E-04	3.35E-07	9.10E-09
Pb-210+D	3.74E+00	2.90E+00	8.37E-01	1.19E-03	7.56E-06
Bi-207	1.42E-02	2.96E-03	8.82E-04	1.71E-06	1.04E-02
Po-209	1.83E+00	1.29E+00	5.41E-01	1.01E-03	2.27E-05
Po-210	1.41E+00	1.03E+00	3.81E-01	7.98E-04	3.17E-08
Ra-226+D	9.29E-01	7.18E-01	1.97E-01	7.36E-04	1.22E-02

Table 38. Low Water Infiltration Case: All Pathways Farmer

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Ra-228+D	9.97E-01	7.78E-01	2.11E-01	5.02E-04	7.68E-03
Ac-227+D	1.03E+01	7.99E+00	1.75E+00	5.75E-01	2.41E-03
Th-228+D	5.69E-01	4.38E-01	9.23E-02	2.95E-02	9.31E-03
Th-229+D	2.83E+00	2.18E+00	4.72E-01	1.85E-01	1.89E-03
Th-230	3.88E-01	2.96E-01	6.42E-02	2.79E-02	3.59E-06
Th-232	1.94E+00	1.47E+00	3.23E-01	1.40E-01	3.47E-04
Pa-231	7.08E+00	5.72E+00	1.25E+00	1.10E-01	2.62E-04
U-232	1.00E+00	7.07E-01	2.35E-01	5.65E-02	1.36E-03
U-233	2.19E-01	1.56E-01	5.13E-02	1.16E-02	1.80E-06
U-234	2.14E-01	1.53E-01	5.03E-02	1.13E-02	5.13E-07
U-235+D	2.03E-01	1.44E-01	4.74E-02	1.05E-02	9.45E-04
U-236	2.04E-01	1.45E-01	4.78E-02	1.07E-02	2.73E-07
U-238+D	2.03E-01	1.45E-01	4.76E-02	1.01E-02	1.48E-04
Np-237+D	2.97E+00	2.40E+00	5.25E-01	4.62E-02	1.32E-03
Pu-236	7.79E-01	6.32E-01	1.34E-01	1.24E-02	3.79E-06
Pu-238	2.14E+00	1.73E+00	3.74E-01	3.35E-02	1.94E-07
Pu-239	2.36E+00	1.91E+00	4.13E-01	3.67E-02	3.66E-07
Pu-240	2.36E+00	1.91E+00	4.13E-01	3.67E-02	1.89E-07
Pu-241+D	4.57E-02	3.70E-02	8.02E-03	7.06E-04	5.79E-08
Pu-242	2.24E+00	1.81E+00	3.92E-01	3.52E-02	1.65E-07
Pu-244+D	2.22E+00	1.79E+00	3.88E-01	3.45E-02	2.30E-03
Am-241	2.43E+00	1.97E+00	4.25E-01	3.80E-02	5.64E-05
Am-242m+D	2.35E+00	1.90E+00	4.13E-01	3.65E-02	8.33E-05
Am-243+D	2.42E+00	1.96E+00	4.24E-01	3.77E-02	1.12E-03
Cm-242	7.58E-02	6.21E-02	1.23E-02	1.47E-03	1.28E-07
Cm-243	1.68E+00	1.36E+00	2.95E-01	2.63E-02	7.20E-04
Cm-244	1.35E+00	1.09E+00	2.37E-01	2.12E-02	1.60E-07
Cm-245	2.50E+00	2.02E+00	4.41E-01	3.89E-02	4.35E-04

Table 38. Low Water Infiltration Case: All Pathways Farmer

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cm-246	2.47E+00	2.00E+00	4.36E-01	3.86E-02	1.50E-07
Cm-247+D	2.29E+00	1.85E+00	4.03E-01	3.54E-02	2.22E-03
Cm-248	9.09E+00	7.34E+00	1.60E+00	1.41E-01	1.13E-07
Cm-250+D	5.19E+01	4.20E+01	9.16E+00	8.04E-01	2.17E-03
Bk-247	3.14E+00	2.54E+00	5.49E-01	4.91E-02	5.44E-04
Cf-248	2.43E-01	1.80E-01	5.87E-02	4.32E-03	1.24E-07
Cf-249	3.55E+00	2.56E+00	9.41E-01	4.94E-02	2.21E-03
Cf-250	1.59E+00	1.15E+00	4.19E-01	2.24E-02	1.50E-07
Cf-251	3.63E+00	2.62E+00	9.63E-01	5.03E-02	6.66E-04
Cf-252	8.01E-01	5.83E-01	2.04E-01	1.34E-02	2.05E-07

Units are mrem per pCi/L in the ground water.

Table 39. Low Water Infiltration Case: Native American Subsistence Resident

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
H-3	1.03E-04	7.01E-05	2.79E-05	5.09E-06	0.00
Be-10	8.25E-03	5.10E-03	3.08E-03	6.44E-05	2.32E-06
C-14	1.34E-02	2.29E-03	1.11E-02	3.80E-07	2.91E-08
Na-22	1.52E-01	1.26E-02	1.17E-01	1.39E-06	2.33E-02
Si-32+D	1.95E-02	1.20E-02	7.21E-03	1.87E-04	2.46E-05
Cl-36	1.80E-01	3.32E-03	1.76E-01	3.98E-06	4.77E-06
K-40	8.37E-02	2.04E-02	6.15E-02	2.26E-06	1.86E-03
Ti-44+D	1.50E-01	2.69E-02	9.70E-02	8.23E-05	2.58E-02
V-49	1.09E-04	6.72E-05	4.12E-05	6.25E-08	0.00
Mn-54	1.24E-02	3.03E-03	2.08E-03	1.21E-06	7.28E-03
Fe-55	1.47E-03	6.65E-04	8.01E-04	4.89E-07	0.00
Co-60	1.04E-01	2.95E-02	4.61E-02	3.98E-05	2.82E-02
Ni-59	4.56E-04	2.30E-04	2.25E-04	2.40E-07	0.00
Ni-63	1.25E-03	6.32E-04	6.18E-04	5.64E-07	0.00
Se-79	3.10E-02	9.53E-03	2.15E-02	1.79E-06	4.08E-08
Rb-87	2.33E-02	5.39E-03	1.79E-02	5.88E-07	3.08E-07
Sr-90+D	3.38E-01	1.68E-01	1.71E-01	4.51E-05	4.98E-05
Zr-93	3.29E-03	1.82E-03	1.42E-03	5.84E-05	3.77E-09
Nb-91	7.63E-03	5.72E-04	7.03E-03	5.31E-06	2.48E-05
Nb-93m	7.52E-03	5.72E-04	6.95E-03	5.31E-06	2.24E-07
Nb-94	1.23E-01	7.82E-03	9.62E-02	7.53E-05	1.85E-02
Mo-93	3.22E-03	1.48E-03	1.73E-03	5.17E-06	1.28E-06
Tc-99	1.23E-02	1.60E-03	1.07E-02	1.51E-06	2.02E-07
Ru-106+D	4.96E-02	3.00E-02	1.76E-02	8.65E-05	1.96E-03
Pd-107	6.34E-04	1.63E-04	4.69E-04	2.33E-06	0.00
Ag-108m+D	6.91E-02	8.34E-03	4.19E-02	5.15E-05	1.88E-02
Cd-109	2.62E-02	1.43E-02	1.18E-02	2.07E-05	2.63E-05

Table 39. Low Water Infiltration Case: Native American Subsistence Resident

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cd-113m	3.32E-01	1.76E-01	1.55E-01	2.78E-04	1.37E-06
In-115	3.20E-01	1.73E-01	1.46E-01	6.81E-04	8.69E-07
Sn-121m+D	1.03E-02	2.46E-03	7.80E-03	2.17E-06	4.60E-06
Sn-126+D	1.20E-01	2.31E-02	7.34E-02	1.84E-05	2.32E-02
Sb-125	9.78E-03	3.08E-03	2.31E-03	2.22E-06	4.39E-03
Te-125m	6.70E-03	4.02E-03	2.67E-03	1.31E-06	9.67E-06
I-129	1.21E+00	3.02E-01	9.10E-01	3.16E-05	2.62E-05
Cs-134	3.06E-01	8.03E-02	2.10E-01	8.41E-06	1.61E-02
Cs-135	2.94E-02	7.74E-03	2.17E-02	8.28E-07	8.39E-08
Cs-137+D	2.14E-01	5.48E-02	1.53E-01	5.81E-06	6.56E-03
Ba-133	1.02E-02	3.72E-03	2.52E-03	1.42E-06	3.94E-03
Pm-147	1.95E-03	1.15E-03	7.97E-04	7.12E-06	9.89E-08
Sm-147	3.62E-01	2.03E-01	1.45E-01	1.36E-02	0.00
Sm-151	7.37E-04	4.26E-04	3.06E-04	5.46E-06	2.15E-09
Eu-150	2.90E-02	6.96E-03	4.99E-03	4.88E-05	1.70E-02
Eu-152	2.51E-02	7.10E-03	5.06E-03	4.02E-05	1.29E-02
Eu-154	3.19E-02	1.05E-02	7.43E-03	5.20E-05	1.40E-02
Eu-155	3.24E-03	1.68E-03	1.18E-03	7.53E-06	3.77E-04
Gd-152	3.39E-01	1.76E-01	1.19E-01	4.42E-02	0.00
Ho-166m	3.53E-02	8.84E-03	6.22E-03	1.41E-04	2.01E-02
Re-187	2.42E-05	1.04E-05	1.37E-05	9.90E-09	0.00
Tl-204	1.14E-02	3.68E-03	7.75E-03	4.38E-07	8.22E-06
Pb-205	2.94E-03	1.78E-03	1.16E-03	7.13E-07	1.55E-08
Pb-210+D	9.91E+00	5.88E+00	4.03E+00	2.52E-03	1.29E-05
Bi-207	2.78E-02	6.00E-03	4.22E-03	3.64E-06	1.76E-02
Po-209	4.72E+00	2.61E+00	2.12E+00	2.15E-03	3.86E-05
Po-210	3.55E+00	2.08E+00	1.47E+00	1.70E-03	5.39E-08
Ra-226+D	2.47E+00	1.46E+00	9.88E-01	1.57E-03	2.07E-02

Table 39. Low Water Infiltration Case: Native American Subsistence Resident

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Ra-228+D	2.65E+00	1.58E+00	1.06E+00	1.05E-03	1.31E-02
Ac-227+D	2.66E+01	1.62E+01	9.20E+00	1.22E+00	4.10E-03
Th-228+D	1.45E+00	8.88E-01	4.87E-01	6.27E-02	1.58E-02
Th-229+D	7.30E+00	4.41E+00	2.49E+00	3.93E-01	3.22E-03
Th-230	9.99E-01	6.00E-01	3.39E-01	5.93E-02	6.10E-06
Th-232	4.99E+00	2.99E+00	1.70E+00	2.98E-01	5.91E-04
Pa-231	1.84E+01	1.16E+01	6.59E+00	2.33E-01	4.45E-04
U-232	2.64E+00	1.43E+00	1.08E+00	1.20E-01	2.31E-03
U-233	5.77E-01	3.16E-01	2.36E-01	2.46E-02	3.07E-06
U-234	5.65E-01	3.10E-01	2.31E-01	2.40E-02	8.72E-07
U-235+D	5.34E-01	2.92E-01	2.18E-01	2.24E-02	1.61E-03
U-236	5.37E-01	2.95E-01	2.20E-01	2.27E-02	4.64E-07
U-238+D	5.34E-01	2.93E-01	2.19E-01	2.15E-02	2.52E-04
Np-237+D	7.73E+00	4.86E+00	2.76E+00	9.83E-02	2.24E-03
Pu-236	2.02E+00	1.28E+00	7.10E-01	2.64E-02	6.45E-06
Pu-238	5.55E+00	3.50E+00	1.98E+00	7.13E-02	3.30E-07
Pu-239	6.14E+00	3.88E+00	2.19E+00	7.81E-02	6.23E-07
Pu-240	6.14E+00	3.88E+00	2.19E+00	7.81E-02	3.21E-07
Pu-241+D	1.19E-01	7.50E-02	4.24E-02	1.50E-03	9.84E-08
Pu-242	5.83E+00	3.68E+00	2.08E+00	7.48E-02	2.81E-07
Pu-244+D	5.76E+00	3.64E+00	2.05E+00	7.33E-02	3.91E-03
Am-241	6.32E+00	3.99E+00	2.25E+00	8.08E-02	9.60E-05
Am-242m+D	6.11E+00	3.85E+00	2.18E+00	7.75E-02	1.42E-04
Am-243+D	6.30E+00	3.97E+00	2.24E+00	8.01E-02	1.91E-03
Cm-242	1.94E-01	1.26E-01	6.45E-02	3.13E-03	2.18E-07
Cm-243	4.36E+00	2.75E+00	1.56E+00	5.59E-02	1.23E-03
Cm-244	3.51E+00	2.21E+00	1.25E+00	4.51E-02	2.72E-07
Cm-245	6.51E+00	4.10E+00	2.33E+00	8.28E-02	7.40E-04

Table 39. Low Water Infiltration Case: Native American Subsistence Resident

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cm-246	6.44E+00	4.05E+00	2.30E+00	8.21E-02	2.55E-07
Cm-247+D	5.95E+00	3.74E+00	2.13E+00	7.53E-02	3.78E-03
Cm-248	2.37E+01	1.49E+01	8.46E+00	3.00E-01	1.92E-07
Cm-250+D	1.35E+02	8.51E+01	4.84E+01	1.71E+00	3.70E-03
Bk-247	8.16E+00	5.15E+00	2.90E+00	1.04E-01	9.25E-04
Cf-248	6.16E-01	3.66E-01	2.41E-01	9.20E-03	2.10E-07
Cf-249	9.01E+00	5.19E+00	3.71E+00	1.05E-01	3.76E-03
Cf-250	4.04E+00	2.33E+00	1.66E+00	4.77E-02	2.55E-07
Cf-251	9.22E+00	5.31E+00	3.80E+00	1.07E-01	1.13E-03
Cf-252	2.03E+00	1.18E+00	8.17E-01	2.85E-02	3.49E-07

Units are mrem per pCi/L in the ground water.

Table 40. Low Water Infiltration Case: Columbia River Population

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
H-3	2.29E-01	1.73E-01	3.48E-02	2.09E-02	0.00
Be-10	1.52E+01	1.26E+01	2.48E+00	1.50E-01	5.60E-03
C-14	1.95E+01	5.64E+00	1.39E+01	8.87E-04	7.02E-05
Na-22	2.14E+02	3.11E+01	1.26E+02	3.25E-03	5.63E+01
Si-32+D	3.55E+01	2.97E+01	5.33E+00	4.37E-01	5.92E-02
Cl-36	1.88E+02	8.18E+00	1.80E+02	9.29E-03	1.15E-02
K-40	1.22E+02	5.02E+01	6.72E+01	5.26E-03	4.49E+00
Ti-44+D	2.40E+02	6.64E+01	1.12E+02	1.92E-01	6.23E+01
V-49	2.03E-01	1.66E-01	3.66E-02	1.46E-04	0.00
Mn-54	2.66E+01	7.48E+00	1.59E+00	2.84E-03	1.76E+01
Fe-55	2.72E+00	1.64E+00	1.08E+00	1.14E-03	0.00
Co-60	1.98E+02	7.26E+01	5.72E+01	9.29E-02	6.81E+01
Ni-59	7.93E-01	5.67E-01	2.26E-01	5.60E-04	0.00
Ni-63	2.18E+00	1.56E+00	6.20E-01	1.32E-03	0.00
Se-79	5.03E+01	2.35E+01	2.68E+01	4.18E-03	9.85E-05
Rb-87	3.23E+01	1.33E+01	1.90E+01	1.37E-03	7.43E-04
Sr-90+D	5.53E+02	4.13E+02	1.39E+02	1.05E-01	1.20E-01
Zr-93	6.10E+00	4.48E+00	1.48E+00	1.36E-01	9.10E-06
Nb-91	1.23E+01	1.41E+00	1.08E+01	1.24E-02	5.98E-02
Nb-93m	1.21E+01	1.41E+00	1.07E+01	1.24E-02	5.42E-04
Nb-94	2.13E+02	1.93E+01	1.48E+02	1.76E-01	4.47E+01
Mo-93	5.46E+00	3.65E+00	1.80E+00	1.21E-02	3.10E-03
Tc-99	1.46E+01	3.94E+00	1.07E+01	3.53E-03	4.87E-04
Ru-106+D	9.36E+01	7.40E+01	1.47E+01	2.02E-01	4.72E+00
Pd-107	8.43E-01	4.02E-01	4.35E-01	5.43E-03	0.00
Ag-108m+D	1.05E+02	2.06E+01	3.87E+01	1.20E-01	4.55E+01
Cd-109	4.52E+01	3.54E+01	9.74E+00	4.83E-02	6.34E-02

Table 40. Low Water Infiltration Case: Columbia River Population

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cd-113m	5.63E+02	4.35E+02	1.28E+02	6.49E-01	3.31E-03
In-115	5.91E+02	4.27E+02	1.63E+02	1.59E+00	2.10E-03
Sn-121m+D	1.91E+01	6.08E+00	1.31E+01	5.05E-03	1.11E-02
Sn-126+D	2.36E+02	5.70E+01	1.23E+02	4.29E-02	5.59E+01
Sb-125	2.03E+01	7.59E+00	2.15E+00	5.18E-03	1.06E+01
Te-125m	1.30E+01	9.91E+00	3.11E+00	3.07E-03	2.33E-02
I-129	1.64E+03	7.45E+02	8.91E+02	7.38E-02	6.32E-02
Cs-134	4.75E+02	1.98E+02	2.38E+02	1.96E-02	3.89E+01
Cs-135	4.39E+01	1.91E+01	2.48E+01	1.93E-03	2.02E-04
Cs-137+D	3.25E+02	1.35E+02	1.74E+02	1.35E-02	1.58E+01
Ba-133	2.07E+01	9.18E+00	2.06E+00	3.31E-03	9.51E+00
Pm-147	3.63E+00	2.84E+00	7.76E-01	1.66E-02	2.39E-04
Sm-147	6.75E+02	5.00E+02	1.43E+02	3.17E+01	0.00
Sm-151	1.36E+00	1.05E+00	3.01E-01	1.27E-02	5.19E-06
Eu-150	6.32E+01	1.72E+01	4.91E+00	1.14E-01	4.10E+01
Eu-152	5.38E+01	1.75E+01	4.98E+00	9.38E-02	3.12E+01
Eu-154	6.70E+01	2.58E+01	7.29E+00	1.21E-01	3.38E+01
Eu-155	6.21E+00	4.13E+00	1.15E+00	1.76E-02	9.11E-01
Gd-152	6.47E+02	4.35E+02	1.09E+02	1.03E+02	0.00
Ho-166m	7.65E+01	2.18E+01	6.00E+00	3.28E-01	4.84E+01
Re-187	3.97E-02	2.57E-02	1.40E-02	2.31E-05	0.00
Tl-204	2.02E+01	9.07E+00	1.11E+01	1.02E-03	1.98E-02
Pb-205	5.33E+00	4.40E+00	9.28E-01	1.66E-03	3.74E-05
Pb-210+D	1.78E+04	1.45E+04	3.25E+03	5.87E+00	3.10E-02
Bi-207	6.07E+01	1.48E+01	3.43E+00	8.49E-03	4.25E+01
Po-209	8.56E+03	6.43E+03	2.13E+03	5.01E+00	9.31E-02
Po-210	6.63E+03	5.13E+03	1.50E+03	3.97E+00	1.30E-04
Ra-226+D	4.41E+03	3.59E+03	7.64E+02	3.65E+00	4.99E+01

Table 40. Low Water Infiltration Case: Columbia River Population

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Ra-228+D	4.74E+03	3.89E+03	8.16E+02	2.34E+00	3.15E+01
Ac-227+D	4.96E+04	4.00E+04	6.74E+03	2.85E+03	9.90E+00
Th-228+D	2.73E+03	2.19E+03	3.56E+02	1.46E+02	3.82E+01
Th-229+D	1.36E+04	1.09E+04	1.82E+03	9.17E+02	7.78E+00
Th-230	1.87E+03	1.48E+03	2.48E+02	1.38E+02	1.47E-02
Th-232	9.31E+03	7.37E+03	1.24E+03	6.96E+02	1.42E+00
Pa-231	3.40E+04	2.86E+04	4.81E+03	5.44E+02	1.07E+00
U-232	4.74E+03	3.54E+03	9.16E+02	2.80E+02	5.58E+00
U-233	1.04E+03	7.80E+02	2.00E+02	5.73E+01	7.40E-03
U-234	1.02E+03	7.64E+02	1.96E+02	5.60E+01	2.11E-03
U-235+D	9.62E+02	7.21E+02	1.85E+02	5.22E+01	3.88E+00
U-236	9.65E+02	7.26E+02	1.86E+02	5.30E+01	1.12E-03
U-238+D	9.60E+02	7.24E+02	1.85E+02	5.01E+01	6.09E-01
Np-237+D	1.42E+04	1.20E+04	2.03E+03	2.29E+02	5.41E+00
Pu-236	3.74E+03	3.16E+03	5.18E+02	6.15E+01	1.56E-02
Pu-238	1.02E+04	8.64E+03	1.44E+03	1.66E+02	7.96E-04
Pu-239	1.13E+04	9.56E+03	1.60E+03	1.82E+02	1.50E-03
Pu-240	1.13E+04	9.56E+03	1.60E+03	1.82E+02	7.75E-04
Pu-241+D	2.19E+02	1.85E+02	3.10E+01	3.50E+00	2.38E-04
Pu-242	1.08E+04	9.07E+03	1.51E+03	1.74E+02	6.77E-04
Pu-244+D	1.06E+04	8.96E+03	1.50E+03	1.71E+02	9.43E+00
Am-241	1.17E+04	9.83E+03	1.64E+03	1.88E+02	2.32E-01
Am-242m+D	1.13E+04	9.50E+03	1.59E+03	1.81E+02	3.42E-01
Am-243+D	1.16E+04	9.80E+03	1.64E+03	1.87E+02	4.61E+00
Cm-242	3.65E+02	3.11E+02	4.73E+01	7.31E+00	5.25E-04
Cm-243	8.05E+03	6.78E+03	1.14E+03	1.30E+02	2.96E+00
Cm-244	6.48E+03	5.45E+03	9.16E+02	1.05E+02	6.57E-04
Cm-245	1.20E+04	1.01E+04	1.70E+03	1.93E+02	1.78E+00

Table 40. Low Water Infiltration Case: Columbia River Population

Nuclide	Total	Ingest (Drink)	Ingest (Other)	Inhale	External
Cm-246	1.19E+04	9.99E+03	1.68E+03	1.91E+02	6.15E-04
Cm-247+D	1.10E+04	9.23E+03	1.56E+03	1.76E+02	9.12E+00
Cm-248	4.36E+04	3.67E+04	6.19E+03	7.00E+02	4.64E-04
Cm-250+D	2.49E+05	2.10E+05	3.54E+04	3.99E+03	8.92E+00
Bk-247	1.51E+04	1.27E+04	2.12E+03	2.44E+02	2.23E+00
Cf-248	1.15E+03	9.02E+02	2.28E+02	2.15E+01	5.07E-04
Cf-249	1.67E+04	1.28E+04	3.66E+03	2.45E+02	9.08E+00
Cf-250	7.49E+03	5.75E+03	1.63E+03	1.11E+02	6.14E-04
Cf-251	1.71E+04	1.31E+04	3.74E+03	2.50E+02	2.73E+00
Cf-252	3.78E+03	2.92E+03	7.95E+02	6.66E+01	8.41E-04

Units are person-rem per pCi/L in the Columbia River.

Table 41. Ratio of Total Dose to Drinking Water Dose

Nuclide	Residential	Agricultural	All Pathways	NASR	Population
H-3	1.05	1.23	1.32	1.47	1.32
Be-10	1.14	1.17	1.27	1.62	1.21
C-14	1.21	4.22	4.14	5.87	3.46
Na-22	3.92	10.51	8.39	12.11	6.88
Si-32+D	1.15	1.16	1.25	1.62	1.20
Cl-36	7.42	26.27	29.41	54.13	22.98
K-40	1.33	3.01	2.82	4.11	2.43
Ti-44+D	2.58	4.89	4.29	5.56	3.62
V-49	1.13	1.18	1.29	1.61	1.22
Mn-54	4.75	4.81	4.14	4.09	3.56
Fe-55	1.14	1.63	1.84	2.21	1.66
Co-60	2.58	3.35	3.15	3.52	2.73
Ni-59	1.14	1.45	1.51	1.98	1.40
Ni-63	1.14	1.45	1.51	1.98	1.40
Se-79	1.14	2.27	2.45	3.25	2.14
Rb-87	1.15	3.17	2.82	4.32	2.43
Sr-90+D	1.16	1.43	1.43	2.02	1.34
Zr-93	1.15	1.32	1.46	1.81	1.36
Nb-91	1.21	10.26	10.86	13.35	8.75
Nb-93m	1.14	10.08	10.68	13.16	8.61
Nb-94	4.70	13.76	13.64	15.68	11.03
Mo-93	1.15	1.58	1.64	2.18	1.50
Tc-99	1.23	5.47	4.49	7.66	3.71
Ru-106+D	1.23	1.27	1.34	1.65	1.26
Pd-107	1.15	2.88	2.40	3.89	2.10
Ag-108m+D	4.54	7.86	6.10	8.29	5.10
Cd-109	1.15	1.32	1.36	1.83	1.28

Table 41. Ratio of Total Dose to Drinking Water Dose

Nuclide	Residential	Agricultural	All Pathways	NASR	Population
Cd-113m	1.15	1.35	1.38	1.88	1.30
In-115	1.14	1.35	1.49	1.85	1.39
Sn-121m+D	1.14	3.16	3.74	4.17	3.15
Sn-126+D	2.65	4.67	4.94	5.18	4.14
Sb-125	3.29	3.40	3.07	3.18	2.68
Te-125m	1.11	1.23	1.40	1.67	1.32
I-129	1.15	2.94	2.53	4.01	2.20
Cs-134	1.44	3.00	2.77	3.82	2.40
Cs-135	1.15	2.83	2.65	3.80	2.30
Cs-137+D	1.33	3.00	2.79	3.91	2.41
Ba-133	2.73	2.79	2.55	2.74	2.26
Pm-147	1.14	1.25	1.36	1.70	1.28
Sm-147	1.16	1.28	1.43	1.79	1.35
Sm-151	1.14	1.26	1.38	1.73	1.30
Eu-150	4.80	4.92	4.28	4.16	3.68
Eu-152	3.87	3.99	3.54	3.54	3.07
Eu-154	3.15	3.27	2.96	3.05	2.60
Eu-155	1.48	1.59	1.63	1.93	1.50
Gd-152	1.21	1.29	1.56	1.92	1.49
Ho-166m	4.55	4.66	4.08	3.99	3.51
Re-187	1.17	1.63	1.70	2.32	1.55
Tl-204	1.14	2.33	2.57	3.11	2.23
Pb-205	1.14	1.19	1.27	1.65	1.21
Pb-210+D	1.15	1.20	1.29	1.69	1.22
Bi-207	5.54	5.64	4.80	4.64	4.10
Po-209	1.14	1.22	1.42	1.81	1.33
Po-210	1.12	1.18	1.37	1.71	1.29
Ra-226+D	1.16	1.25	1.29	1.69	1.23

Table 41. Ratio of Total Dose to Drinking Water Dose

Nuclide	Residential	Agricultural	All Pathways	NASR	Population
Ra-228+D	1.15	1.23	1.28	1.68	1.22
Ac-227+D	1.16	1.16	1.29	1.64	1.24
Th-228+D	1.18	1.18	1.30	1.64	1.25
Th-229+D	1.17	1.17	1.30	1.66	1.25
Th-230	1.17	1.17	1.31	1.66	1.26
Th-232	1.17	1.17	1.31	1.67	1.26
Pa-231	1.15	1.15	1.24	1.59	1.19
U-232	1.17	1.29	1.41	1.84	1.34
U-233	1.16	1.28	1.40	1.82	1.33
U-234	1.16	1.28	1.40	1.82	1.33
U-235+D	1.17	1.29	1.41	1.83	1.33
U-236	1.16	1.28	1.40	1.82	1.33
U-238+D	1.16	1.28	1.40	1.82	1.33
Np-237+D	1.15	1.15	1.24	1.59	1.19
Pu-236	1.14	1.14	1.23	1.57	1.18
Pu-238	1.15	1.15	1.24	1.58	1.19
Pu-239	1.15	1.15	1.24	1.58	1.19
Pu-240	1.15	1.15	1.24	1.58	1.19
Pu-241+D	1.15	1.15	1.24	1.59	1.19
Pu-242	1.15	1.15	1.24	1.58	1.19
Pu-244+D	1.15	1.15	1.24	1.59	1.19
Am-241	1.15	1.15	1.24	1.58	1.19
Am-242m+D	1.15	1.15	1.24	1.59	1.19
Am-243+D	1.15	1.15	1.24	1.58	1.19
Cm-242	1.13	1.14	1.22	1.54	1.18
Cm-243	1.15	1.15	1.24	1.59	1.19
Cm-244	1.15	1.15	1.24	1.59	1.19
Cm-245	1.15	1.15	1.24	1.59	1.19

Table 41. Ratio of Total Dose to Drinking Water Dose

Nuclide	Residential	Agricultural	All Pathways	NASR	Population
Cm-246	1.15	1.15	1.24	1.59	1.19
Cm-247+D	1.15	1.15	1.24	1.59	1.19
Cm-248	1.15	1.15	1.24	1.59	1.19
Cm-250+D	1.15	1.15	1.24	1.59	1.19
Bk-247	1.15	1.15	1.24	1.58	1.19
Cf-248	1.14	1.23	1.35	1.68	1.28
Cf-249	1.15	1.26	1.39	1.74	1.31
Cf-250	1.15	1.26	1.38	1.73	1.30
Cf-251	1.15	1.26	1.39	1.74	1.31
Cf-252	1.14	1.25	1.37	1.71	1.30

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Appendix A

Hand Calculations for Tritium

HAND CALCULATIONS FOR TRITIUM

A.1 No Water Infiltration Exposure Scenarios

Each of the exposure scenarios listed in Table 2 will be evaluated. The external exposures are not computed for tritium because the external dose rate factor for tritium is zero. Absorption through the skin is included in the inhalation dose factor for tritium.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

A.1.1 Offsite Farmer

Assume 1 curie H-3 is released into the air during the year. The bounding annual average air transport factor is 1.0E-04 s/m^3.

Inhalation Dose: From Table 28, 0.0237 mrem

A.1.2 Onsite Resident

Assume the H-3 emanation rate is 1 pCi/m^2/s. The average air concentration in a dwelling with an air exchange to floor area ratio of 5.0E-04 m/s is computed as shown below.

C_{eq} = (1 pCi/m^2/s)/(5.0E-04 m/s) = 2000 pCi/m^3

The individual is present in his dwelling about 6966 h/y from Table 17. The total volume of air inhaled during this period is computed as shown below.

V_{air} = (2920 h/y)(0.45 m^3/h) + (4046 h/y)(1.2 m^3/h) = 6170 m^3/y

Inhalation Dose:

(2000 pCi/m^3)(6170 m^3)(9.60E-08 mrem/pCi) = 1.18 mrem

A.1.3 Intruder (Well Driller)

Assume 1 curie H-3 is exhumed from the well shaft during the 5 day operation. The soil is spread over an area of 100 m^2 so the average soil concentration is computed as shown below.

C_s = (1 Ci)(1E12 pCi/Ci)/(100 m^2)/(225 kg/m^2) = 4.444E+7 pCi/kg

A mass loading approach is used, so that the driller inhales a total of 4.8 mg (4.8E-06 kg) of soil. He ingests a total of 500 mg (5.0E-4 kg) soil. The inhalation and ingestion dose calculations are shown below.

Inhalation Dose:

(4.8E-06 kg inhaled)(4.444E+7 pCi/kg)(9.60E-08 mrem/pCi) = 2.05E-05 mrem

Ingestion Dose:

(5.0E-04 kg ingested)(4.444E+7 pCi/kg)(6.40E-08 mrem/pCi) = 1.42E-03 mrem

External Dose:

(40 h)(4.444E+7 pCi/kg)(225 kg/m²)(0 mrem/h per Ci/m²) = 0 mrem

Total Dose to Driller:

2.05E-05 + 1.42E-03 mrem = 1.44E-03 mrem per Ci exhumed

A.1.4 Post-Intrusion Resident (Gardener)

Assume 1 curie H-3 is exhumed from the well shaft and spread over an area of 200 m². The average soil concentration is computed as shown below.

C_s = (1 Ci)(1E12 pCi/Ci)/(200 m²)/(225 kg/m²) = 2.222E+7 pCi/kg

This concentration decreases with time due to leaching from the surface layer during the irrigation season and radioactive decay. Decay factors used in the dose calculations are computed below (Table 30).

λ_r = (0.69315)/(12.33 y) = 0.056216 y^{-1} λ_l = 2.22 y^{-1} (Table 27)
$\lambda_t = \lambda_r + \lambda_l$ = 2.27622 y^{-1}

$\lambda_t T_{irr}$ = (2.27622 y^{-1})(0.5 y) = 1.13811
$DS(T_{irr})$ = Exp(-1.13811) = 0.32042
$IDS(T_{irr})$ = [1 - Exp(-1.13811)]/(1.13811) = 0.59711

$\lambda_r T_{no}$ = (0.056216 y^{-1})(0.5 y) = 0.028108
$IDR(T_{no})$ = [1 - Exp(-0.028108)]/(0.028108) = 0.98608

$T_{irr} \cdot IDS(T_{irr}) + T_{no} \cdot DS(T_{irr}) \cdot IDR(T_{no})$ =
(0.5y)(0.59711) + (0.5y)(0.32042)(0.98608) = 0.45653 y

$DS(T_h)$ = Exp[-(2.27622 y^{-1})(0.25 y)] = 0.56606

$\lambda_r T_{veg}$ = (0.056216 y^{-1})(90 d)/(365.25 d/y) = 0.013852

$IDR(T_{veg}) = [1 - Exp(-0.013852)]/(0.013852) = 0.99311$

$DS(T_h) \cdot IDR(T_{veg}) = (0.56606)(0.99311) = 0.56216$

A mass loading approach is used, so that the resident inhales a total of 573 mg (5.73E-04 kg) of soil over the course of a year. He also ingests a total of 0.0365 kg soil during the year. The inhalation and ingestion doses from these sources are shown below.

Inhalation Dose: (resuspended soil)
(5.73E-4 kg/y)(2.222E+7 pCi/kg)(9.60E-8 mrem/pCi)(0.45653 y) = 5.58E-4 mrem

Ingestion Dose: (soil only)
(0.0365 kg)(2.222E+7 pCi/kg)(6.40E-8 mrem/pCi)(0.45653 y) = 0.0237 mrem

External Dose:
(900 h/y)(2.222E+7 pCi/kg)(225 kg/m²)(0 mrem/h per Ci/m²)(0.45653 y) = 0 mrem

The vegetable produce from the garden is contaminated by root uptake and rain splash. Doses from each are shown below. The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y. The product of soil concentration and ingestion dose is combined into a single quantity to simplify the calculation.
(2.222E+7 pCi/kg)(6.40E-8 mrem/pCi)=1.4221 mrem/kg

Ingestion Dose: (root uptake only)
(1.4221 mrem/kg)(51)(0.09)(4.1 kg)(0.59711) = 16.0 mrem
(1.4221 mrem/kg)(18)(0.25)(13.9 kg)(0.56216) = 50.0 mrem
(1.4221 mrem/kg)(25)(0.18)(9.6 kg)(0.56216) = 34.5 mrem
(1.4221 mrem/kg)(3.4)(0.91)(18.5 kg)(0.56216) = 45.8 mrem
Total from root uptake: 146.3 mrem

Ingestion Dose: (rain splash only)
To simplify the calculation, the mass loading, ground deposition speed, soil concentration and ingestion dose factor are combined in a single factor.
(1 mg/m³)(0.01 m/s)(1.4221 mrem/kg)(86,400 s/d) = 1.229E-3 mrem/d/m²

(1.229E-3mrem/d/m²)(18d)(0.407)(1.0)/(2.0kg/m²)(4.1kg)(0.59711) = 0.0110mrem
(1.229E-3mrem/d/m²)(20d)(0.835)(0.1)/(2.0kg/m²)(13.9kg)(0.56216) = 0.0080mrem
(1.229E-3mrem/d/m²)(20d)(0.857)(0.1)/(3.0kg/m²)(9.6kg)(0.56216) = 0.0038mrem
(1.229E-3mrem/d/m²)(20d)(0.371)(0.1)/(0.8kg/m²)(18.5kg)(0.56216) = 0.0119mrem
Total from rain splash: 0.0347mrem

Total Dose to Gardener:
5.58E-04 + 0.0237 + 146.3 + 0.0347 mrem = 146 mrem per Ci exhumed

A.1.5 Post-Intrusion Resident (HSRAM Residential)

Assume 1 curie H-3 is exhumed from the well shaft and spread over an area of 200 m^2. The average soil concentration is computed as before. The same decay factors used for the Gardener also apply here. Doses from each pathway are shown below.

Inhalation Dose: (resuspended soil)
(3.65E-4 kg/y)(2.222E+7 pCi/kg)(9.60E-8 mrem/pCi)(0.45653 y) = 3.55E-4 mrem

Ingestion Dose: (soil only)
(0.0365 kg)(2.222E+7 pCi/kg)(6.40E-8 mrem/pCi)(0.45653 y) = 0.0237 mrem

External Dose:
(7008 h/y)(2.222E+7 pCi/kg)(225 kg/m^2)(0 mrem/h per Ci/m^2)(0.45653 y) = 0 mrem

Ingestion Dose: (root uptake only)
(1.4221 mrem/kg)(51)(0.09)(3.7 kg)(0.59711) = 14.4 mrem
(1.4221 mrem/kg)(18)(0.25)(11.0 kg)(0.56216) = 39.6 mrem
(1.4221 mrem/kg)(25)(0.18)(15.3 kg)(0.56216) = 55.0 mrem
(1.4221 mrem/kg)(3.4)(0.91)(14.6 kg)(0.56216) = 36.1 mrem
Total from root uptake: 145.1 mrem

Ingestion Dose: (rain splash only)
(1.229E-3mrem/d/m^2)(18d)(0.407)(1.0)/(2.0kg/m^2)(3.7kg)(0.59711) = 0.0099mrem
(1.229E-3mrem/d/m^2)(20d)(0.835)(0.1)/(2.0kg/m^2)(11.0kg)(0.56216) = 0.0063mrem
(1.229E-3mrem/d/m^2)(20d)(0.857)(0.1)/(3.0kg/m^2)(15.3kg)(0.56216) = 0.0060mrem
(1.229E-3mrem/d/m^2)(20d)(0.371)(0.1)/(0.8kg/m^2)(14.6kg)(0.56216) = 0.0094mrem
Total from rain splash: 0.0317mrem

Total Dose to HSRAM Residential:
3.55E-04 + 0.0237 + 145.1 + 0.0317 mrem = 145 mrem per Ci exhumed

A.2 Low Water Infiltration Exposure Scenarios

Each of the exposure scenarios listed in Table 4 will be evaluated. The external exposures are not computed for tritium because the external dose rate factor for tritium is zero. Absorption through the skin is included in the inhalation dose factor for tritium. The main dose pathway in every case is the drinking water pathway.

It will be assumed in each exposure scenario that the well water concentration is 1 pCi/L. Thus the doses computed are per pCi/L.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

A.2.1 Industrial (HSRAM)

The worker inhales 2.1 L/y during routine showering and ingests 250 L/y of drinking water (untreated). The soil pathways do not apply because the soil is not contaminated.

Inhalation Dose: (showering)
(2.1 L/y)(1 pCi/L)(9.60E-08 mrem/pCi)(1 y) = 2.02E-7 mrem

Ingestion Dose: (drinking)
(250 L/y)(1 pCi/L)(6.40E-08 mrem/pCi)(1 y) = 1.60E-5 mrem

Total Dose to Industrial Worker:
2.02E-7 + 1.60E-5 mrem = 1.62E-5 mrem per pCi/L

A.2.2 Residential (HSRAM)

The soil concentration decreases with time due to leaching from the surface layer during the irrigation season and radioactive decay. Decay factors used in the dose calculations are computed below (Table 30). Equilibrium model assumptions lead to somewhat different decay factors than in the no-infiltration cases.

$\lambda_r T_{no} = (0.056216\ y^{-1})(0.5\ y) = 0.028108$
$IDR(T_{no}) = [1 - Exp(-0.028108)]/(0.028108) = 0.98608$

$T_{irr} + T_{no} \cdot IDR(T_{no}) = (0.5y) + (0.5y)(0.98608) = 0.99304\ y$

$\lambda_r T_{veg} = (0.056216\ y^{-1})(90\ d)/(365.25\ d/y) = 0.013852$
$IDR(T_{veg}) = [1 - Exp(-0.013852)]/(0.013852) = 0.99311$

Inhalation of well water during showers amounts to 3.1 L/y. Inhalation of resuspended soil amounts to 365 mg (3.65E-04 kg) of soil over the course of a year. The individual also ingests a total of 0.0365 kg soil and 730 L water during the year. The soil concentration is based on the soil moisture having the same tritium concentration as the well water (adjusted for natural precipitation by Equation 15). The soil concentration and the resulting inhalation and ingestion doses from the soil and water are shown below.

$C_{s,H3} = (8.94)(0.022)(1\ pCi/L)(82.3\ cm)/(82.3 + 5.23\ cm)/(1\ kg/L)$
$C_{s,H3} = 0.1849\ pCi/kg$

Inhalation Dose: (showering)
(3.1 L/y)(1 pCi/L)(9.60E-08 mrem/pCi)(1 y) = 2.98E-7 mrem

Inhalation Dose: (resuspended soil)
(3.65E-4 kg/y)(0.1849 pCi/kg)(9.60E-8 mrem/pCi)(0.99304 y) = 6.43E-12 mrem

Ingestion Dose: (drinking)
(730 L/y)(1 pCi/L)(6.40E-08 mrem/pCi)(1 y) = 4.67E-5 mrem

Ingestion Dose: (soil)
(0.0365 kg/y)(0.1849 pCi/kg)(6.40E-8 mrem/pCi)(0.99304 y) = 4.29E-10 mrem

External Dose:
(7008 h/y)(0.1849 pCi/kg)(225 kg/m²)(0 mrem/h per Ci/m²)(0.99304 y) = 0 mrem

The vegetable produce contamination is based on the plant moisture having the same tritium concentration as the well water (adjusted for natural precipitation by Equation 15). The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y. The product of plant water concentration and ingestion dose factor is combined into a single quantity to simplify the calculation.

(0.94)(1 pCi/L)(6.40E-8 mrem/pCi)=6.016E-8 mrem/L

The factors 0.894 L/kg and 0.6079 L/kg in the calculations below are the volume of water per kilogram of plant. They are calculated from the hydrogen fractions shown in Table 23 multiplied by 8.94 kg water per kg hydrogen, and divided by the density of water, 1.0 kg/L.

Ingestion Dose: (garden produce)
(6.016E-8 mrem/L)(0.894 L/kg)(3.7 kg)(1.00) = 1.99E-7 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(11.0 kg)(0.99311) = 5.88E-7 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(15.3 kg)(0.99311) = 8.17E-7 mrem
(6.016E-8 mrem/L)(0.6079L/kg)(14.6 kg)(0.99311) = 5.30E-7 mrem
Total from garden produce: 2.13E-6 mrem

Total Dose to Resident:
2.98E-7+6.43E-12+4.67E-5+4.29E-10+2.13E-6 mrem = 4.92E-5 mrem per pCi/L

A.2.3 Agricultural (HSRAM)

Both inhalation doses as well as the ingestion doses for drinking water, soil, and garden produce are the same as the HSRAM Residential case. They are listed below.

Inhalation Dose: (showering)
(3.1 L/y)(1 pCi/L)(9.60E-08 mrem/pCi)(1 y) = 2.98E-7 mrem

Inhalation Dose: (resuspended soil)
(3.65E-4 kg/y)(0.1849 pCi/kg)(9.60E-8 mrem/pCi)(0.99304 y) = 6.43E-12 mrem

Ingestion Dose: (drinking)
(730 L/y)(1 pCi/L)(6.40E-08 mrem/pCi)(1 y) = 4.67E-5 mrem

Ingestion Dose: (soil)
(0.0365 kg/y)(0.1849 pCi/kg)(6.40E-8 mrem/pCi)(0.99304 y) = 4.29E-10 mrem

External Dose:
(7008 h/y)(0.1849 pCi/kg)(225 kg/m^2)(0 mrem/h per Ci/m^2)(0.99304 y) = 0 mrem

Ingestion Dose: (garden produce)
Total from garden produce: 2.13E-6 mrem

Total from the above pathways = 4.915E-05 mrem

The agricultural scenario adds the dose from animal products that are contaminated by ingestion of well water, contaminated fodder and soil. The decay factors are based on Table 32 and are shown below.

$\lambda_r T_s = (0.056216\ y^{-1})(90\ d/365.25\ d/y) = 0.013852$
$DR(T_s) = Exp(-0.013852) = 0.98624$

$\lambda_r T_{beef} = (0.056216\ y^{-1})(120\ d)/(365.25\ d/y) = 0.018469$
$IDR(T_{beef}) = [1 - Exp(-0.018469)]/(0.018469) = 0.99082$

$DR(T_s) \cdot IDR(T_{beef}) = (0.98624)(0.99082) = 0.97719$

$\lambda_r T_{an} = (0.056216\ y^{-1})(90\ d)/(365.25\ d/y) = 0.013852$
$IDR(T_{an}) = [1 - Exp(-0.013852)]/(0.013852) = 0.99311$

$DR(T_s) \cdot IDR(T_{an}) = (0.98624)(0.99311) = 0.97944$

$\lambda_r T_{no} = (0.056216\ y^{-1})(0.5\ y) = 0.028108$
$IDR(T_{no}) = [1 - Exp(-0.028108)]/(0.028108) = 0.98608$

$T_{irr} + T_{no} \cdot IDR(T_{no}) = (0.5y) + (0.5y)(0.98608) = 0.99304\ y$

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the annual amount consumed by the individual, the ingestion dose factor, the equilibrium transfer factor, the water concentration, and the ingestion period.

Ingestion Dose: (beef)

(21.9 kg/y)(6.40E-8 mrem/pCi)(0.01 d/kg)(1 pCi/L)(1 y) = 1.402E-8 mrem·d/L

(1.402E-8 mrem·d/L)(0.94)(0.894 L/kg)(14 kg/d grass)(0.99082) = 1.63E-7 mrem
(1.402E-8 mrem·d/L)(0.94)(0.894 L/kg)(27 kg/d hay)(0.97719) = 3.11E-7 mrem
(1.402E-8 mrem·d/L)(0.94)(0.6079L/kg)(3 kg/d grain)(0.97719) = 2.35E-8 mrem
(1.402E-8 mrem·d/L)(0.94)(0.1967L/kg)(0.6 kg/d soil)(0.99082) = 1.54E-9 mrem
(1.402E-8 mrem·d/L)(1.00) (50 L/d water)(0.99082) = 6.95E-7 mrem
Total from beef: 1.19E-6 mrem

Ingestion Dose: (milk)

(110 L/y)(6.40E-8 mrem/pCi)(0.0082 d/L)(1 pCi/L)(1 y) = 5.773E-8 mrem·d/L

(5.773E-8 mrem·d/L)(0.94)(0.894 L/kg)(36 kg/d grass)(0.99304) = 1.73E-6 mrem
(5.773E-8 mrem·d/L)(0.94)(0.894 L/kg)(29 kg/d hay)(0.97944) = 1.38E-6 mrem
(5.773E-8 mrem·d/L)(0.94)(0.6079L/kg)(2 kg/d grain)(0.97944) = 6.46E-8 mrem
(5.773E-8 mrem·d/L)(0.94)(0.1967L/kg)(0.8 kg/d soil)(0.99304) = 8.48E-9 mrem
(5.773E-8 mrem·d/L)(1.00)(60 L/d water)(1.00) = 3.46E-6 mrem
Total from milk: 6.65E-6 mrem

Ingestion Dose: (poultry)

(5.5 kg/y)(6.40E-8 mrem/pCi)(1.9 d/kg)(1 pCi/L)(1 y) = 6.688E-7 mrem·d/L

(6.688E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 7.26E-8 mrem
(6.688E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 mrem
(6.688E-7 mrem·d/L)(0.94)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 3.37E-8 mrem
(6.688E-7 mrem·d/L)(0.94)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 1.35E-9 mrem
(6.688E-7 mrem·d/L)(1.00)(0.3 L/d water)(1.00) = 2.01E-7 mrem
Total from poultry: 3.08E-7 mrem

Total Dose to HSRAM Agricultural:

4.915E-5+1.19E-6+6.65E-6+3.08E-7 mrem = 5.73E-5 mrem per pCi/L

A.2.4 All Pathways

The doses for each pathway are calculated in the same manner as the HSRAM Agricultural case except most of the exposure parameters are different. The revised doses are listed below.

Inhalation Dose: (showering and ambient humidity)

(4.5+39 L/y)(1 pCi/L)(9.60E-08 mrem/pCi)(1 y) = 4.18E-6 mrem

Inhalation Dose: (resuspended soil)

(5.73E-4 kg/y)(0.1849 pCi/kg)(9.60E-8 mrem/pCi)(0.99304 y) = 1.01E-11 mrem

Ingestion Dose: (drinking)
(540 L/y)(1 pCi/L)(6.40E-08 mrem/pCi)(1 y) = 3.46E-5 mrem

Ingestion Dose: (soil)
(0.0365 kg/y)(0.1849 pCi/kg)(6.40E-8 mrem/pCi)(0.99304 y) = 4.29E-10 mrem

External Dose:
(4120 h/y)(0.1849 pCi/kg)(225 kg/m²)(0 mrem/h per Ci/m²)(0.99304 y) = 0 mrem

Ingestion Dose: (garden produce)
(6.016E-8 mrem/L)(0.894 L/kg)(4.1 kg)(1.00) = 2.21E-7 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(13.9 kg)(0.99311) = 7.42E-7 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(9.6 kg)(0.99311) = 5.13E-7 mrem
(6.016E-8 mrem/L)(0.6079L/kg)(18.5 kg)(0.99311) = 6.72E-7 mrem
Total from garden produce: 2.15E-6 mrem

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the annual amount consumed by the individual, the ingestion dose factor, the equilibrium transfer factor, the water concentration, and the ingestion period.

Ingestion Dose: (beef)
(21 kg/y)(6.40E-8 mrem/pCi)(0.01 d/kg)(1 pCi/L)(1 y) = 1.344E-8 mrem·d/L

(1.344E-8 mrem·d/L)(0.94)(0.894 L/kg)(14 kg/d grass)(0.99082) = 1.57E-7 mrem
(1.344E-8 mrem·d/L)(0.94)(0.894 L/kg)(27 kg/d hay)(0.97719) = 2.98E-7 mrem
(1.344E-8 mrem·d/L)(0.94)(0.6079L/kg)(3 kg/d grain)(0.97719) = 2.25E-8 mrem
(1.344E-8 mrem·d/L)(0.94)(0.1967L/kg)(0.6 kg/d soil)(0.99082) = 1.48E-9 mrem
(1.344E-8 mrem·d/L)(1.00)(50 L/d water)(0.99082) = 6.66E-7 mrem
Total from beef: 1.14E-6 mrem

Ingestion Dose: (milk)
(51.7 L/y)(6.40E-8 mrem/pCi)(0.0082 d/L)(1 pCi/L)(1 y) = 2.713E-8 mrem·d/L

(2.713E-8 mrem·d/L)(0.94)(0.894 L/kg)(36 kg/d grass)(0.99304) = 8.15E-7 mrem
(2.713E-8 mrem·d/L)(0.94)(0.894 L/kg)(29 kg/d hay)(0.97944) = 6.48E-7 mrem
(2.713E-8 mrem·d/L)(0.94)(0.6079L/kg)(2 kg/d grain)(0.97944) = 3.04E-8 mrem
(2.713E-8 mrem·d/L)(0.94)(0.1967L/kg)(0.8 kg/d soil)(0.99304) = 3.99E-9 mrem
(2.713E-8 mrem·d/L)(1.00)(60 L/d water)(1.00) = 1.63E-6 mrem
Total from milk: 3.12E-6 mrem

Ingestion Dose: (poultry)
(5.3 kg/y)(6.40E-8 mrem/pCi)(1.9 d/kg)(1 pCi/L)(1 y) = 6.445E-7 mrem·d/L

(6.445E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 6.99E-8 mrem
(6.445E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 mrem
(6.445E-7 mrem·d/L)(0.94)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 3.25E-8 mrem
(6.445E-7 mrem·d/L)(0.94)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 1.30E-9 mrem
(6.445E-7 mrem·d/L)(1.00)(0.3 L/d water)(1.00) = 1.93E-7 mrem
Total from poultry: 2.97E-7 mrem

Ingestion Dose: (eggs)
(5.3 kg/y)(6.40E-8 mrem/pCi)(2.1 d/kg)(1 pCi/L)(1 y) = 7.123E-7 mrem·d/L

(7.123E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 7.73E-8 mrem
(7.123E-7 mrem·d/L)(0.94)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 mrem
(7.123E-7 mrem·d/L)(0.94)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 3.59E-8 mrem
(7.123E-7 mrem·d/L)(0.94)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 1.44E-9 mrem
(7.123E-7 mrem·d/L)(1.00)(0.3 L/d water)(1.00) = 2.14E-7 mrem
Total from eggs: 3.28E-7 mrem

Total of all animal pathways = 4.89E-6 mrem

Total Dose from All Pathways:
4.18E-6+1.01E-11+3.46E-5+4.29E-10+2.15E-6+4.89E-6 mrem
= 4.58E-5 mrem per pCi/L

A.2.5 Native American Subsistence Resident

The doses for each pathway are calculated in the same manner as the HSRAM Agricultural case except that the exposure parameters are larger. The revised doses are listed below.

Inhalation Dose: (sweat lodge and ambient humidity)
(14+39 L/y)(1 pCi/L)(9.60E-08 mrem/pCi)(1 y) = 5.09E-6 mrem

Inhalation Dose: (resuspended soil)
(1.095E-3 kg/y)(0.1849 pCi/kg)(9.60E-8 mrem/pCi)(0.99304 y) = 1.93E-11 mrem

Ingestion Dose: (drinking)
(1095 L/y)(1 pCi/L)(6.40E-08 mrem/pCi)(1 y) = 7.01E-5 mrem

Ingestion Dose: (soil)
(0.0730 kg/y)(0.1849 pCi/kg)(6.40E-8 mrem/pCi)(0.99304 y) = 8.58E-10 mrem

External Dose:
(7008 h/y)(0.1849 pCi/kg)(225 kg/m^2)(0 mrem/h per Ci/m^2)(0.99304 y) = 0 mrem

Ingestion Dose: (garden produce)

(6.016E-8 mrem/L)(0.894 L/kg)(20 kg)(1.00) = 1.08E-6 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(67 kg)(0.99311) = 3.58E-6 mrem
(6.016E-8 mrem/L)(0.894 L/kg)(46 kg)(0.99311) = 2.46E-6 mrem
(6.016E-8 mrem/L)(0.6079L/kg)(108kg)(0.99311) = 3.92E-6 mrem
Total from garden produce: 1.10E-5 mrem

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the annual amount consumed by the individual, the ingestion dose factor, the equilibrium transfer factor, the water concentration, and the ingestion period.

Ingestion Dose: (beef)

(42 kg/y)(6.40E-8 mrem/pCi)(0.01 d/kg)(1 pCi/L)(1 y) = 2.688E-8 mrem·d/L

(2.688E-8 mrem·d/L)(0.94)(0.894 L/kg)(14 kg/d grass)(0.99082) = 3.13E-7 mrem
(2.688E-8 mrem·d/L)(0.94)(0.894 L/kg)(27 kg/d hay)(0.97719) = 5.96E-7 mrem
(2.688E-8 mrem·d/L)(0.94)(0.6079L/kg)(3 kg/d grain)(0.97719) = 4.50E-8 mrem
(2.688E-8 mrem·d/L)(0.94)(0.1967L/kg)(0.6 kg/d soil)(0.99082) = 2.95E-9 mrem
(2.688E-8 mrem·d/L)(1.00)(50 L/d water)(0.99082) = 1.33E-6 mrem
Total from beef: 2.29E-6 mrem

Ingestion Dose: (milk)

(219 L/y)(6.40E-8 mrem/pCi)(0.0082 d/L)(1 pCi/L)(1 y) = 1.149E-7 mrem·d/L

(1.149E-7 mrem·d/L)(0.94)(0.894 L/kg)(36 kg/d grass)(0.99304) = 3.45E-6 mrem
(1.149E-7 mrem·d/L)(0.94)(0.894 L/kg)(29 kg/d hay)(0.97944) = 2.74E-6 mrem
(1.149E-7 mrem·d/L)(0.94)(0.6079L/kg)(2 kg/d grain)(0.97944) = 1.29E-7 mrem
(1.149E-7 mrem·d/L)(0.94)(0.1967L/kg)(0.8 kg/d soil)(0.99304) = 1.69E-8 mrem
(1.149E-7 mrem·d/L)(1.00)(60 L/d water)(1.00) = 6.89E-6 mrem
Total from milk: 1.32E-5 mrem

Ingestion Dose: (poultry)

(11 kg/y)(6.40E-8 mrem/pCi)(1.9 d/kg)(1 pCi/L)(1 y) = 1.338E-6 mrem·d/L

(1.338E-6 mrem·d/L)(0.94)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 1.45E-7 mrem
(1.338E-6 mrem·d/L)(0.94)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 mrem
(1.338E-6 mrem·d/L)(0.94)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 6.74E-8 mrem
(1.338E-6 mrem·d/L)(0.94)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 2.70E-9 mrem
(1.338E-6 mrem·d/L)(1.00)(0.3 L/d water)(1.00) = 4.01E-7 mrem
Total from poultry: 6.17E-7 mrem

Ingestion Dose: (eggs)

(11 kg/y)(6.40E-8 mrem/pCi)(2.1 d/kg)(1 pCi/L)(1 y) = 1.478E-6 mrem·d/L

(1.478E-6 mrem·d/L)(0.94)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 1.60E-7 mrem
(1.478E-6 mrem·d/L)(0.94)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 mrem
(1.478E-6 mrem·d/L)(0.94)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 7.44E-8 mrem
(1.478E-6 mrem·d/L)(0.94)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 2.99E-9 mrem
(1.478E-6 mrem·d/L)(1.00)(0.3 L/d water)(1.00) = 4.43E-7 mrem
Total from eggs: 6.81E-7 mrem

Total of all animal pathways = 1.68E-5 mrem

Total Dose for the NASR:
5.09E-6+1.93E-11+7.01E-5+8.58E-10+1.10E-5+1.68E-5 mrem
= 1.03E-4 mrem per pCi/L

A.2.6 Columbia River Population

The collective doses for each pathway are calculated in the same manner as the All Pathways Irrigator case scaled up for a population of 5 million, with a lower irrigation rate, and reduced by a factor of 1000 to convert from mrem to rem. The inhalation and ingestion doses are adjusted for the population and unit conversion as shown below. The new soil concentration is shown also.

Inhalation: (9.60E-8 mrem/pCi)(5.0E+6)(0.001 rem/mrem) = 4.80E-4 rem/pCi
Ingestion: (6.40E-8 mrem/pCi)(5.0E+6)(0.001 rem/mrem) = 3.20E-4 rem/pCi

$C_{s,H3}$ = (8.94)(0.022)(1 pCi/L)(63.5 cm)/(63.5 + 5.23 cm)/(1 kg/L)
$C_{s,H3}$ = 0.1817 pCi/kg

Inhalation Dose: (showering and ambient humidity)
(4.5+39 L/y)(1 pCi/L)(4.80E-4 rem/pCi)(1 y) = 2.09E-2 rem

Inhalation Dose: (resuspended soil)
(4.16E-4 kg/y)(0.1817 pCi/kg)(4.80E-4 rem/pCi)(0.99304 y) = 3.60E-8 rem

Ingestion Dose: (drinking)
(540 L/y)(1 pCi/L)(3.20E-4 rem/pCi)(1 y) = 0.1728 rem

Ingestion Dose: (soil)
(0.0365 kg/y)(0.1817 pCi/kg)(3.20E-4 rem/pCi)(0.99304 y) = 2.11E-6 rem

External Dose:
(4383 h/y)(0.1817 pCi/kg)(225 kg/m²)(0 mrem/h per Ci/m²)(0.99304 y) = 0 mrem

With a lower irrigation rate, the irrigation dilution factor changes to become (63.5

cm)/(63.5+5.23cm)=0.924. The common factor used in the garden produce calculation is shown below.

(0.924)(1 pCi/L)(3.20E-4 rem/pCi)=2.957E-4 rem/L

Ingestion Dose: (garden produce)

(2.957E-4 rem/L)(0.894 L/kg)(4.1 kg)(1.00) = 1.08E-3 rem
(2.957E-4 rem/L)(0.894 L/kg)(13.9 kg)(0.99311) = 3.65E-3 rem
(2.957E-4 rem/L)(0.894 L/kg)(9.6 kg)(0.99311) = 2.52E-3 rem
(2.957E-4 rem/L)(0.6079L/kg)(18.5 kg)(0.99311) = 3.30E-3 rem
Total from garden produce: 1.06E-2 rem

The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the annual amount consumed by the individual, the ingestion dose factor, the equilibrium transfer factor, the water concentration, and the ingestion period.

Ingestion Dose: (beef)

(21 kg/y)(3.20E-4 rem/pCi)(0.01 d/kg)(1 pCi/L)(1 y) = 6.720E-5 rem·d/L

(6.720E-5 rem·d/L)(0.924)(0.894 L/kg)(14 kg/d grass)(0.99082) = 7.70E-4 rem
(6.720E-5 rem·d/L)(0.924)(0.894 L/kg)(27 kg/d hay)(0.97719) = 1.46E-3 rem
(6.720E-5 rem·d/L)(0.924)(0.6079L/kg)(3 kg/d grain)(0.97719) = 1.11E-4 rem
(6.720E-5 rem·d/L)(0.924)(0.1967L/kg)(0.6 kg/d soil)(0.99082) = 7.26E-6 rem
(6.720E-5 rem·d/L)(1.00)(50 L/d water)(0.99082) = 3.33E-3 rem
Total from beef: 5.68E-3 rem

Ingestion Dose: (milk)

(51.7 L/y)(3.20E-4 rem/pCi)(0.0082 d/L)(1 pCi/L)(1 y) = 1.357E-4 rem·d/L

(1.357E-4 rem·d/L)(0.924)(0.894 L/kg)(36 kg/d grass)(0.99304) = 4.01E-3 rem
(1.357E-4 rem·d/L)(0.924)(0.894 L/kg)(29 kg/d hay)(0.97944) = 3.18E-3 rem
(1.357E-4 rem·d/L)(0.924)(0.6079L/kg)(2 kg/d grain)(0.97944) = 1.49E-4 rem
(1.357E-4 rem·d/L)(0.924)(0.1967L/kg)(0.8 kg/d soil)(0.99304) = 1.96E-5 rem
(1.357E-4 rem·d/L)(1.00)(60 L/d water)(1.00) = 8.14E-3 rem
Total from milk: 1.55E-2 rem

Ingestion Dose: (poultry)

(5.3 kg/y)(3.20E-4 rem/pCi)(1.9 d/kg)(1 pCi/L)(1 y) = 3.222E-3 rem·d/L

(3.445E-3 rem·d/L)(0.924)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 3.44E-4 rem
(3.222E-3 rem·d/L)(0.924)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 rem
(3.222E-3 rem·d/L)(0.924)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 1.60E-4 rem
(3.222E-3 rem·d/L)(0.924)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 6.40E-6 rem
(3.222E-3 rem·d/L)(1.00)(0.3 L/d water)(1.00) = 9.67E-4 rem
Total from poultry: 1.48E-3 rem

Ingestion Dose: (eggs)

(5.3 kg/y)(3.20E-4 rem/pCi)(2.1 d/kg)(1 pCi/L)(1 y) = 3.562E-3 rem·d/L

(3.562E-3 rem·d/L)(0.924)(0.894 L/kg)(0.13 kg/d grass)(0.99304) = 3.80E-4 rem
(3.562E-3 rem·d/L)(0.924)(0.894 L/kg)(0.0 kg/d hay)(0.97944) = 0.0 rem
(3.562E-3 rem·d/L)(0.924)(0.6079L/kg)(0.09 kg/d grain)(0.97944) = 1.76E-4 rem
(3.562E-3 rem·d/L)(0.924)(0.1967L/kg)(0.011 kg/d soil)(0.99304) = 7.07E-6 rem
(3.562E-3 rem·d/L)(1.00)(0.3 L/d water)(1.00) = 1.07E-3 rem
Total from eggs: 1.63E-3 rem

Ingestion Dose: (fish)

(0.003 kg/y)(1 L/kg)(1 pCi/L)(3.20E-4 rem/pCi)(1 y) = 9.60E-7 rem

Total of all animal pathways = 2.43E-2 rem

Total Collective Dose to the Population:

2.09E-2 + 3.60E-8 + 0.1728 + 2.11E-6 + 1.06E-2 + 2.43E-2 rem
= 0.229 person-rem per pCi/L

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Appendix B

Hand Calculations for Carbon-14

HAND CALCULATIONS FOR CARBON-14

B.1 No Water Infiltration -- Post-Intrusion Resident

Only two of the exposure scenarios listed in Table 2 will be evaluated, the post-intrusion gardener and the all-pathways irrigator. These two exercise all of the relevant calculations. The other scenarios are very similar to previous calculations with tritium, or are very similar to the calculations shown for C-14.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

It will be assumed that 1 curie C-14 is exhumed from the well shaft and spread over an area of 200 m^2. The average soil concentration is computed as shown below.

C_s = (1 Ci)(1E12 pCi/Ci)/(200 m^2)/(225 kg/m^2) = 2.222E+7 pCi/kg

This concentration decreases with time due to leaching from the surface layer during the irrigation season and radioactive decay. Decay factors used in the dose calculations are computed below (see Table 30).

λ_r = (0.69315)/(5730 y) = 1.210E-4 y^{-1} λ_l = 0.0644 y^{-1} (Table 27)
$\lambda_t = \lambda_r + \lambda_l$ = 0.064521 y^{-1}

$\lambda_t T_{irr}$ = (0.064521 y^{-1})(0.5 y) = 0.032261
$DS(T_{irr})$ = Exp(-0.032261) = 0.96825
$IDS(T_{irr})$ = [1 - Exp(-0.032261)]/(0.032261) = 0.98404

$\lambda_r T_{no}$ = (1.21E-4 y^{-1})(0.5 y) = 6.05E-5
$IDR(T_{no})$ = [1 - Exp(-6.05E-5)]/(6.05E-5) = 0.99997

$T_{irr} \cdot IDS(T_{irr}) + T_{no} \cdot DS(T_{irr}) \cdot IDR(T_{no})$ =
(0.5y)(0.98404) + (0.5y)(0.96825)(0.99997) = 0.97613 y

$DS(T_h)$ = Exp[-(0.064521 y^{-1})(0.25 y)] = 0.98400

$\lambda_r T_{veg}$ = (1.21E-4 y^{-1})(90 d)/(365.25 d/y) = 2.98E-5
$IDR(T_{veg})$ = [1 - Exp(-2.98E-5)]/(2.98E-5) = 0.99999

$DS(T_h) \cdot IDR(T_{veg})$ = (0.98400)(0.99999) = 0.98399

A mass loading approach is used, so that the resident inhales a total of 573 mg, or 5.73E-04 kg (Table 17) of soil over the course of a year. He also ingests a total of 0.0365 kg soil (Table 13) during the year. The inhalation and ingestion doses from these sources are shown below. Note that the C-14 internal dose factors for inhalation and ingestion are the same.

Inhalation Dose: (resuspended soil)

(5.73E-4 kg/y)(2.222E+7 pCi/kg)(2.09E-6 mrem/pCi)(0.97613 y) = 0.0260 mrem

Ingestion Dose: (soil only)

(0.0365 kg)(2.222E+7 pCi/kg)(2.09E-6 mrem/pCi)(0.97613 y) = 1.65 mrem

External dose is computed from the external dose rate factor for C-14, the soil concentration and the exposure time (900 h from Section 2.2.5). A modified form of the soil concentration is used to simplify the calculation. This is shown below.

External Dose:

(900 h/y)(1 Ci)/(200 m^2)(6.82E-3 mrem/h per Ci/m^2)(0.97613 y) = 0.0300 mrem

The vegetable produce from the garden is contaminated by root uptake and rain splash. Doses from each are shown below. The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y. The product of soil concentration and ingestion dose is combined into a single quantity to simplify the calculation.

(2.222E+7 pCi/kg)(2.09E-6 mrem/pCi)=46.44 mrem/kg

Ingestion Dose: (root uptake only)

(46.44 mrem/kg)(0.7)(0.09)(4.1 kg)(0.98404) = 11.8 mrem
(46.44 mrem/kg)(0.7)(0.25)(13.9 kg)(0.98399) = 111.2 mrem
(46.44 mrem/kg)(0.7)(0.18)(9.6 kg)(0.98399) = 55.3 mrem
(46.44 mrem/kg)(0.7)(0.91)(18.5 kg)(0.98399) = 538.5 mrem
Total from root uptake: 716.7 mrem

Ingestion Dose: (rain splash only)

To simplify the calculation, the mass loading, ground deposition speed, soil concentration and ingestion dose factor are combined in a single factor.

(1 mg/m^3)(0.01 m/s)(46.44 mrem/kg)(86,400 s/d) = 0.04012 mrem/d/m^2

(0.04012mrem/d/m^2)(18d)(0.407)(1.0)/(2.0kg/m^2)(4.1kg)(0.98404) = 0.593mrem
(0.04012mrem/d/m^2)(20d)(0.835)(0.1)/(2.0kg/m^2)(13.9kg)(0.98399) = 0.458mrem
(0.04012mrem/d/m^2)(20d)(0.857)(0.1)/(3.0kg/m^2)(9.6kg)(0.98399) = 0.217mrem
(0.04012mrem/d/m^2)(20d)(0.371)(0.1)/(0.8kg/m^2)(18.5kg)(0.98399) = 0.677mrem
Total from rain splash: 1.945mrem

Total Dose to Gardener:

0.0260 + 1.65 + 0.0298 + 716.7 + 1.945 mrem = 720 mrem per Ci exhumed

B.2 Low Water Infiltration -- All Pathways Farmer

It will be assumed in each exposure scenario that the well water concentration is 1 pCi/L. Thus the doses computed are per pCi/L. The main dose pathway in every case is the drinking water pathway.

Normally, three significant digits are kept during calculations. Because the spreadsheet software keeps several digits, agreement with the spreadsheet can only be obtained if 4 or 5 significant digits are retained. This is particularly true in the calculation of decay factors.

Inhalation of well water during showers amounts to 0.045 L/y (Table 18). Inhalation of evaporated well water under ambient conditions amounts to 0.39 L/y. The individual ingests a total of 540 L/y of drinking water (Table 13). The doses from these pathways are shown below. Because the ground water comes from the well and is ingested or inhaled shortly after, no decay factors are needed.

Inhalation Dose: (showering and ambient humidity)

(0.046+0.039 L/y)(1 pCi/L)(2.09E-06 mrem/pCi)(1 y) = 1.76E-7 mrem

Ingestion Dose: (drinking)

(540 L/y)(1 pCi/L)(2.09E-06 mrem/pCi)(1 y) = 1.13E-3 mrem

The soil concentration at the end of the year (apart from decay corrections) is based on 82.3 cm of irrigation water applied to the garden and pasture (Section 2.5). The soil concentration is shown below in two units. Both are used in the calculations that follow.

C_s = (82.3 cm/y)(10,000 cm²/m²)(0.001 L/cm³)(1 pCi/L) = 823 pCi/m²

or

C_s = (823 pCi/m²)/(225 kg/m²) = 3.6578 pCi/kg

The soil concentration decreases with time due to leaching from the surface layer during the irrigation season and radioactive decay. Additional decay factors used in the dose calculations for the all pathways irrigation scenario are shown below (see Tables 30 and 31).

$\lambda_1 T_{irr}$ = (0.064521 y^{-1})(0.5 y) = 0.032261

$DI(T_{irr})$ = [1 - Exp(-0.032261)]/(0.032261) = 0.98404

$IDI(T_{irr})$ = [0.032261 - 1 + Exp(-0.032261)]/(0.032261)² = 0.49471

$T_{irr} \cdot IDI(T_{irr}) + T_{no} \cdot DI(T_{irr}) \cdot IDR(T_{no}) =$
$(0.5y)(0.49471) + (0.5y)(0.98404)(0.99997) = 0.73936$ y

$\lambda_r T_{veg} = (1.21E\text{-}4\ y^{-1})(90\ d)/(365.25\ d/y) = 2.98E\text{-}5$
$IDR(T_{veg}) = [1 - Exp(-2.98E\text{-}5)]/(2.98E\text{-}5) = 0.99999$

$DI(T_{irr}) \cdot IDR(T_{veg}) = (0.98404)(0.99999) = 0.98403$

$\lambda_r T_{beef} = (1.21E\text{-}4\ y^{-1})(120\ d)/(365.25\ d/y) = 3.98E\text{-}5$
$IDR(T_{beef}) = [1 - Exp(-3.98E\text{-}5)]/(3.98E\text{-}5) = 0.99998$

$DI(T_{irr}) \cdot IDR(T_{beef}) = (0.98404)(0.99998) = 0.98402$

$DR(T_s) = Exp[-(1.21E\text{-}4\ y^{-1})(90\ d)/(365.25\ d/y)] = 0.99997$

$DR(T_s) \cdot IDR(T_{beef}) = (0.99997)(0.99998) = 0.99995$

$DI(T_{irr}) \cdot DR(T_s) \cdot IDR(T_{beef}) = (0.98404)(0.99997)(0.99998) = 0.98399$

$\lambda_r T_{an} = (1.21E\text{-}4\ y^{-1})(90\ d)/(365.25\ d/y) = 2.98E\text{-}5$
$IDR(T_{an}) = [1 - Exp(-2.98E\text{-}5)]/(2.98E\text{-}5) = 0.99999$

$DI(T_{irr}) \cdot DR(T_s) \cdot IDR(T_{an}) = (0.98404)(0.99997)(0.99999) = 0.98400$

$DR(T_s) \cdot IDR(T_{an}) = (0.99997)(0.99999) = 0.99996$

Inhalation of resuspended soil amounts to 573 mg (5.73E-04 kg) of soil over the course of a year. The individual also ingests a total of 0.0365 kg soil during the year. The time of exposure to external radiation is 4120 h/y. The inhalation, ingestion, and external doses from the soil are shown below.

Inhalation Dose: (resuspended soil)
(5.73E-4 kg/y)(3.6578 pCi/kg)(2.09E-6 mrem/pCi)(0.73936 y) = 3.24E-9 mrem

Ingestion Dose: (soil)
(0.0365 kg/y)(3.6578 pCi/kg)(2.09E-6 mrem/pCi)(0.73936 y) = 2.06E-7 mrem

External Dose:
(4120 h/y)(8.23E-10 Ci/m²)(6.82E-3 mrem/h per Ci/m²)(0.73936 y) = 1.71E-8 mrem

The vegetable produce contamination is calculated as shown below. The contaminated food consumption rate is combined with the ingestion period (1 year) so that the column of consumption rates has units of kg rather than kg/y. The product of the soil concentration and the ingestion dose factor is computed below and used in the calculations to simplify the equations.

(3.6578 pCi/kg)(2.09E-6 mrem/pCi)=7.645E-6 mrem/kg

Separate dry-to-wet ratios and consumption amounts are needed for each plant type. The soil-to-plant concentration ratio is 0.7 for all plant types (Table 25). The ingestion doses from root uptake and rain splash are shown below.

Ingestion Dose -- Garden Produce: (root uptake only)

(7.645E-6 mrem/kg)(0.7)(0.09)(4.1 kg)(0.49471) = 9.77E-7 mrem
(7.645E-6 mrem/kg)(0.7)(0.25)(13.9 kg)(0.98403) = 1.83E-5 mrem
(7.645E-6 mrem/kg)(0.7)(0.18)(9.6 kg)(0.98403) = 9.10E-6 mrem
(7.645E-6 mrem/kg)(0.7)(0.91)(18.5 kg)(0.98403) = 8.87E-5 mrem
Total from root uptake: 1.17E-4 mrem

Ingestion Dose -- Garden Produce: (rain splash only)

To simplify the calculation, the mass loading, ground deposition speed, soil concentration and ingestion dose factor are combined in a single factor.

(1 mg/m³)(0.01 m/s)(7.645E-6 mrem/kg)(86,400 s/d) = 6.605E-9 mrem/d/m²

(6.605E-9mrem/d/m²)(18d)(0.407)(1.0)/(2.0kg/m²)(4.1kg)(0.49471)=4.91E-8mrem
(6.605E-9mrem/d/m²)(20d)(0.835)(0.1)/(2.0kg/m²)(13.9kg)(0.98403)=7.54E-8mrem
(6.605E-9mrem/d/m²)(20d)(0.857)(0.1)/(3.0kg/m²)(9.6kg)(0.98403)=3.56E-8mrem
(6.605E-9mrem/d/m²)(20d)(0.371)(0.1)/(0.8kg/m²)(18.5kg)(0.98403)=1.12E-7mrem
Total from rain splash: 2.72E-7mrem

Ingestion Dose -- Garden Produce: (direct deposition)

To simplify the calculation, the activity addition rate and ingestion dose factor are soil concentration and ingestion dose factor are combined in a single factor.

(823 pCi/m²)/(0.5 y)/(365.25 d/y)(2.09E-6 mrem/pCi) = 9.419E-6 mrem/d/m²

(9.419E-6mrem/d/m²)(18d)(0.25)(1.0)/(2.0kg/m²)(4.1kg)(1.00)=8.69E-5mrem
(9.419E-6mrem/d/m²)(20d)(0.25)(0.1)/(2.0kg/m²)(13.9kg)(0.99999)=3.27E-5mrem
(9.419E-6mrem/d/m²)(20d)(0.25)(0.1)/(3.0kg/m²)(9.6kg)(0.99999)=1.51E-5mrem
(9.419E-6mrem/d/m²)(20d)(0.25)(0.1)/(0.8kg/m²)(18.5kg)(0.99999)=1.09E-4mrem
Total from direct deposition: 2.44E-4mrem

Total Dose from Garden Produce:

1.17E-4 + 2.72E-7 + 2.44E-4 mrem = 3.61E-4 mrem

The animal pathways add the dose from animal products that are contaminated by ingestion of well water, contaminated fodder and soil. The dose for each pathway is the sum of contributions to the animal's diet. In particular, there is fresh feed, stored hay, stored grain, soil, and drinking water. Each of these has a common factor made of the annual amount consumed by the individual, the ingestion dose factor, the equilibrium transfer factor, the water concentration, and the ingestion period.

Common Factor for Beef:
(0.049 d/kg)(21 kg/y)(2.09E-6 mrem/pCi)(1 y) = 2.151E-6 mrem·d/pCi

Ingestion Dose from Beef: (drinking water ingestion)
(2.151E-6 mrem·d/pCi)(50 L/d)(1 pCi/L)(0.99998) = 1.08E-4 mrem

Ingestion Dose from Beef: (soil ingestion)
(2.151E-6 mrem·d/pCi)(0.6 kg/d)(3.6578 pCi/kg)(0.98402) = 4.65E-6 mrem

Ingestion Dose from Beef: (root uptake into feed)
(2.151E-6 mrem·d/pCi)(3.6578 pCi/kg) = 7.868E-6 mrem·d/kg

(7.868E-6 mrem·d/kg)(0.7)(0.22)(14 kg/d grass)(0.98402) = 1.67E-5 mrem
(7.868E-6 mrem·d/kg)(0.7)(0.22)(27 kg/d hay)(0.98399) = 3.22E-5 mrem
(7.868E-6 mrem·d/kg)(0.7)(0.91)(3 kg/d grain)(0.98399) = 1.48E-5 mrem
Total from root uptake: 6.37E-5 mrem

Ingestion Dose from Beef: (rain splash onto feed)
(1 mg/m^3)(0.01 m/s)(7.868E-6 mrem·d/kg)(86,400 s/d) = 6.798E-9 mrem/m^2

(6.798E-9mrem/m^2)(15.6d)(0.616)(1.0)/(1.5kg/m^2)(14kg/d)(0.98402)=6.00E-7mrem
(6.798E-9mrem/m^2)(18.0d)(0.472)(1.0)/(1.0kg/m^2)(27kg/d)(0.98399)=1.53E-6mrem
(6.798E-9mrem/m^2)(20.0d)(0.472)(0.1)/(1.0kg/m^2)(3kg/d)(0.98399)=1.89E-8mrem
Total from rain splash: 2.15E-6mrem

Ingestion Dose from Beef: (direct deposition onto feed)
To simplify the calculation, the activity addition rate and ingestion dose factor are soil concentration and ingestion dose factor are combined in a single factor.
(823 pCi/m^2)/(0.5 y)/(365.25 d/y)(2.151E-6 mrem·d/pCi) = 9.693E-6 mrem/m^2

(9.693E-6mrem/d/m^2)(15.6d)(0.25)(1.0)/(1.5kg/m^2)(14kg/d)(0.99998)=3.53E-4mrem
(9.693E-6mrem/d/m^2)(18.0d)(0.25)(1.0)/(1.0kg/m^2)(27kg/d)(0.99995)=1.18E-3mrem
(9.693E-6mrem/d/m^2)(20.0d)(0.25)(0.1)/(1.0kg/m^2)(3kg/d)(0.99995)=1.45E-5mrem
Total from direct deposition: 1.54E-3mrem

Total Dose from Beef: 1.72E-3 mrem

Common Factor for Milk:
(0.0105 d/L)(51.7 L/y)(2.09E-6 mrem/pCi)(1 y) = 1.135E-6 mrem·d/pCi

Ingestion Dose from Milk: (drinking water ingestion)
(1.135E-6 mrem·d/pCi)(60 L/d)(1 pCi/L) = 6.81E-5 mrem

Ingestion Dose from Milk: (soil ingestion)
(1.135E-6 mrem·d/pCi)(0.8 kg/d)(3.6578 pCi/kg)(0.73936) = 2.46E-6 mrem

Ingestion Dose from Milk: (root uptake into feed)
(1.135E-6 mrem·d/pCi)(3.6578 pCi/kg) = 4.152E-6 mrem·d/kg

(4.152E-6 mrem·d/kg)(0.7)(0.22)(36 kg/d grass)(0.73936) = 1.70E-5 mrem
(4.152E-6 mrem·d/kg)(0.7)(0.22)(29 kg/d hay)(0.98400) = 1.82E-5 mrem
(4.152E-6 mrem·d/kg)(0.7)(0.91)(2 kg/d grain)(0.98400) = 5.21E-6 mrem
Total from root uptake: 4.05E-5 mrem

Ingestion Dose from Milk: (rain splash onto feed)
(1 mg/m³)(0.01 m/s)(4.152E-6 mrem·d/kg)(86,400 s/d) = 3.587E-9 mrem/m²

(3.587E-9mrem/m²)(15.6d)(0.616)(1.0)/(1.5kg/m²)(36kg/d)(0.73936)=6.12E-7mrem
(3.587E-9mrem/m²)(18.0d)(0.472)(1.0)/(1.0kg/m²)(29kg/d)(0.98400)=8.70E-7mrem
(3.587E-9mrem/m²)(20.0d)(0.472)(0.1)/(1.0kg/m²)(2kg/d)(0.98400)=6.66E-9mrem
Total from rain splash: 1.49E-6mrem

Ingestion Dose from Milk: (direct deposition onto feed)
To simplify the calculation, the activity addition rate and ingestion dose factor are soil concentration and ingestion dose factor are combined in a single factor.
(823 pCi/m²)/(0.5 y)/(365.25 d/y)(1.135E-6 mrem·d/pCi) = 5.115E-6 mrem/m²

(5.115E-6mrem/m²)(15.6d)(0.25)(1.0)/(1.5kg/m²)(36kg/d)(1.00)=4.79E-4mrem
(5.115E-6mrem/m²)(18.0d)(0.25)(1.0)/(1.0kg/m²)(29kg/d)(0.99996)=6.67E-4mrem
(5.115E-6mrem/m²)(20.0d)(0.25)(0.1)/(1.0kg/m²)(2kg/d)(0.99996)=5.11E-6mrem
Total from direct deposition: 1.15E-3mrem

Total Dose from Milk: 1.26E-3 mrem

Common Factor for Poultry:
(4.2 d/kg)(5.3 kg/y)(2.09E-6 mrem/pCi)(1 y) = 4.652E-5 mrem·d/pCi

Ingestion Dose from Poultry: (drinking water ingestion)
(4.652E-5 mrem·d/pCi)(0.3 L/d)(1 pCi/L) = 1.40E-5 mrem

Ingestion Dose from Poultry: (soil ingestion)
(4.652E-5 mrem·d/pCi)(0.011 kg/d)(3.6578 pCi/kg)(0.73936) = 1.38E-6 mrem

Ingestion Dose from Poultry: (root uptake into feed)

(4.652E-5 mrem·d/pCi)(3.6578 pCi/kg) = 1.702E-4 mrem·d/kg

(1.702E-4 mrem·d/kg)(0.7)(0.22)(0.13 kg/d grass)(0.73936) = 2.52E-6 mrem
(1.702E-4 mrem·d/kg)(0.7)(0.22)(0.0 kg/d hay)(0.98400) = 0.0 mrem
(1.702E-4 mrem·d/kg)(0.7)(0.91)(0.09 kg/d grain)(0.98400) = 9.60E-6 mrem
Total from root uptake: 4.05E-5 mrem

Ingestion Dose from Poultry: (rain splash onto feed)

(1 mg/m³)(0.01 m/s)(1.702E-4 mrem·d/kg)(86,400 s/d) = 1.471E-7 mrem/m²

(1.471E-7mrem/m²)(15.6d)(0.616)(1.)/(1.5kg/m²)(.13kg/d)(0.73936)=9.06E-8mrem
(1.471E-7mrem/m²)(18.0d)(0.472)(1.)/(1.0kg/m²)(.0 kg/d)(0.98400)=0.0 mrem
(1.471E-7mrem/m²)(20.0d)(0.472)(.1)/(1.0kg/m²)(.09kg/d)(0.98400)=1.23E-8mrem
Total from rain splash: 1.03E-7mrem

Ingestion Dose from Poultry: (direct deposition onto feed)

To simplify the calculation, the activity addition rate and ingestion dose factor are soil concentration and ingestion dose factor are combined in a single factor.

(823 pCi/m²)/(0.5 y)/(365.25 d/y)(4.652E-5 mrem·d/pCi) = 2.096E-4 mrem/m²

(2.096E-4mrem/m²)(15.6d)(0.25)(1.)/(1.5kg/m²)(.13kg/d)(1.00)=7.08E-5mrem
(2.096E-4mrem/m²)(18.0d)(0.25)(1.)/(1.0kg/m²)(0.0kg/d)(0.99996)=0.0 mrem
(2.096E-4mrem/m²)(20.0d)(0.25)(.1)/(1.0kg/m²)(.09kg/d)(0.99996)=9.43E-6mrem
Total from direct deposition: 8.03E-5mrem

Total Dose from Poultry: 1.08E-4 mrem

Common Factor for Eggs:

(3.1 d/kg)(5.3 kg/y)(2.09E-6 mrem/pCi)(1 y) = 3.434E-5 mrem·d/pCi

Ingestion Dose from Eggs: (drinking water ingestion)

(3.434E-5 mrem·d/pCi)(0.3 L/d)(1 pCi/L) = 1.03E-5 mrem

Ingestion Dose from Eggs: (soil ingestion)

(3.434E-5 mrem·d/pCi)(0.011 kg/d)(3.6578 pCi/kg)(0.73936) = 1.02E-6 mrem

Ingestion Dose from Eggs: (root uptake into feed)

(3.434E-5 mrem·d/pCi)(3.6578 pCi/kg) = 1.256E-4 mrem·d/kg

(1.256E-4 mrem·d/kg)(0.7)(0.22)(0.13 kg/d grass)(0.73936) = 1.86E-6 mrem
(1.256E-4 mrem·d/kg)(0.7)(0.22)(0.0 kg/d hay)(0.98400) = 0.0 mrem
(1.256E-4 mrem·d/kg)(0.7)(0.91)(0.09 kg/d grain)(0.98400) = 7.09E-6 mrem
Total from root uptake: 8.94E-6 mrem

Ingestion Dose from Eggs: (rain splash onto feed)

(1 mg/m³)(0.01 m/s)(1.256E-4 mrem·d/kg)(86,400 s/d) = 1.085E-7 mrem/m²

(1.085E-7mrem/m²)(15.6d)(0.616)(1.)/(1.5kg/m²)(.13kg/d)(0.73936)=6.68E-8mrem
(1.085E-7mrem/m²)(18.0d)(0.472)(1.)/(1.0kg/m²)(.0 kg/d)(0.98400)=0.0 mrem
(1.085E-7mrem/m²)(20.0d)(0.472)(.1)/(1.0kg/m²)(.09kg/d)(0.98400)=9.07E-9mrem
Total from rain splash: 7.59E-8mrem

Ingestion Dose from Eggs: (direct deposition onto feed)

To simplify the calculation, the activity addition rate and ingestion dose factor are soil concentration and ingestion dose factor are combined in a single factor.

(823 pCi/m²)/(0.5 y)/(365.25 d/y)(3.434E-5 mrem·d/pCi) = 1.548E-4 mrem/m²

(1.548E-4mrem/m²)(15.6d)(0.25)(1.)/(1.5kg/m²)(.13kg/d)(1.00)=5.23E-5mrem
(1.548E-4mrem/m²)(18.0d)(0.25)(1.)/(1.0kg/m²)(0.0kg/d)(0.99996)=0.0 mrem
(1.548E-4mrem/m²)(20.0d)(0.25)(.1)/(1.0kg/m²)(.09kg/d)(0.99996)=6.97E-6mrem
Total from direct deposition: 5.93E-5mrem

Total Dose from Eggs: 7.96E-5 mrem

Total of All Animal Pathways = 3.17E-3 mrem

Total Dose from All Pathways:

1.76E-7 + 1.13E-3 + 3.24E-9 + 2.06E-7 + 1.70E-8 + 3.61E-4 + 3.17E-3 mrem
= 4.67E-3 mrem per pCi/L

Appendix C

Output from CAP88-PC for H-3 and Carbon-14

OUTPUT FROM CAP88-PC FOR H-3 AND CARBON-14

From the SYNOPSIS report, the worst-case wind direction was east southeast (ESE). From the CHI/Q TABLE report, the air transport factor for this direction is 7.980E-6 s/m³. From the SUMMARY report, the effective dose equivalent for H-3 is 0.00189 mrem, and for C-14 0.105 mrem.

At a location where the air transport factor is 1.0E-4 s/m³, the CAP88-PC dose is computed as shown below. These values are listed in Table 28.

H-3: (0.00189 mrem)(1.0E-4 s/m³)/(7.98E-6 s/m³) = 0.0237 mrem

C-14: (0.105 mrem)(1.0E-4 s/m³)/(7.98E-6 s/m³) = 1.32 mrem

The EPA default parameter file was used as input to the CAP88-PC calculations rather than the Hanford-specific parameter file.

C A P 8 8 - P C

Version 1.00

Clean Air Act Assessment Package - 1988

S Y N O P S I S R E P O R T

Non-Radon Individual Assessment
Nov 30, 1999 7:45 am

Facility: Various Cases
Address:
City: Richland
State: WA Zip: 99352

Effective Dose Equivalent
(mrem/year)

1.07E-01

At This Location: 1000 Meters East Southeast
Source Category:
Source Type: Stack
Emission Year: 1996

Comments:

Dataset Name: ILAW PA
Dataset Date: Nov 30, 1999 7:45 am
Wind File: WNDFILES\HB-200E.WND

Nov 30, 1999 7:45 am
SYNOPSIS

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 1000 Meters East Southeast
Lifetime Fatal Cancer Risk: 2.61E-06

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Dose Equivalent (mrem/y)
GONADS	4.68E-02
BREAST	1.19E-01
R MAR	2.08E-01
LUNGS	5.64E-02
THYROID	5.61E-02
ENDOST	4.32E-01
RMNDR	1.02E-01
EFFEC	1.07E-01

RADIONUCLIDE EMISSIONS DURING THE YEAR 1996

Nuclide	Class	Size	Source #1 Ci/y	TOTAL Ci/y
H-3	*	0.00	1.0E+00	1.0E+00
C-14	*	0.00	1.0E+00	1.0E+00

SITE INFORMATION

Temperature:	12 degrees C
Precipitation:	17 cm/y
Mixing Height:	1000 m

SOURCE INFORMATION

Source Number: 1

Stack Height (m): 1.00
Diameter (m): 0.10

Plume Rise Pasquill Cat:	A	B	C	D	E	F	G
Zero:	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	1.000	1.000	1.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	0.000	0.000	0.000

Food Arrays were not generated for this run.
Default Values used.

DISTANCES USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

1000

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Version 1.00

Clean Air Act Assessment Package - 1988

D O S E A N D R I S K E Q U I V A L E N T S U M M A R I E S

Non-Radon Individual Assessment
Nov 30, 1999 7:45 am

Facility: Various Cases
Address:
City: Richland
State: WA Zip: 99352

Source Category:
Source Type: Stack
Emission Year: 1996

Comments:

Dataset Name: ILAW PA
Dataset Date: Nov 30, 1999 7:45 am
Wind File: WNDFILES\HB-200E.WND

Nov 30, 1999 7:45 am

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Selected Individual (mrem/y)
GONADS	4.68E-02
BREAST	1.19E-01
R MAR	2.08E-01
LUNGS	5.64E-02
THYROID	5.61E-02
ENDOST	4.32E-01
RMNDR	1.02E-01
EFFEC	1.07E-01

PATHWAY EFFECTIVE DOSE EQUIVALENT SUMMARY

Pathway	Selected Individual (mrem/y)
INGESTION	1.06E-01
INHALATION	2.82E-04
AIR IMMERSION	0.00E+00
GROUND SURFACE	0.00E+00
INTERNAL	1.07E-01
EXTERNAL	0.00E+00
TOTAL	1.07E-01

NUCLIDE EFFECTIVE DOSE EQUIVALENT SUMMARY

Nuclide	Selected Individual (mrem/y)
H-3	1.89E-03
C-14	1.05E-01
TOTAL	1.07E-01

CANCER RISK SUMMARY

Cancer	Selected Individual Total Lifetime Fatal Cancer Risk
LEUKEMIA	6.60E-07
BONE	7.65E-08
THYROID	2.55E-08
BREAST	4.67E-07
LUNG	2.80E-07
STOMACH	2.48E-07
BOWEL	1.26E-07
LIVER	2.70E-07
PANCREAS	1.67E-07
URINARY	8.36E-08
OTHER	2.04E-07
TOTAL	2.61E-06

PATHWAY RISK SUMMARY

Pathway	Selected Individual Total Lifetime Fatal Cancer Risk
INGESTION	2.60E-06
INHALATION	7.62E-09
AIR IMMERSION	0.00E+00
GROUND SURFACE	0.00E+00
INTERNAL	2.61E-06
EXTERNAL	0.00E+00
TOTAL	2.61E-06

NUCLIDE RISK SUMMARY

Nuclide	Selected Individual Total Lifetime Fatal Cancer Risk
H-3	5.12E-08
C-14	2.56E-06
TOTAL	2.61E-06

Nov 30, 1999 7:45 am

INDIVIDUAL EFFECTIVE DOSE EQUIVALENT RATE (mrem/y)
(All Radionuclides and Pathways)

	Distance (m)
Direction	1000
N	3.2E-02
NNW	4.3E-02
NW	4.2E-02
WNW	3.4E-02
W	2.7E-02
WSW	2.0E-02
SW	2.1E-02
SSW	1.9E-02
S	2.4E-02
SSE	3.1E-02
SE	6.2E-02
ESE	1.1E-01
E	7.5E-02
ENE	4.3E-02
NE	3.1E-02
NNE	2.6E-02

Nov 30, 1999 7:45 am

INDIVIDUAL LIFETIME RISK (deaths)
(All Radionuclides and Pathways)

	Distance (m)
Direction	1000
N	7.9E-07
NNW	1.0E-06
NW	1.0E-06
WNW	8.2E-07
W	6.6E-07
WSW	5.0E-07
SW	5.2E-07
SSW	4.8E-07
S	5.8E-07
SSE	7.6E-07
SE	1.5E-06
ESE	2.6E-06
E	1.8E-06
ENE	1.1E-06
NE	7.6E-07
NNE	6.4E-07

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C A P 8 8 - P C

Version 1.00

Clean Air Act Assessment Package - 1988

C H I / Q T A B L E S

Non-Radon Individual Assessment
Nov 30, 1999 7:45 am

Facility: Various Cases
Address:
City: Richland
State: WA Zip: 99352

Source Category:
Source Type: Stack
Emission Year: 1996

Comments:

Dataset Name: ILAW PA
Dataset Date: Nov 30, 1999 7:45 am
Wind File: WNDFILES\HB-200E.WND

Nov 30, 1999 7:45 am

CHIQ
Page 1

GROUND-LEVEL CHI/Q VALUES FOR H-3
CHI/Q TOWARD INDICATED DIRECTION (SEC/CUBIC METER)

	Distance (meters)
Dir	1000
N	2.429E-06
NNW	3.192E-06
NW	3.166E-06
WNW	2.521E-06
W	2.025E-06
WSW	1.524E-06
SW	1.595E-06
SSW	1.455E-06
S	1.784E-06
SSE	2.326E-06
SE	4.672E-06
ESE	7.980E-06
E	5.598E-06
ENE	3.251E-06
NE	2.330E-06
NNE	1.946E-06

Nov 30, 1999 7:45 am

CHIQ
Page 2

GROUND-LEVEL CHI/Q VALUES FOR C-14
CHI/Q TOWARD INDICATED DIRECTION (SEC/CUBIC METER)

	Distance (meters)
Dir	1000
N	2.429E-06
NNW	3.192E-06
NW	3.166E-06
WNW	2.521E-06
W	2.025E-06
WSW	1.524E-06
SW	1.595E-06
SSW	1.455E-06
S	1.784E-06
SSE	2.326E-06
SE	4.672E-06
ESE	7.980E-06
E	5.598E-06
ENE	3.251E-06
NE	2.330E-06
NNE	1.946E-06

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Appendix D

Quality Assurance Considerations

Quality Assurance Considerations

For analysis of data and calculations in this report, a peer review procedure was established and followed. The peer reviewers were selected based on their experience and knowledge of specific subject areas. The internal peer review was provided per Fluor Daniel Northwest (FDNW) internal procedures. PNNL provided the Hanford Environmental Dose Overview (HEDOP) technical review for this report.

Example hand calculations are provided in Appendices A and B to illustrate in detail the methods used. Reviewer checklists are attached.

PEER REVIEW CHECKLIST

Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:	HNF-SD-WM-TI-707, Revision 1
Title:	Exposure Scenarios and Unit Dose Factors for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment
Author:	Paul D. Rittmann
Date:	December 28, 1999
Scope of Review:	Full Document

Yes	No*	NA	
[✓]	[ ]	[ ]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[✓]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[✓]	Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]*	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[✓]*	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]	Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[✓]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[ ]	[ ]	[✓]	Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]	[ ]	[✓]	Format consistent with applicable guides or other standards.
[✓]		[ ]**	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]	Document approved (for example, the reviewer affirms the technical accuracy of the document).

* Data and hand calculations were spot checked. Every number was not checked. Time allotted did not allow checking each, and every number. Discrepancies found were in last figure which had negligible effect.

Harvey J. Goldberg — 28 December 1999
Reviewer: (Printed and Signed) — Date

* All "NO" responses must be explained below or on an additional page.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

HEDOP REVIEW CHECKLIST

Document Reviewed: Exposure Scenarios and Unit Dose Factors for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment

Scope of Review:

Yes	No*	N/A		
[X]	[ ]	[ ]	1.	A detailed technical review and approval of the environmental transport and dose calculation portion of the analysis has been performed and documented.
[X]	[ ]	[ ]	2.	Detailed technical review(s) and approval(s) of scenario and release determinations have been performed and documented.
[ ]	[X]	[ ]	3.	HEDOP-approved code(s) were used.
[X]	[ ]	[ ]	4.	Receptor locations were selected according to HEDOP recommendations.
[X]	[ ]	[ ]	5.	All applicable environmental pathways and code options were included and are appropriate for the calculations.
[X]	[ ]	[ ]	6.	Hanford site data were used.
[ ]	[ ]	[X]	7.	Model adjustments external to the computer program were justified and performed correctly.
[ ]	[X]	[ ]	8.	The analysis is consistent with HEDOP recommendations.
[X]		[ ]	9.	Supporting notes, calculations, comments, comment resolutions, or other information is attached. (Use the "Page 1 of X" page numbering format and sign and date each added page.)
[X]	[ ]		10.	**Approval is granted on behalf of the Hanford Environmental Dose Overview Panel.**

*All "No" responses must be explained. The use of nonstandard methods must be justified.

HEDOP Reviewer: K Rhoads 12/28/99
Signature Date

COMMENTS (add additional signed and dated pages if necessary):

3. Calculations performed by spreadsheet rather than standard software; values are consistent with those obtained using software approved by HEDOP.
8. Alternate assumptions used for some parameters as noted in document; these have minor impact on final result.
9. See attached memo regarding comments & resolution.

APPENDIX P

PROSSER AGRICULTURAL REPORT

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PNNL-13125

Evaluation of the Potential for Agricultural Development at the Hanford Site

R. G. Evans[a]
M. J. Hattendorf[a]
C. T. Kincaid, Project Manager

January 2000

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352

(a) Washington State University.

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Executive Summary

By 2050, when cleanup of the Hanford Site is expected to be completed, large worldwide demands to increase the global production of animal/fish protein, food, and fiber are anticipated, despite advancements in crop breeding, genetic engineering, and other technologies. World population is projected to double to more than 12 billion people, straining already stressed worldwide agricultural resources. The current world surpluses in many commodities will not last when faced with increasing population, decreasing ocean fisheries, and rapid loss of productive lands from soil salination and erosion. The production of pharmaceuticals from bioengineered plants and animals will undoubtedly add more pressure on the already limited (and declining) arable land base. In addition, there will be pressure to produce crops that can help reduce the world's dependence on petroleum and be used for chemical plant feedstock.

These external, formidable pressures will necessitate increasing investments in irrigation infrastructures in many areas of the world to increase productivity. Intensive greenhouse culture and aquaculture also will be greatly expanded. There will be large economic and social pressures to expand production in areas such as the Pacific Northwest. Agricultural exports will continue to be important

The most likely large areas for expanded irrigation in the Pacific Northwest are the undeveloped East High areas of the Columbia Basin Project and non-restricted areas within the Hanford Site in south-central Washington State. Both of these are potentially highly productive areas for producing food and export capital. The environmental concerns will be large; however, the favorable growing conditions, high-quality (low-salinity) abundant water supplies and minimal problems with salination of soils make the Pacific Northwest a very desirable region for economically sustainable expansion from a world perspective.

The area known as the Hanford Site has all the components that favor successful irrigated farming. This semi-arid desert steppe area has deep soils, long summer days, a long growing season, good drainage, mild winters, and an abundant, high-quality, and dependable potential water supply from the Columbia River. Economically, the Hanford Site benefits from excellent transportation systems (roads, rail, and barge), extensive power systems, and the already well developed agricultural processing, supply, and service infrastructure that supports the regions agriculture.

Constraints to agricultural development of the Hanford Site are political and social, not economic or technical. Obtaining adequate water rights for any irrigated development will be a major issue.

Analysis of the land use data shows that the total irrigable area (not including buffer areas), including both the north (wildlife refuge areas) and south side of the river, is about 120,380 hectares (297,442 acres). Excluding the wildlife refuges, 6300 hectares (15576 acres) are classified for tree and vine crops, and 62,640 hectares (154775 acres) are classified for field crops. Over the entire site, not including buffer areas, 27,160 hectares (67116 acres) were classified as unsuitable for irrigation. One-kilometer-wide

buffers were excluded from all rivers and lakes (20,100 hectares [49,681 acres]) and currently restricted areas (16,280 hectares [40239 acres]). State and federal wildlife reserves account for 35,740 hectares (88315 acres).

Potential land use and economic scenarios on the Hanford Site favor intensive, large-scale agricultural development growing high-value orchard, vineyard, and vegetable crops. Such large enterprises would be able to afford to import clean water and use high-level water management to minimize deep drainage. Irrigation technologies would be limited to highly efficient methods such as center pivots and microirrigation. Any suburban or small ranchette developments should be examined carefully in light of safety concerns and the associated generally poor levels of water management.

Numerous anticipated future advances in irrigation and resource conservation techniques will greatly minimize the negative environmental impacts of agricultural activities. These include precision agriculture techniques, improved irrigation systems, and controls. It is believed that such improved systems will be the norm for farming in 50 years.

Scientific irrigation scheduling and a network of supporting weather stations must be part of the total system for water and pest management of any future agricultural development on the Hanford Site. It is highly probable that any future irrigation development on the Hanford Site would be pressurized irrigation systems because of the site's very sandy soils and undulating topography. Water would be supplied to the fields by pressurized pipelines rather than canals or ditches. Because of the light soils and widely variable topography of new lands such as the Hanford Site, new advances in microirrigation and self-propelled irrigation (i.e., linear move and center pivot systems) will probably have the most promise for future irrigation.

A reasonable estimate of deep percolation in 50 years would be the current best achievable levels of the best technology: from 2% to 15% of the applied water, not including water applied for frost protection or other non-irrigation uses. Recharge from irrigation would probably range from 50 to 500 mm/yr compared to historical estimated natural recharge rates, even with the expected improved technologies and systems. Wine grapes would have the least recharge, while field crops would potentially have the greatest deep percolation losses. Small acreage, irrigated ranchette development would probably contribute about twice the recharge to the unconfined aquifer systems as large scale irrigation.

Acknowledgments

Pat Daly with the Franklin County Conservation District and Jeff Godfrey with the Grant County Conservation District by providing GIS files on agricultural land use in their counties. Ms. Cindy Mead and Tammy Killian did the land use mapping needs for this project. Mr. Chas Scripter with the USDA-NRCS in Spokane provided GIS soils maps and needed othrophotos for the analysis. Dr. Mary J. Hattendorf conducted the GIS analysis of the combined data sets. Dr. Charles Kincaid and Dr. Michael Fayer with PNNL provided valuable assistance by providing maps and documentation and thoughtful review.

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Acronyms

AWC	available water holding capacity of a soil
BIA	Bureau of Indian Affairs
CBP	Columbia Basin Project (irrigation and power)
DEM	digital elevation maps
DOE	U.S. Department of Energy
DLG	digital line graphics
ET	evapotranspiration
ETr	reference evapotranspiration for alfalfa
GIS	geographic information system
GPS	global positioning system
LEPA	Low Energy Precision Application
LIGO	Laser Interferometer Gravitational-Wave Observatory
PAM	polyacrylamide formulation used to control soil erosion
PAWS	Public Agricultural Weather System
SIS	scientific irrigation scheduling
USBR	U.S. Bureau of Reclamation
USDA-ARS	U.S. Department of Agriculture - Agricultural Research Service
USDA-NRCS	U.S. Department of Agricultural-Natural Resource Conservation Service
USGS-EROS	U.S. Geological Survey - Earth Resources Observation Systems
WDOE	Washington Department of Ecology
WSU	Washington State University

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1.0 Introduction

In the early 1940s, the U.S. Department of Defense used the right of eminent domain to acquire about 1520 square kilometers (586 square miles) in Benton and Grant Counties of Washington State as part of the Manhattan Project to develop the atomic bomb. Until the late 1980s, the Hanford Site in south-central Washington continued to be involved in the production of weapons-grade fissionable materials (Figure 1.1). More recently, the primary mission of the Hanford Site has focused on the cleanup and disposal of hazardous waste and radioactive materials resulting from this previous industrial endeavor.

Cleanup efforts are estimated to be completed around 2050. A small fraction of the total Hanford Site will be reserved by the U.S. Department of Energy (DOE) for waste disposal and protection from residual radiation sources. The remainder of the land is anticipated to be declared as excess and gradually returned to other uses until all excess lands are returned at the end of the DOE mission. There are tremendous regional and national pressures to establish the future use of these excess lands.

A substantial portion of the Hanford Site is ideally suited to the type of high-value production agriculture currently practiced in the mid-Columbia region. Agricultural development of portions of this area could have a large impact in both regional and state economies, providing new employment opportunities and growth. Consequently, there are intense regional political and economic pressures to release at least some of these lands for agricultural uses.

On the other hand, the portion of the Columbia River flowing past the Hanford Site, known as the Hanford Reach, is the last section of the lower Columbia River unaffected by dams. In addition, the Hanford Site is part of the oldest and largest remaining old-growth desert ecology community in Eastern Washington. Thus, there are equally fierce proponents for protecting the Hanford Site from any future development and maintaining it as an ecologically sensitive reserve.

The DOE released the Hanford Site Comprehensive Land Use EIS (DOE 1999), which suggests future cropping patterns, agricultural land use, and associated water issues. This study and the information will be the basis for agricultural land use scenarios used to estimate risk and radiation dose to future inhabitants of the Hanford Site. These scenarios will become part of assessments conducted to evaluate remedial actions and disposal alternatives at the Hanford Site until the cleanup is completed within the next 50 years.

This particular study is not related to any existing DOE study of potential future land use. Likewise, this study does not consider existing proposals by the Benton County Planning Commission or other agencies, public, or private groups, or currently restricted non-industrial lands (i.e., the Arid Lands Ecology Reserve). Similarly, endangered species, biological diversity and wildlife management, global climate change, potential concerns by lending organizations to finance development, effect on utility systems, waste management and refuse disposal, waste water (septic tanks, livestock containment) treatment, hazardous waste management, public health concerns with hazardous waste and exposure, or the affects of agricultural development on specialized installations such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) were not part of this evaluation. The purpose of this report is

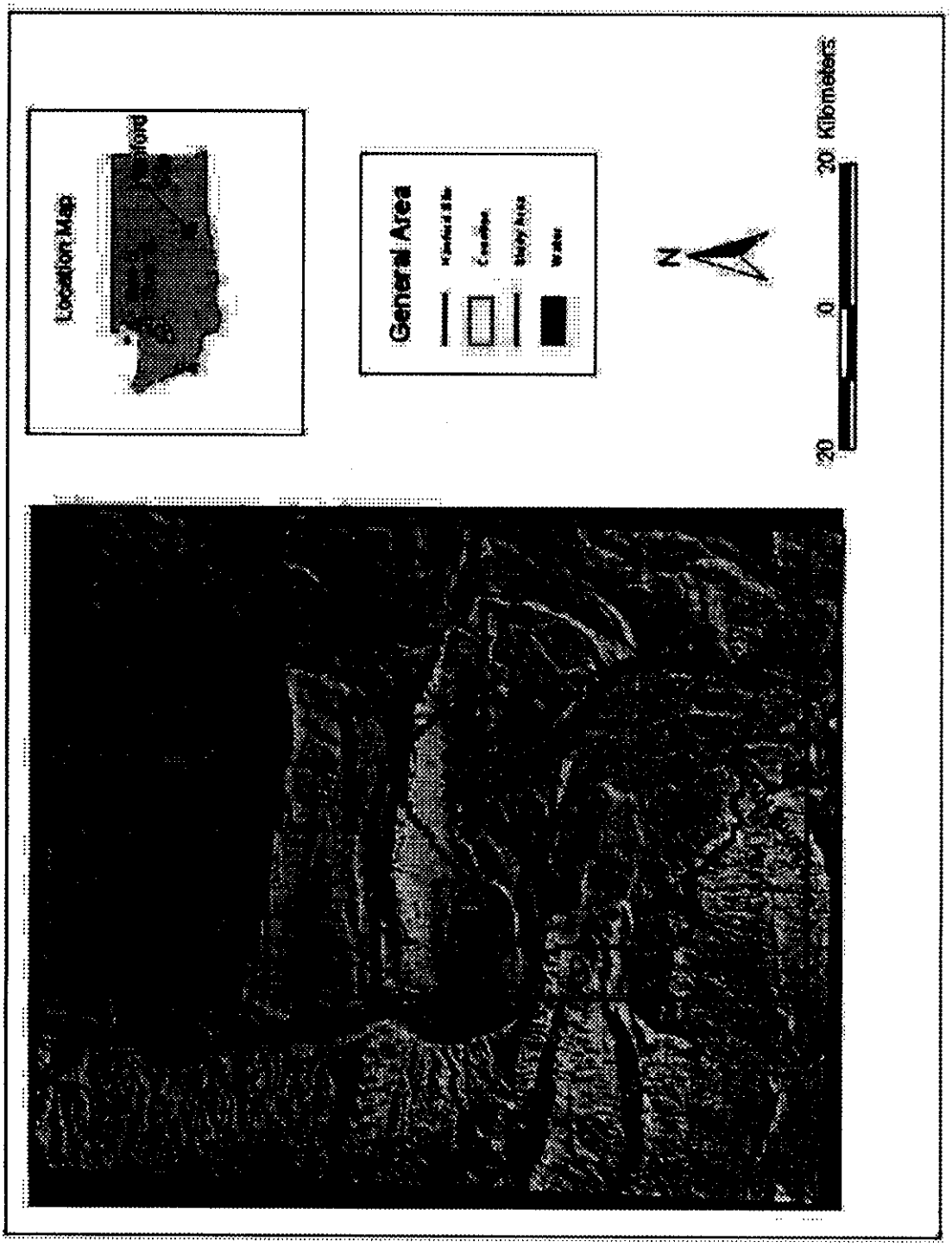

Figure 1.1. Map Showing the General Location of the Hanford Site and the Study Area

to suggest potential cropping patterns and related water requirements after closure of the Hanford Site in the event that some lands are opened to *irrigated* agricultural development. Potential future agricultural land uses were based on current irrigation and cultural practices that will continue to be improved and developed over the next 50 years. While there is some speculation, the intent is only to suggest reasonable future uses of Hanford lands in the event they become available for agricultural development based on *current* farming practices.

This is an attempt to characterize the attributes of the Hanford Site that are appropriate for agricultural development and determine the potential for future agricultural land use given current irrigation technology, crops, and crop rotation scenarios. It was assumed that development must be economically sustainable using current agricultural enterprises as a basis. Anticipated future advances in irrigation and resource conservation techniques, water rights issues, and impacts of possible shifts in agricultural production are discussed. Also examined are crop water use needs per unit area, potential advances in irrigation technology that would impact irrigation efficiencies, and issues of environmental stewardship.. Anticipated average irrigation rates and amounts for various crops and net infiltration rates (groundwater recharge) also are part of the analysis.

Rainfed or "dryland" agriculture was not included as part of this analysis because such operations might not be sustainable due to low annual precipitation and low commodity prices. The economics may change in the future, and these options should be re-evaluated at that time. A potential exists to use various areas of the Hanford Site for dryland livestock grazing or winter wheat production. However, these uses present challenges because of the large acreage requirements per animal, perceived incompatibility with various ecosystems, and the Hanford Site's lower natural precipitation relative to nearby lands where winter wheat is grown.

The analysis is based on comparison of the acreage and water requirements of the current farming community and trends in Franklin, Grant, and Adams counties. The year 1996 was used as the baseline because of the availability of orthoquad maps for that year and data from the 1997 Census of Agriculture. The lands used as the study area were approximately bounded on the north by the Frenchman Hills (Royal Slope), on the east by Highway 395, and on the south by the Yakima River.

One particular goal was to obtain estimates of the amount of deep percolation and recharge that might result from development of irrigated agriculture on the Hanford Site. Deep percolation (also called deep drainage) is defined as the amount of water from natural or artificial sources that travels downward through the soil profile until it is below the plant's root zone and unavailable for crop use. Deep percolation is generally the result of infiltrated water that exceeds the soil's ability to hold it. However, small channels and other established flow pathways in the soil can carry substantial amounts of water directly to the groundwater (preferential flow), effectively bypassing the plant rooting zone. Preferential flow exists in almost all soils and is a major factor in soil water movement, but it is generally neglected because it is difficult to measure.

Recharge, on the other hand, is the flux of water that arrives at the upper boundary of the unconfined aquifer (water table). Deep percolation and recharge are assumed to be equal in magnitude when integrated over many years, but temporal distribution will be different because of the transit time through the

vadose zone towards the groundwater. Recharge can influence the elevation of the water table, but is generally viewed as a problem only when it carries excessive contaminants to the groundwater.

Existing data and geographic information system (GIS) software (ArcView) were used to make maps of soils and topography and to summarize 1996 crop use of the current irrigated lands surrounding the Hanford Site. These data were compared to soil and topographic conditions at the Hanford Site to assess suitability and/or limitations for various crop and irrigation system scenarios. All lands currently within the Hanford Site, except for disposal sites such as the central plateau (200 East and West Areas) and other industrialized sites that might be restricted in the future, were considered for their potential for agricultural development regardless of their current status.

2.0 Environmental Setting

This section briefly describes the physical and environmental setting of the Hanford Site to set the stage for the discussion on agriculture. Hanford Site geology, soils, topography, climate, potential evapotranspiration, recharge rates, and water resources (surface and subsurface) are discussed.

2.1 Geology

The geology and hydrology of the Hanford Site have been studied extensively over the past 50 years (Cole et al. 1997; Neitzel et al. 1997). Geologically, the Hanford Site lies within the Pasco Basin, a large structural depression that has collected a relatively thick sequence of fluvial, lacustrine, and glacio-fluvial sediments over the past several thousand years. The Pasco Basin and nearby anticlines and synclines are underlain by or composed of the Columbia River Basalt Group, a sequence of continental flood basalts covering more than 163,000 km^2 (63,000 mi^2) in Washington, Oregon, and Idaho that occurred over a period from 17 million to 6 million years ago.

Landslides have occurred along the northern portions of the Yakima Ridge folds of the Pasco Basin along basalt and sedimentary interfaces. They have also occurred along steep river embankments (i.e., White Bluffs) to the east of the Hanford Site and are primarily due to subsurface irrigation return flows that have saturated lower portions of the embankments, resulting in slumping.

The underlying basalt layers are often fractured, and numerous geologic faults run through the Hanford Site. The basalt flows are frequently separated by interbeds of epiclastic and volcaniclastic sedimentary layers and old residual soils. Overlying the basalts are fluvial and lacustrine sediments of the Ringold formation and the glacio-fluvial Hanford formation.

The sediments in the Hanford formation are primarily the result of cataclysmic flooding due to the periodic breaching of ice dams in western Montana and northern Idaho that caused huge volumes of water to spill across eastern and central Washington. These floods are among the largest ever documented anywhere in the world, the last of which occurred about 13,000 years ago. These sediments were channeled and alluvium was deposited between flood events. Later aeolian depositions of glacial till cover portions of the site. Recently, the sediments have been locally reworked by winds, and sand dunes are common in southern and eastern portions of the Hanford Site.

2.2 Soils

Hajek (1966) described 15 different general surface soil types on the Hanford Site, ranging from sand to silty and sandy loams. These same soils are found elsewhere in Benton, Grant, Adams, and Franklin counties, and most are being irrigated. Figure 2.1 shows the distribution of major soil types in the study area and the Hanford Site. As can be seen, the major agricultural soil types in the surrounding area are loamy sands, sandy loams, fine sandy loams, silt loams, and sands, all of which are common on the Hanford Site. These soils are characterized by relatively high infiltration rates, low water holding

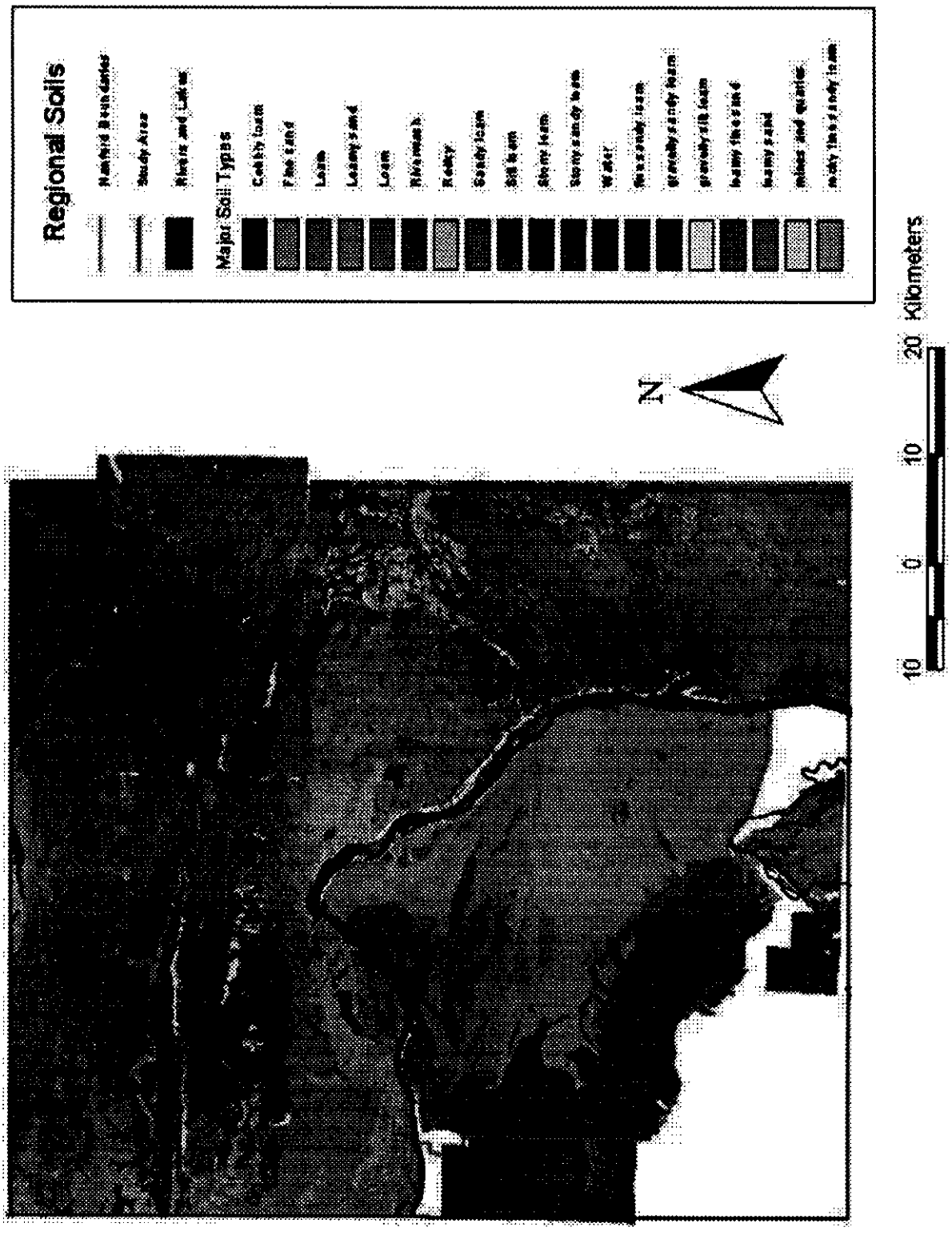

Figure 2.1. General Soils Map of the Study Area and the Hanford Site

capacities, and very low clay and organic matter contents. They are easily eroded by wind and water. Probable ranges of infiltration rates and available water holding capacity (AWC) for each soil type, based on texture from soil survey information, are presented in Table 2.1.

2.3 Topography

The Hanford Site occupies an area roughly 50 km (N-S) by 40 km (E-W) that is about 1517 km^2 (586 mi^2) in south-central Washington. It lies north of the confluence of the Yakima and Columbia Rivers. The Columbia River flows in an easterly direction across part of the northern boundary and, turning south, forms part of the eastern boundary of the Hanford Site. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundary. The Saddle Mountains lie to the north of the Hanford Site. Adjoining lands to the west, north, and east are principally range and commercial agricultural land. The cities of Richland, Kennewick, and Pasco (the Tri-Cities) and West Richland are located southeast of the site and constitute the nearest population centers.

About 1100 km^2 (427 mi^2) of the Hanford Site are in Benton County. The remainder lies in Grant County, north of the Columbia River, and although it is part of the site, is primarily managed by the National Fish and Wildlife Service and the State of Washington as wildlife refuges and recreation areas. A large portion of land (30,900 hectares [76,300 acres]) in the southwest portion of the site on the eastern side of Rattlesnake Mountain is currently set aside as the Fitzner-Eberhardt Arid Lands Ecology Reserve. Only about 6% (about 90 km^2 [33 mi^2]) of the total area has been disturbed and is used for the production of special nuclear materials and the storage and disposal of wastes.

Figure 2.2 is a graphical representation of the diverse and widely varying topography in the region around the Hanford Site. Elevations within the Hanford Site vary from about 120 m (400 ft) above mean sea level near the Columbia River to more than 1060 m (3480 ft) at the top of Rattlesnake Mountain at the southern end of the site. Wahatis Peak in the Saddle Mountains at the north end of the Hanford Site reaches almost 800 m (2500 ft). However, most of the site is relatively flat and similar to many of the irrigated agricultural lands in the region.

2.4 Climate

Annual precipitation on the Hanford Site is only about 160 mm (6.3 in.), and irrigation is required for economic production of most crops. Average Class A pan evaporation for the area is about 1400 mm (4.6 ft) for the growing season. Winds are generally from the northwest although considerable winds from the southwest occur in the spring and fall. The record maximum temperature is 45°C (113°F), and the record minimum temperature -31°C (-23°F). Additional information on climate on the Hanford Site is contained in Hoitink and Burke (1997).

Table 2.1. Range of Permeabilities and Available Water Holding Capacities (AWC) of Selected Soils

Soil	Soil Survey[a]	Permeability mm/hr		AWC† mm/mm		Bulk Density[b]	AWC[b,c] mm/m	
		Low	High	Low	High		Low	High
Ritzville Silt Loam (Ri)	BC/G	20.32	63.5	0.18	0.20			
Rupert Sand (Rp)	BC/G	127.00	254.0	0.10	0.12	1.52	58.3	666.7
Hezel Sand (He)	BC/G	127.00	254.0	0.10	0.12	1.60	66.7	83.3
Koehler Sand (Kf)	BC/G	127.00	254.0	0.09	0.11	1.48	33.3	50.0
Burbank Loamy Sand (Ba)	BC/G	>	254.0	0.07	0.09	1.50	41.7	50.0
Ephrata Sandy Loam (El)	G	50.80	152.4	0.13	0.16	1.70	208.3	241.7
Lickskillet Silt Loam (Ls)	BC/G	5.08	20.3	0.08	0.10			
Ephrata Stoney Loam (Eb)	G	50.80	152.4	0.10	0.13			
Kiona Silt Loam (Ki)	BC/G	20.32	63.5	0.08	0.10			
Warden Silt Loam (Wa)	BC/G	20.32	63.5	0.18	0.20	1.40	150.0	183.3
Scootney Silt Loam (Sc)	BC/G	20.32	63.5	0.18	0.20	1.40	158.3	166.7
Pasco Silt Loam (p)	BC/G	20.32	63.5	0.18	0.20			
Equatzel Silt Loam (Qn)	BC/G	20.32	63.5	0.18	0.20	1.52	241.7	291.7
River Wash (Rv)	BC/G	>	254.0	0.03	0.05			
Dune Sand (D)	BC/G	>	254.0	0.05	0.07			

(a) BC is Benton County Soil Survey (USDA- Soil Conservation Service 1971), G is the Grant Count Soil Survey (USDA - Soil Conservation Service 1984).
(b) Data are the ranges of values found by Hagood et al. 1970.
(c) AWC is available water holding capacity of soil or the amount of soil water available for crop use. AWC is the difference between measured values of field capacity and permanent wilting point.

2.5 Potential Evapotranspiration

Potential evapotranspiration (ET) is basically the maximum amount of water that will be used by a crop, depending on growth stage and climatic conditions. For simplicity, these calculations are usually made for a "reference" crop such as well watered alfalfa (ET_r) or grass (ET_o). Actual water use of a particular crop is adjusted by decimal values of "crop coefficients" that are multiplied times the reference evapotranspiration. The Penman equation (Penman 1948) as modified by Wright (1982) and Allen et al. (1989) was used to calculate the reference potential evapotranspiration (ET_r) for the area.

Climatic records for several weather stations in the irrigated agricultural areas near the Hanford Site were analyzed to determine potential crop water use, also called potential evapotranspiration. The Public Agricultural Weather System (PAWS) station operated by Washington State University (WSU) near Mattawa is probably the most representative agricultural weather station for expected Hanford Site conditions. The average alfalfa reference evapotranspiration (ET_r) for the April through October growing

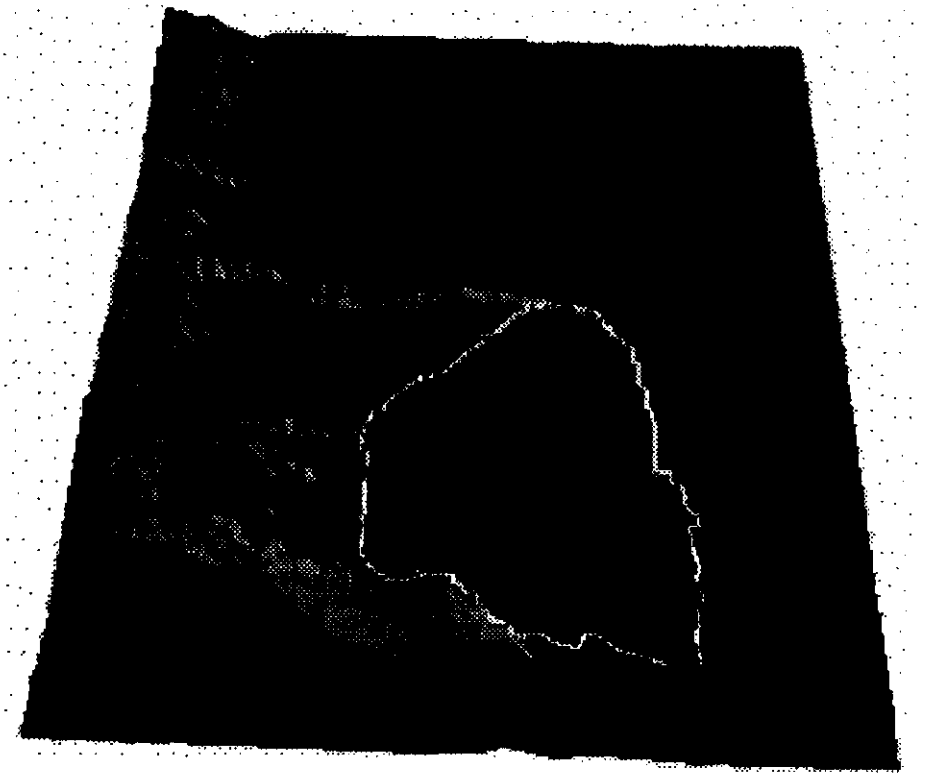

Figure 2.2. Three-Dimensional Map Showing Elevation Ranges for the Area Surrounding the Hanford Site (white line) and the Study Area (dark line) and the Columbia River in Central Washington

season is about 978 mm (38.5 in.) for all stations and 1060 mm (41.7 in.) for Mattawa. Figure 2.3 is a graph of the long-term average alfalfa ET_r for several PAWS weather stations around the Hanford Site, with the peak water use of about 225 mm (8.9 in) occurring in July. Crop water use can vary substantially from year to year depending on climatic conditions. Table 2.2 is a listing of the long-term average crop water use over the season from stored soil water (winter precipitation) and irrigation. Deficit irrigation or other management practices may reduce these values.

2.6 Recharge Rates

Determining recharge rates is critical to the long-term environmental cleanup efforts and management at the Hanford Site to ensure long-term protection of groundwater from industrial wastes. Gee et al. (1992) estimated that the time required for contaminants to travel through the thick unsaturated zone at the Hanford Site ranged from thousands of years, for recharge rates below 1 mm/yr, to tens of years for recharge rates above 50 mm/yr.

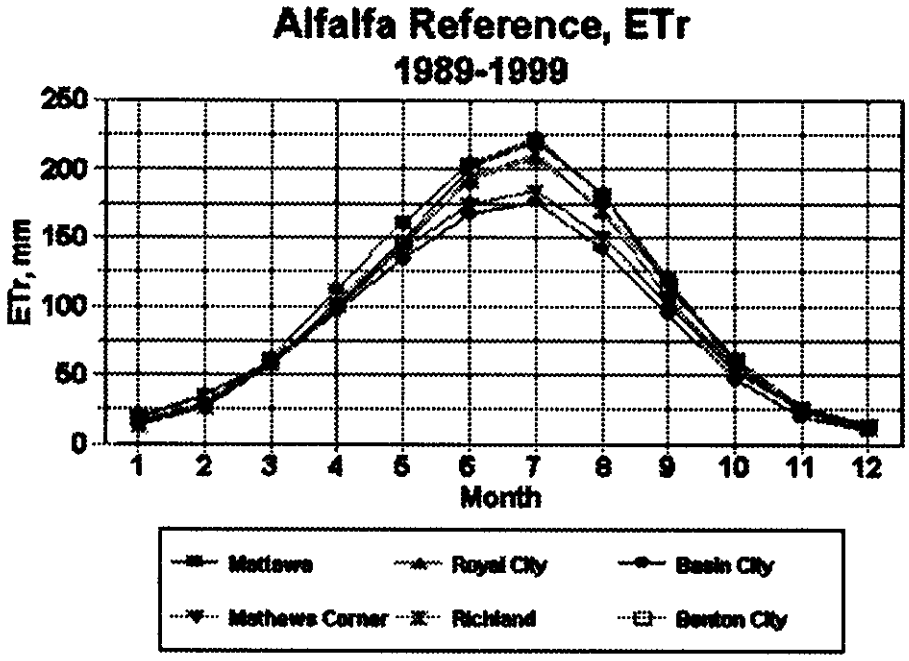

Figure 2.3. Annual Distribution of Potential Evapotranspiration of Alfalfa (ETr) for PAWS Weather Stations in Irrigated Agricultural Areas Near Hanford for 1989-1999

Currently, most of the recharge is from natural precipitation, although significantly higher recharge rates are estimated due to localized industrial activities (i.e., central plateau operational areas). Some artificial recharge to the Hanford Site that results from private irrigation development (from deep wells) lies to the north of the Site in the Cold Creek drainage. This amount is estimated to be small because the irrigation systems are efficient and the high cost of pumping water encourages good management. Estimated recharge from any future irrigated agriculture development on the Hanford Site will likewise depend on the types of irrigation systems used and their management.

The wide discrepancies in estimated recharge rates for the Hanford Site are attributed to variations in precipitation, vegetative cover, and surface soil textures. Gephart et al. (1979) analyzed data from long-term field studies at the Hanford Site and concluded that recharge from natural precipitation through thick unsaturated sections is almost negligible. Gee et al. (1992), using lysimeter data collected at a number of locations on the Hanford Site over a period of 20 years, found that recharge rates ranged from more than 100 mm/yr to rates near zero (i.e., no measurable drainage). Coarse-textured soils without plants yielded the most recharge, and fine-textured soils with or without plants yielded the least. Deep-rooted plants, such as sagebrush, were generally successful in limiting recharge on all soils on the Hanford Site to near-zero amounts, but shallow-rooted plants such as cheatgrass appeared unable to prevent recharge. Subsurface drainage (i.e., recharge) from a cheatgrass-covered lysimeter averaged about 35% of the total annual precipitation during a 3-yr test (1984 to 1986). Fayer and Walters (1995) estimated that annual recharge for the non-industrial areas of the Hanford Site typically averaged less than 10 mm/yr (i.e., "background recharge rates").

Table 2.2. Long-Term Average Crop Water Use in mm per Year at Various PAWS Weather Stations Near the Hanford Site

Crop	Mattawa	Royal City	Basin City	Mathews Corner	Richland	Benton City	Pasco
Penman Alfalfa[a]	1441.1	1355.6	1184.1	1258.1	1357.4	1417.2	1384.9
Alfalfa	1140.1	1071.6	927.1	979.8	1067.6	1116.4	1097.3
Asparagus	869.3	819.4	702.6	745.0	811.1	852.0	836.7
Carrots	599.7	560.9	484.2	508.2	564.9	585.7	582.7
Grain Corn	816.6	763.0	655.3	688.0	764.7	798.0	793.3
Sweet Corn	561.1	524.2	453.9	475.8	529.8	548.0	545.5
Dry Beans	587.0	548.3	475.9	498.8	553.0	571.4	569.1
Dry Onions	847.8	789.8	686.4	719.5	790.0	819.7	814.7
Early Potato	756.4	705.6	616.4	645.9	705.8	728.4	724.1
Mid-Season Potato	781.9	728.8	630.4	660.3	731.9	761.1	756.7
Late Potato	780.6	730.2	624.2	656.8	731.3	764.5	759.8
Green Bean	516.4	483.3	416.3	437.0	485.6	504.1	501.6
Sugar Beet	985.6	927.5	789.8	834.0	915.9	961.8	950.6
Spring Grain	713.7	664.2	588.8	615.3	664.2	681.2	676.2
Winter Wheat	553.7	513.3	466.7	488.0	513.0	523.1	515.8
WW Sweet Onion	338.5	313.9	281.6	294.5	310.9	319.1	316.3
Grass Hay	1013.2	950.4	830.3	877.7	950.7	988.7	973.3
Pasture	1196.5	1125.4	982.4	1043.9	1126.6	1176.2	1149.4
Hops	984.8	921.4	794.0	836.8	922.8	966.2	954.5
Spearmint	1145.9	1075.7	932.9	987.2	1070.5	1118.9	1101.0
Peppermint	941.8	886.2	762.5	808.6	883.8	927.1	910.3
Concord Grapes	826.2	778.5	670.2	711.5	775.3	813.4	797.5
Wine Grapes	377.4	355.6	299.3	316.2	652.3	372.4	368.3
Apples/Pears[b] w/cover	1182.7	1114.0	956.3	1014.1	1106.4	1160.8	1141.2
Apples/Pears[b] w/o cover	931.8	877.9	754.2	799.6	872.8	915.5	899.5
Stone Fruits[b] w/ cover	1099.0	1035.0	889.5	943.2	1028.5	1078.7	1060.2
Stone Fruits[b] w/o cover	839.2	789.9	680.1	721.2	787.0	824.6	810.0

(a) Penman alfalfa is the calculated value of evaporation based on an alfalfa reference over the whole year. It is indicative of clear water pond evaporation over the year.
(b) Many orchard crops are grown with (w/) grass cover crops between rows, which requires additional water. Orchards without (w/o) cover crops would be representative of drip-irrigated blocks.

2.7 Water Resources

Water resources within the Columbia Plateau region must be considered in a regional and international framework. Withdrawals from the Columbia River may have a large impact on downstream water users (domestic, municipal, industrial, and agricultural) and on recreation, navigation, and hydropower production. Human activities have negatively affected surface and subsurface water quality over broad areas. Reservoir releases for power and other uses are jointly coordinated by the U.S. Bureau of Reclamation (USBR) and the U.S. Army Corps of Engineers to manage often competing demands. Withdrawals from deep confined aquifers affect piezometric levels in wells over large areas. In addition, specific recharge areas for the deep aquifers are largely unknown, but may be hundreds of kilometers from the withdrawal locations.

2.7.1 Surface Water

The Columbia River is the dominant surface water source at the Hanford Site. It rises in Canada along the western side of the Selkirk Mountains in British Columbia and enters Washington State north of Spokane before heading west and then south to the Hanford Site, where it makes a bend to the east before going south and to the west. It is the second largest river in the contiguous United States in terms of total flow. The Columbia River drains a total area of 680,000 km^2 (262,480 mi^2) and is about 2000 km (1243 mi) long. It flows into the Pacific Ocean and forms much of the boundary between Oregon and Washington. Major tributaries include the Snake and Yakima rivers, which join the Columbia River in the Tri-Cities area.

Average discharge at the mouth of the Columbia River is about 7250 m^3/s (256,000 ft^3/s). Irrigation diversions throughout the entire Columbia drainage area currently account for less than 5% of the total annual flow at the mouth of the river. Average daily flows of the Columbia River in the Hanford Reach range from 1000 to 7000 m^3/s (36,000 to 250,000 ft^3/s), which are largely controlled by upstream releases from Grand Coulee Dam.

Some communities and the Hanford Site use the Columbia River for municipal and industrial water supplies. However, the primary uses of the Columbia River are hydropower production and irrigation. In addition, recreational uses of the Columbia River include sport fishing, hunting, boating, sailboarding, swimming, water skiing, and diving. Considerations for threatened and endangered species of fish currently impact the total management of the Columbia River resource. The substantial amount of electrical power produced in the region from hydro, nuclear, and other sources also relies on water from the river system and has a major regional economic impact.

The Yakima River borders a short length of the southern boundary of the Hanford Site. Average annual flow is about 104 m^3/s (3712 ft^3/s). Approximately one-third of the Hanford Site is drained by the Yakima River system. Surface runoff from the Hanford Site is estimated to be about 3% of the total annual precipitation to the area.

2.7.2 Groundwater

Unconfined and confined aquifers underlie the Hanford Site, both of which would be available for future agricultural development of the area. Many small municipalities and industrial users that are not adjacent to the rivers use deep, confined aquifers as a water supply. The Tri-Cities communities use a mix of Columbia River and supplemental groundwater sources (confined and unconfined aquifers), whereas almost all rural domestic (homesteads and livestock) water comes from unconfined aquifers (<100 m deep). Groundwater from both aquifers systems is used for irrigation.

The Ringold and Hanford formations compose the unconfined system, which is directly connected to and discharges into the Columbia River. Unconfined groundwater flow direction at the Hanford Site is predominately from west to east. Specific yields for the Ringold formation typically range from 0.05 to 0.2 and from 0.1 to 0.3 for the Hanford formation. Effective porosity ranges from 0.01 to 0.37, with an average value estimated to be about 0.25. Groundwater quality is generally quite good with relatively low salt levels, although domestic wells usually require a water softener because of calcium carbonates precipitates. In addition, there are localized plumes of contaminants from past Hanford operations (i.e., tritium, iodine-129, uranium, technetium-99, strontium-90, trichloroethylene, chloroform, and carbon tetrachloride) in the unconfined aquifer system.

The saturated thickness of the unconfined aquifer system varies from close to zero near the basalt ridges and Rattlesnake Mountain to the west to more than 60 m near the Columbia River. Depth to groundwater ranges from less than 0.3 m near the river to more than 100 m elsewhere on the Hanford Site. Recharge to unconfined aquifers is from runoff from the elevated areas along the western side of the site (i.e., Rattlesnake Mountain), spring discharges from the extensive confined aquifer system, artificial recharge from processing waste water disposal, and local precipitation. There is a direct hydraulic connection to the Yakima and Columbia rivers.

Within the Pasco Basin, the Columbia River Basalt Group consists of the Saddle Mountain, Wanapum, and Grande Ronde basalts. These subsurface basalt groups contain numerous confined aquifers associated with the more permeable interflow and interbed zones generally located between the dense, columnar confining units. Yields range from quite small to quite large. The locations of recharge areas for these aquifers and hydraulic connections between the various confined aquifers are not well understood. Hydraulic connections between the confined and unconfined aquifers also exist due to substantial artesian pressures (from 300 to 400 m of head in some cases) in the confined aquifers. Some of these aquifers are extensively used for large-scale irrigation in areas not served by the various Columbia River Basin irrigation projects. Piezometric pressures are declining in some confined aquifers in some areas as a direct result of agricultural and municipal pumping. Water quality is good with low levels of total dissolved solids. However, most of the salts are sodium bicarbonates, which require that the water always be treated with acids to lower pH before any agricultural use. These deep aquifers would be available for future agricultural uses on the Hanford Site. However, because of recently observed declines in hydraulic head, their long-term sustainability for large-scale development is doubtful and needs more study.

An analysis of well data was derived from records on file with the Washington Department of Ecology (WDOE) in Spokane. The information contained in these records was very sparse in most instances. Domestic well data are likely incomplete, whereas the other categories are close to actual. Table 2.3 summarizes the characteristics of the domestic, industrial, irrigation, and municipal wells in the study area that were registered with the WDOE.

Table 2.3. Summary of Well Characteristics for all Wells by Major Use Category Within the Study Area Based on WDOE Well Permit Records (values in parenthesis are one standard deviation)

Use	Total Wells	Number of Wells with Screens or Perforations	Average Screened Length, m	Average Depth, m	Average Discharge, l/s
Domestic	116	19	6.6 (4.81)	86.1 (76.49)	4.54 (10.92)
Industrial	38	18	6.8 (9.39)	84.4 (72.75)	22.3 (31.75)
Irrigation	883	443	9.8 (7.04)	116.7 (126.14)	81.6 (78.85)
Municipal	57	18	20.8 (29.05)	182.5 (110.26)	36.4 (52.30)

The WDOE records for 1226 wells in the study area surrounding the Hanford Site were analyzed and characterized. There were 883 wells classified as irrigation, 116 as domestic, 38 as industrial, and 57 as municipal. Another 132 wells were registered as "fish" (11), "other" (24) or "test" (97). It is safe to assume that the domestic category may not be accurate because it is highly probable that numerous domestic wells in the area were not registered with WDOE and some domestic users are also using water classified as "irrigation."

Figure 2.4 is a frequency distribution of well depths in the study area based on the WDOE records. There is tremendous variability in these records, and statistical measures describing the distributions have limited use. The majority of wells (799), and the largest numbers in the bimodal distribution, are primarily located in the unconfined aquifers. However, a number of wells less than 60 m deep are high-volume wells located in unconsolidated gravel deposits near the Columbia River (i.e., 56% of all irrigation wells were less than 60 m deep). Figure 2.5 shows well depth distribution by use. Most of the wells deeper than 100 m (426) are withdrawing water from the confined aquifers in the basalts and are used for large irrigation (35% of irrigation wells) or municipal purposes (72% of municipal wells).

Many of the wells were only partially cased, leaving portions of the bore holes open, particularly in the basalt formations. Less than 41% (498) of all four major categories that were examined had screens, perforations or both.

Screen length is an indication of the thickness of the water bearing strata. There are 573 wells out of the 1226 and 498 from the four major categories that have screens and/or perforations. Figures 2.6 and 2.7 show the distribution of the length of screens (and/or perforations) for all wells and all categories by

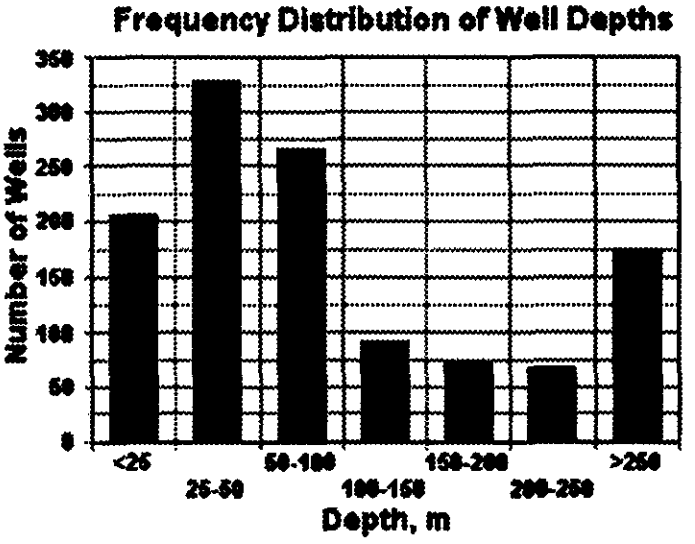

Figure 2.4. Frequency Distribution of Depths for 1225 Nearby Wells in the Areas North and East of the Hanford Site Based on WDOE Filed Well Records

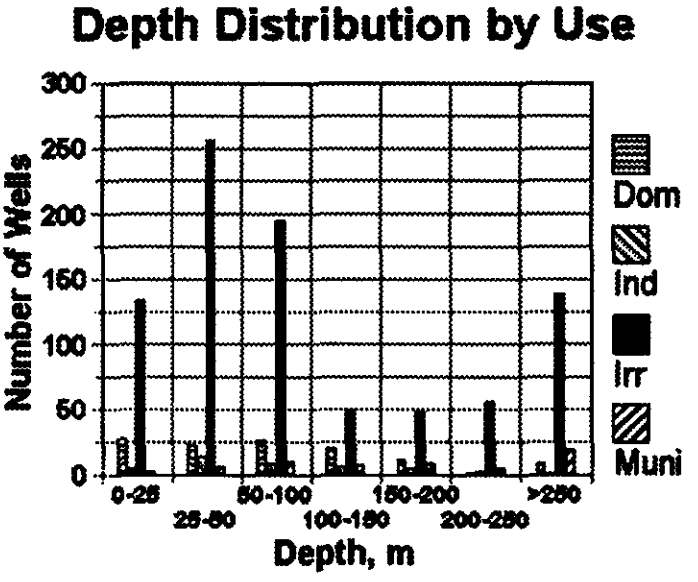

Figure 2.5. Frequency Distribution of the Depth of Wells by Use in the Study Area Based on WDOE Filed Well Records

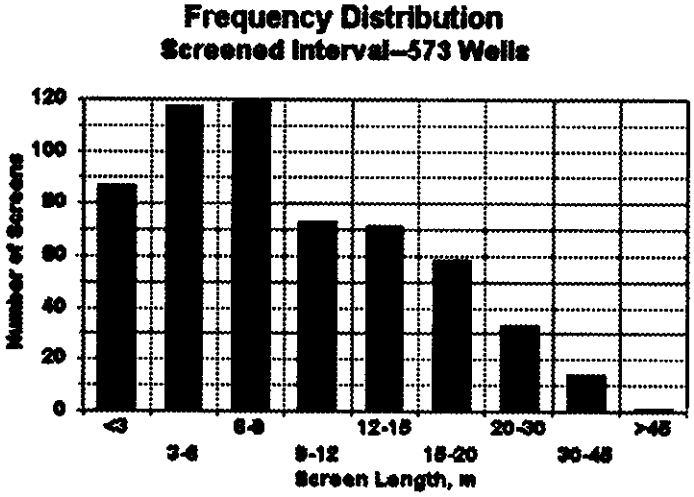

Figure 2.6. Frequency Distribution of the Length of Screens or Perforations of 573 Wells Near the Hanford Site

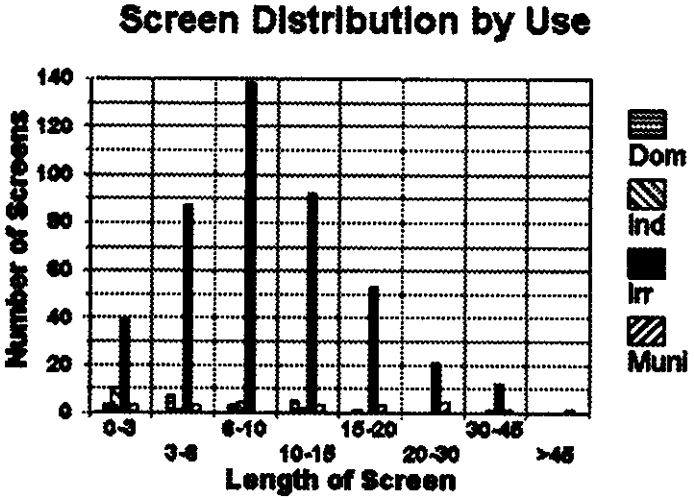

Figure 2.7. Distribution of the Length in Meters of Well Screens or Perforations by Major Use Category (498 wells since test and other miscellaneous types of wells are not included)

use from the permits that were examined. Fifty percent of the irrigation, 16.4% of the domestic, 43.6% of the industrial, and 32% of municipal wells are screened and/or perforated. The average length of screened interval for all wells of all types is 9.5 m, with 41% between 3 and 9 m. The majority of the wells in the unconfined aquifers have screens and/or perforated casings.

Three-fourths of the domestic and almost two-thirds of the irrigation wells are less than 100 m deep and most likely in the unconfined aquifers. Most of the water extracted by sustained, higher yielding wells in the unconfined aquifers is likely from irrigation return flows or direct hydraulic connections to the rivers. Natural recharge to the water tables is small. For wells less than 100 m (300 ft) deep, the average discharge for domestic wells is about 4.5 l/s (72 gpm), for irrigation wells 75 l/s (1200 gpm), for industrial users 23 l/s (360 gpm), and for municipal wells 26.4 l/s (420 gpm). Table 2.4 characterizes wells less than 100 m in the study area.

Table 2.4. Summary of Well Characteristics for Wells Less Than 100 m in Depth Within the Study Area Based on WDOE Well Permit Records. (Values in Parenthesis are one standard deviation)

Use	Number of Wells <100 m	Number of Wells <100 m with Screens or Perforations	Average Screened Length, m	Average Depth, m	Average Discharge, l/s
Domestic	76	13	6.17 (4.16)	40.3 (22.37)	5.24 (12.98)
Industrial	25	16	4.6 (3.77)	40.2 (19.52)	21.1 (33.29)
Irrigation	583	412	9.7 (7.01)	41.2 (19.82)	75.3 (83.74)
Municipal	18	6	7.2 (6.16)	58.0 (23.41)	24.7 (50.76)

3.0 Agricultural Development in the Region

Central Washington is one of the most productive and diverse agricultural areas in the world. Some of the highest yields ever measured for many crops have been reported there. Over 80 different crops are typically grown in the region every year including many high-value specialty crops. Because of the low annual rainfall in the region (from 150 to 200 mm/yr), development of high-value agriculture has depended on irrigation to supplement natural precipitation. In addition, the area has abundant, high-quality water from the Columbia River and low-salinity soils.

Soil erosion by wind and water is a significant problem, but can be minimized with appropriate agricultural practices. Waterlogging of soils tends to be localized in small areas because of subsurface bedrock topography, but is easily controlled by installing subsurface drainage systems.

A well developed infrastructure is in place to support large-scale agriculture in the region, including transportation (excellent road, rail, and river transport systems), strong electrical power network, service industries, equipment retailers, and research centers (WSU and the U.S. Department of Agriculture (USDA)-Agricultural Research Service). Large investments have been made in food processing and storage facilities, especially in the Tri-Cities area. This infrastructure would be available to support any future agricultural development of the Hanford Site.

Irrigated agriculture and its related industries (agricultural services, food processing, transportation, and retailing) is, and will continue to be, a fundamental part of the state's economy. Annual production from the state's irrigated lands exceeds $3.5 billion at the farm gate and is a major source of exports. A large infrastructure has been developed for processing, transporting, and retailing agricultural products with huge large economic effect on the regional economy. Secondary processing of agricultural products is estimated to add an additional $20-25 billion a year to the state's economy.

The region's agricultural industry affects almost all economic sectors, resulting in purchase of billions of dollars in goods and services every year. It provides a stable base for growth in other sectors as it quietly, steadily, and reliably produces a huge proportion of the state's income.

Yakima, Grant, Franklin, Benton, and Walla Walla Counties, which surround the Hanford Site, are the top five counties in Washington, respectively, in terms of the farm gate value of their agricultural production. Washington State currently ranks 15th nationally in the value of its total agricultural output (farm gate: livestock and crops) with a substantial portion of that output from irrigated agriculture in this region. Washington is ranked 8th nationally in total crop value, 3rd in vegetables, and 3rd in the production of fruit and nuts. The region's crop production is high, and it is reasonable to assume that irrigated agricultural production would be similar for the Hanford Site. The Appendix summarizes the current agricultural production in Grant, Adams, and Franklin Counties.

3.1 Irrigation Development

The main irrigated areas near the Hanford Site are the Yakima River Project and the Columbia Basin Project. Both of these projects were built by the U.S. Department of the Interior, Bureau of Reclamation. Several large-scale private irrigation developments also exist to the south and east of the Hanford Site on sandy soils, which are almost exclusively irrigated by center pivot machines.

Starting about 25 years ago, a relatively small irrigated area was developed adjacent to the northern boundary of the Hanford Site (along Cold Creek) for the production of wine grapes and fruit trees. Recent developments include center pivoted irrigated alfalfa and potatoes (however, these will likely be converted to drip irrigated wine grapes in the near future). These developments are significant to this study since they successfully demonstrate the types of crops that could be grown in many parts of the Hanford Site with similar slopes, aspects, and soil types.

3.1.1 Yakima River Project

The Yakima River Project is the oldest irrigation development in the region and contains about 182,000 actively irrigated hectares (450,000 acres). Six main irrigation districts operate in the project with about 20 small, private districts that typically irrigate less than 1000 hectares (2,500 acres). The Kittitas Irrigation District serves the Ellensburg area in the upper Yakima Basin. The Tieton, Roza, Sunnyside, and Wapato (Yakama Indian Reservation) irrigation districts serve lands in the lower Columbia Basin from near Yakima to the Tri-Cities. The Kennewick Irrigation District serves lands in the Badger Canyon and west Kennewick areas. Land ownership in the Columbia Basin is about 40% federal, 30% Native American, and 30% private.

The earliest irrigation recorded in the Yakima River drainage is in 1852 in the Ahtanum Creek near a Catholic Mission and in 1853 when construction of the Indian Ditch near Tampico began. Cattlemen and sheep herders were attracted by the abundance of bunch grass and wild game. Miners started arriving in 1854, leading to conflicts with Native Americans and the construction of Fort Simcoe. Settlers arriving as early as 1861 developed additional irrigation along the Naches River. Additional irrigation diversions near Prosser and Kiona were in existence around 1878. In 1886, completion of the Northern Pacific Transcontinental Railroad spurred new agricultural expansion in the region. The railroad company and several private land development companies made large investments in irrigation to aggressively attract settlers. By 1900, after construction of the early Sunnyside and Congdon Canal systems, the Yakima Valley was the largest irrigated area in the state with about 48,600 hectares (120,000 acres) irrigated.

In 1905, Congress authorized the 200,000 hectares (500,000 acres) Yakima Federal Reclamation Project to be built by the USBR). Construction funds for the Tieton and Sunnyside divisions were authorized in 1906. Over the next 20 years, construction of the Kittitas, Roza, and Kennewick divisions were authorized, and six reservoirs were constructed. Today, the USBR manages the surface water supply in the Yakima Basin through control of reservoir releases.

Starting in the late 1890s and completed in the 1950s, the Wapato Project was constructed and managed by the Bureau of Indian Affairs (BIA) on Yakama Indian Reservation lands south of the Yakima

River. The BIA contracted with the USBR to supply water for the Wapato Project. Most of the natural flows of Toppenish, Simcoe, and Satus Creeks are also captured and used within the district.

Many of the earliest irrigation developments were consolidated into the various federal Yakima Basin projects. A considerable amount of water is reused and shared within and between irrigation districts by capturing return flows and water markets.

An undefined amount of water is pumped from both shallow and deep wells inside and outside the irrigation district lands (estimated at an additional 20,000 hectares [50,000 acres]). The deep wells are in the confined aquifers in the basalt and relatively high yielding. Shallow wells in the unconfined aquifers are mostly for domestic use since they generally have low yields (<6 l/s), except for some localized gravel deposits in the Wapato Irrigation District that have high yielding wells.

Orchards were planted early in the agricultural development of the lower Yakima Valley. Railroads provided rapid transportation of produce to urban markets, and the fruit industry grew and continues to flourish. Hops were introduced into the area in the early 1900s. Wine grapes were planted before the turn of the century, and although the industry died due to prohibition, it has made a major resurgence starting in the late 1970s. Concord grapes have been grown for juice since the 1940s. In general, there is a high percentage of permanent crops.

Because of the limitations of available agricultural production technology before World War II and the high labor requirements of orchard, vine, and hop, the general tendency in the area is to maintain small individual fields (<15 hectares [<40 acres]). The rugged and/or steep topography combined with early irrigation methods that eroded the surface also mandated small fields in many areas, particularly on higher lands in the Roza and Sunnyside Districts. Crops grown in the Kittitas area are mostly small grains, Timothy hay, alfalfa, pasture and field corn, and a small number of orchards. Field sizes are also generally small for many of the same reasons.

Originally, all of the water was applied by furrow and ridge methods (gravity-flow surface irrigation), but presently less than 20% of the lands use these methods. Solid set sprinklers and microirrigation (drip and micro sprinklers) methods have largely replaced older methods. There are few center pivots. The initial shift to adopt pressurized irrigation methods was driven by the benefits of frost protection and erosion control (cover crops) for the rapidly increasing permanent crop industries (orchards and vineyards) in the area. However, current restrictions on return flows to the river imposed by the Endangered Species Act have resulted in many conversions of the remaining surface irrigated lands to pressurized methods. It is expected that within a few years, surface irrigation will be used in only a few small areas of the basin.

Currently, Yakima County is ranked tenth in the list of leading agricultural counties in the United States. It ranks first in the nation in the production of hops, apples, and mint. More than 80 crops are grown including wine and juice grapes, mint, asparagus, sweet corn for processing, cut flowers, and alfalfa hay. The county is a major center for beef cattle feeding in the state, and numerous large dairies have located in the area.

3.1.2 Columbia Basin Project

The Columbia Basin Project (CBP) has three irrigation districts: the Quincy District, the East District, and the South District, which are located to the north and east of the Hanford Site. The CBP service area contains portions of Grant, Adams, Lincoln, Franklin, and Walla Walla counties. The South District lands are adjacent to the Hanford Site (across the Columbia River to the east and north). Construction of the CBP began in 1933, and the first water was delivered in 1952. The last block to be developed was Block 26 in the Mattawa area, just north of the Hanford Site.

Congress initially authorized the CBP to irrigate about 405,000 hectares (1,000,000 acres); however, because of a subsequent moratorium on future development of the project, only about 60% of the original area is currently irrigated with project water. The East High canals were never constructed even though many of the head works and siphons needed to supply the water to the area were built. An estimated 30% of the original East High area is currently irrigated using water from deep wells in the confined aquifers that were privately developed; however, it is doubtful that this is sustainable due to pumping costs and the cumulative effects of using high-sodium groundwaters on soils.

Current acreage figures also include about 16,320 hectares (40,300 acres) being irrigated through "artificially stored groundwater" or subsurface return flows from other project lands in the Black Sands area near George, Washington that were not part of the original project Irrigation has expanded (about 32,000 hectares [80,000 acres]) to "marginal" lands in other parts of the CBP because of advancements in irrigation technologies (i.e., center pivots and drip) that were not available when the project was designed. Annual production from CBP lands contributes more than $800 million in direct and secondary income that benefits several counties.

Most CBP water comes from Grand Coulee Dam, located on the main stem of the Columbia River about 90 miles west of Spokane. Natural inflows from Crab Creek, Rocky Ford Creek, and other natural tributaries provide small contributions (generally <1% of total project needs) to the project's water supply. Irrigation canals and other project works extend southward from Grand Coulee Dam about 125 miles to the vicinity of Pacso, Washington near the confluence of the Columbia River with the Snake and Yakima rivers. The Columbia River forms the western boundary of the project.

The CBP diverts about 3% (standard deviation about 5%) of the annual inflows to Lake Roosevelt, 0.3-0.33 M ha-m (2.5-2.7 MAF), to irrigate more than 251,840 hectares (622,000 acres) of land. With return flows back to the Columbia, the net water withdrawal from the Columbia River is about 1% of the total annual runoff of the entire river basin, 24.4 M ha-m (198 MAF). The average on-farm delivery is about 1.13 ha-m/ha (3.7 acre-ft/acre). Average annual crop irrigation requirements are estimated at 0.83 ha-m/ha (2.71 af/a) (Montgomery Water Group 1997).

Water delivery to farms (per unit area) has decreased since the project began because of changes in irrigation practices and some changes in cropping patterns. Farmers have converted from less efficient gravity irrigation systems to more efficient pressurized methods such as center pivots and drip or micro-irrigation methods. Since 1969, the percentage of farmers using pressurized irrigation systems has increased from 40% to 70% across the entire project. About 90% of the South District uses pressurized

systems, as does the Wahluke Slope (Mattawa) irrigated areas. All three irrigation districts actively encourage and provide assistance to their growers to convert to pressurized systems, greatly accelerating this trend. Also, the rapid conversion in some areas to orchard and vine crops and specialty seed crops (i.e., carrot seed), which use much less water than do historical crops, has helped to reduce water requirements. The CBP is the most rapidly growing orchard and vine crop area in the Pacific Northwest.

In 1993, the USBR issued a moratorium on all further water development in the CBP in response to requests from the Northwest Power Planning Council and the National Marine Fisheries Service. At the same time, the water resources agencies in Washington, Idaho, and Oregon simultaneously announced that they would no longer issue permits for new diversions in the basin's salmon streams. Thus, it is highly likely the CBP irrigated acreage will remain at present levels in the future.

3.1.3 Historical Irrigation in the Hanford Site

In 1818, Fort Nez Perce was founded near present day Wallula to protect fur trappers and traders. It was later renamed Fort Walla Walla. The permanent non-Indian settlers in the area were largely cattle ranchers. The area's mild winters, sand grass, and white sage fattened cattle that were driven the Vancouver, Canada and other regional markets. However, extreme cold and heavy snowfalls during the winters of 1880-81 and again in 1886-87 decimated the cattle industry. Settlers then began building small dams and canal systems using gravity flow irrigation methods along the lower Yakima and the Columbia rivers. Most of the early irrigated crop produced on the Hanford Site was hay for feeding livestock. From 1880 until the early 1890s, numerous homestead claims were filed in the Wahluke Slope/Hanford Reach area.

During the early 1900s until 1943, the area continued to grow. The towns of White Bluffs, Hanford, and Richland flourished. Irrigated areas produced apples, cherries, pears, alfalfa, potatoes, and many other vegetables. Beef cattle, horses, chickens, pigs, dairy cattle, and large flocks of sheep were raised and grazed in the area. The average 160-mm (6.3-in.) annual precipitation made production of rainfed or dryland crops such as wheat and barley impractical. In 1954, the USDA rated the soils in the Hanford Site as marginally suited for cultivation, primarily because of the type of irrigation (gravity flow) available at the time (USDA 1954). However, with the advent of pressurized sprinkler and micro-irrigation technologies, these early classifications are no longer valid as has been convincingly demonstrated in many nearby areas.

In March 1943, all the private lands within the current Hanford Site boundaries were acquired by right of eminent domain by the U.S. Government for the Manhattan Project as part of the war effort. The land has passed from the U.S. Department of Defense to DOE, which now operates and maintains the Hanford Site. Since 1943, there has been no agriculture within the site.

4.0 Agricultural Technologies

It is an exciting time to be involved in agriculture. The state of the art of agricultural technology is advancing extremely rapidly. Crop production methods and management 50 years from now undoubtedly will be much different than today. Agrichemical restrictions, environmental concerns, and the need to be competitive in world markets are fueling tremendous strides along many fronts improvements. This section explores some of the more probable future developments in agriculture and examines current technologies and the economic impacts of irrigated agriculture in the region.

Future farm management and cultural practices will be much different from today. Bioengineered plants will be more common because they will be more resistant to insects and disease, more salt tolerant, and will use nutrients and water more efficiently (less water will be needed). The production of pharmaceuticals will be more common in agriculture in addition to food and fiber. Biologically based pest control combined with genetically engineered crops resistant to many plant diseases will continue to reduce agrichemical use.

The development of site-specific, integrated real-time precision irrigation, fertigation and pesticide systems is currently underway. Global positioning systems (GPS), detailed field-yield monitoring, GIS, computer models, extensive field sampling programs, and real-time monitoring of climate and field parameters make it possible to optimize crop management for spatial and seasonal variability. Inputs can be optimally matched to yields, greatly reducing costs and improving environmental stewardship. Advances in remote sensing, crop protection, precision planting, precision tillage, precision irrigation, and harvest mapping are changing agriculture. Collectively, these are referred to as precision agriculture.

4.1 Precision Agriculture

Precision agriculture means carefully tailoring soil and crop management to fit the different conditions found in each field using a wide variety of technologies. Precision agriculture is sometimes called precision farming, prescription farming, site-specific farming, site-specific crop management or variable rate technology. It involves aspects of remote sensing, crop protection, precision planting, precision tillage, precision fertilizer placement, precision irrigation, on-the-go yield monitoring and other emerging applications. Some of the emerging technologies undoubtedly will be part of future crop production systems in the Pacific Northwest (Evans 1997a,b). Emerging technologies have the potential for reducing inputs, and improving use of existing resources, improving environmental stewardship, and improving farm profitability.

Some believe that the potential consequences of precision agriculture technologies will have as great an impact on future agricultural production as the "green revolution" is having currently. However, at present the technology is ahead of the science to use it correctly. Research is currently underway by universities and the USDA to give farmers confidence that the use of these technologies is practical and potentially valuable for improving production of irrigated crops in the near future.

The U.S. Congress has published the following definition of precision agriculture:

"Gathering on-farm information pertaining to the variation and interaction of site-specific spatial and temporal factors affecting crop production. Use of that information to prescribe and deliver site-specific applications of agricultural management practices and inputs to maximize productive efficiency while minimizing negative environmental impacts." (House Bill 725, 105th Congress, 1st Session, February 12, 1997)

Congress extended this concept by defining precision agriculture technologies to be:

"Instrumentation and techniques ranging from sophisticated sensors and software systems to manual sampling and data collection tools that measure, record and manage spatial and temporal data. Technologies for data processing that produce valued information for farm management decisions. Machines that deliver information-based management practices and inputs to accomplish the objectives of precision agriculture."

Thus, precision agriculture is basically about information: its collection, management, and interpretation. It has been made possible by advances in computer and communications technologies that allow growers to use equipment and software to manage inputs in ways that account for the inherent yield variability across any field. Precision agriculture is a systematic way to look at the total farming operation.

The necessary "components" to implement precision agriculture on irrigated lands have recently become readily and economically available. These include: 1) GPS, 2) GIS, 3) improved techniques for real-time remote sensing of soil and crop status, and 4) improved computers, communications, "smart" sensors, and monitoring systems to provide adequate feedback and control capabilities. These improved techniques for remote sensing of soil and crop status, [already discussed above], [already discussed above], advanced crop growth and disease models, [already discussed above], and real-time data collection systems that provide adequate feedback and control capabilities make it possible to develop integrated, economically viable, site-specific crop management systems. These data must be used with software to statistically evaluate, enhance, and spatially combine with other GIS data layers to look at inter-relationships and causes of yield variability.

Yield monitors, grid sampling, and remotely sensed data are valuable tools that provide critical information on field variability and evaluate the results of a site-specific management program. The amounts of water (and nitrogen) applied by center pivot and drip irrigation systems can be carefully managed to match the spatial variability in water holding capacity and related nutrient availability. Yields and crop quality are affected by many factors. Variations in quality and quantity of yields are increased by weeds, pests, and pathogen effects on crop growth as well as microclimate changes across a field, which can cause further variability in water and nutrient usage. In addition, the method used to correct one problem may have unwanted side effects that create new, and possibly more serious, problems that must then be corrected.

The large potential of precision agriculture is recognized by fertilizer companies and major farm equipment companies such as Ag Chem, John Deere, Case-IH, Heston and others, who are making

significant efforts to develop various applications. Companies like CENEX-Land 'O Lakes, Simplot Soilbuilders, and others are making large investments in equipment and employee training to provide related services. Self-propelled irrigation system manufacturers are also very interested and conducting research in precision agriculture. Software for site-specific evaluation is becoming more available at low prices.

Research is underway around the world to fit the various components of precision agriculture together. These are 1) optimizing yields and quality from each area within a field, 2) reducing product variability, 3) protecting the environment, 4) reducing inputs, and 5) maximizing returns on investments. Ideally, processing and marketing parameters also should be included to form a holistic approach to agriculture.

Because growers must irrigate in the arid west and can control soil water, they can maximize the benefits of many precision agriculture technologies. The arid climate of the Hanford Site enhances management ability since uncontrolled natural precipitation is a minor factor, and its influence is easily included by adjusting irrigation management strategies/programs. This can greatly reduce drainage/deep percolation losses.

Advances in farm equipment and management capabilities that are part of precision agriculture or precision farming will undoubtedly influence all of the world's agriculture in the next century. The alternative management practices of precision agriculture technologies will be fundamental to profitable and sustainable farming in the future. Environmental issues, reduced water supplies, and reduced availability of chemicals/pesticides must be addressed, and components of precision agriculture will be a part of the solution. Precision agriculture can make U.S. producers more competitive, and agrichemical use will be reduced to minimum levels.

4.2 Irrigation Technologies

Irrigation technology has advanced significantly since World War II. Center pivots and microirrigation techniques were developed in the 1950s and 1970s, respectively. These technologies are continuing to evolve. Thus, future decisions must be based on the current and expected advances in irrigation technologies for application of water and agrichemicals as well as management. The best area on which to base future agricultural land use for the Hanford Site is the CBP lands that are adjacent to the site to the north and east.

To select the type of irrigation system to install, a number of different factors must be considered. These include the crop and crop water requirements; water supply; soil characteristics; topography, size, and shape of the field; climate of the area; and economic factors such as labor requirements, available capital, and resource costs. Many of these factors are interdependent, and while one factor may or may not indicate a definite need for a particular irrigation method (or even the need for irrigation), the relationships between these factors must be considered.

Many crop factors influence the irrigation system choice. For crop consumptive use, both the total seasonal water needs and the pattern of water needs during the season (relative to growth stages)

compared to rainfall amounts and patterns determine the net irrigation requirements. Net irrigation requirements (over and above rainfall) range from only 125 to 300 mm (5 to 12 in.) of moisture for short-season vegetable crops and wine grapes to 630-900 mm (25 to 35 in.) for orchard and forage crops. The actual amount depends strongly on crop and location. Average daily peak period water needs for most Eastern Washington crops and locations is from 5 to 7 mm (0.20 to 0.28 in.) per day. This translates to a required continuous supply of from 1 to 1.2 L/s/ha (4 to 6 U.S. gallons per minute per acre) to be supplied by irrigation. Wetting of the crop foliage or fruit may cause disease or pest control problems, and depending on the quality of the irrigation water, crop wetting may not be recommended to avoid quality or toxicity problems. Lack of aeration in the root zone over time may reduce plant performance. Cultivation requirements or other cultural practices may preclude the use of certain methods. The expected economic return of the crop in both quantity and quality must be analyzed to determine how much can be invested in irrigation.

Water supply factors include the quantity and quality of the source. The kinds and amounts of any salts dissolved in the water must be known. Central Washington has high- quality, abundant surface water supplies with low soil salinity. The availability of the water (timing and frequency) affect the design and management of an irrigation system, and boosts the required supply rate if the supply is not continuous. The size of the available stream may limit the choice of systems to only the most efficient. If water is not available during critical dry periods or critical growth stages, irrigation is moot.

Soil characteristics that must be assessed include the infiltration rate, water holding capacity, depth, drainage conditions, reaction to water and salts, and soil erodibility. The variability of these properties throughout a field must also be known. The rate at which soil accepts water (the infiltration rate) will often eliminate some methods of irrigation. The soil water holding capacity and the depth of the soil in conjunction with the crop rooting depth, the crop water requirements, and climatic conditions may actually indicate irrigation is not needed, i.e., enough water is held in the soil and available to the crop for the entire growing season or to carry the crop during dry intervals. Typically, this will only be the case for deeper rooted crops grown on finer textured soils, or where dry spells during the summer are of short duration. Soil drainage conditions are extremely important in western Washington. Soils that do not have adequate natural drainage may rapidly become waterlogged under irrigation. Applied irrigation water may be lost in runoff and valuable topsoil may be eroded.

Field size, shape, and topography require differing degrees of flexibility in the irrigation system. The topography of the field may require extensive land leveling to use certain methods. Certain irrigation methods are not recommended for steep slopes, and others require special design requirements. All these factors increase the cost of the system.

Climate is the driving factor in determining crop water requirements and the need for irrigation to provide the portion of the requirement not met by precipitation. Seasonal and annual variations in climate will often decide the need for irrigation to produce high yields of high-quality crops in environments that otherwise do not need irrigation. This is also the case when irrigation is used for environmental modification to protect the crop (e.g., frost protection).

Irrigation as a cultural practice adds costs to production. Initial capital costs vary widely from method to method. The method chosen also affects total costs for irrigation water, energy, labor, and land preparation. In considering the economics of irrigation systems, trade-offs exist between costs of capital, labor, water, energy, and land. The system yielding the highest return is a compromise between these resource costs. Table 4.1 shows the range of typical capital and annual costs of the various irrigation methods. Capital costs include materials and construction of the irrigation system but does not include the cost of land, land preparation, and water source development costs. Annual costs include labor, amortization of the irrigation system, and energy costs (to pressurize the system, if needed) but does not include the cost of water, taxes, interest charges or amortization of the water delivery system (e.g., pump and well).

Furrow irrigation is a limited option at the Hanford Site because of high sand soil texture classifications. The small amount of silt loams may be suitable but are subject to severe erosion. Soil erosion is being addressed successfully by growers using formulations of polyacrylamide (PAM) in small quantities essentially to halt furrow irrigation-induced erosion on thousands of acres in the Yakima Valley and the CBP (details are on the Internet at http://kimberly.ars.usda.gov/pampage.ssi).

Table 4.1. Comparative Approximate Range of Initial and Annual Costs per Hectare (Including Labor) of Various Irrigation Methods, Not Including Land Purchase, Taxes or Water Development Costs

Method		Capita Costs		Annual Costs	
		Low, $	High, $	Low, $	High, $
Surface:					
	Furrow (rill)	500	1000	250	450
	Furrow w/Land Leveling	600	1500	250	450
	Furrow w/Automation	750	1600	300	500
	Furrow w/Tailwater Reuse	750	1500	300	600
Sprinkle:					
	Aluminum hand-move	875	2000	375	600
	Wheel-move	875	1850	225	500
	Center pivot	1000	2000	375	1100
	Precision System	1250	2500	450	1200
	LEPA	1250	2500	450	1100
	Traveling gun	1000	2000	250	1250
	Solid set	1850	3700	250	1000
Microirrigation:					
	Drip/trickle	1850	3700	500	1000
	Micro-sprayers	1900	4500	500	1000

The most appropriate irrigation methods for most of the Hanford Site, based on current technology and expected advances, will probably be self-propelled center pivots, linear move irrigation systems, and microirrigation. These methods are discussed in more detail below.

The amount of water that can be saved depends on the ability of a particular type of irrigation system to improve management. However, the major factor is grower knowledge and the existence of incentives to adopt the improved management practices. A critical link in improved management is the implementation of scientific irrigation scheduling (SIS) techniques that will be required for any irrigation scheme.

4.2.1 Irrigation Scheduling

Irrigation scheduling is generally defined as deciding when to irrigate and how much water to apply. All irrigators schedule their irrigations differently. Some follow a calendar, while others irrigate because their neighbor is watering. Whatever criteria are used, relatively few irrigators currently use an approach based on sound scientific principles, or, SIS.

In general, a fairly large number of studies throughout the western United States shows that scientific irrigation scheduling can, in most cases, reduce the gross amount of water normally pumped from 15% to 44%. Water savings of about 20% seems to be a generally achievable level over "non-scientific" methods.

The concept of scientific irrigation scheduling (SIS) involves soil water holding capacity, volume balance, application efficiency, crop stress related to productivity and economic benefits, when and how much to irrigate, and how to apply the target amount of water. All SIS methods are based on two fundamental approaches, 1) monitoring soil and/or plant water status, and 2) predicting irrigation schedules from a computed soil water budget that estimates water depletion in the root zone. The first approach provides a direct reading of soil/plant status in the field and of water use since the last reading, but limits the potential for forecasting or planning. The second approach provides a planning element but alone does not have a "ground truthing" component as a baseline check to ensure accuracy. Thus, most SIS methods use a combination of the two approaches with wide variation in frequency and rigor of ground truthing activities and the development of new schedules.

Scientific irrigation scheduling is a concept that dates from the early 1950s. However, despite decades of promotion by public agencies and private consultants, its success and dissemination has been limited. As a result of recent droughts, groundwater contamination issues, and endangered species programs, growers are much more willing to look at SISSIS seriously as a viable part of their operations. Farmers in the Pacific Northwest are sensitive to the increased public demands that irrigated agriculture conserve more water and reduce agrichemical usage by using improved irrigation methods and better management. The shift away from low-energy surface irrigation methods to moderate to high-energy pressurized sprinkler and microirrigation techniques is accelerating, causing additional demand for electric energy and creating an even greater need to conserve electric power in the region. These factors, in addition to using irrigation systems for multiple purposes(e.g., frost protection and crop cooling) and adopting new irrigation methods is creating interest in and acceptance of SIS. SIS Irrigators are now more open to educational opportunities that will help them stay competitive. Recent successful SIS

projects in Washington have also contributed to growing local approbation. The major incentives for adopting SIS currently are related to the cost of SIS services/technology and the cost of water, which includes the expense of pumping. Environmental regulations seem certain to provide additional incentives in many areas throughout the Pacific Northwest.

Educational programs are the only way to address problems related to an irrigator's insufficient knowledge of 1) irrigated soil properties; 2) irrigation system application capacities, rates and efficiencies; 3) crop characteristics relative to water use and the patterns of water use; 4) climate and environmental effects on crop water demand and irrigation performance; and 5) economic benefits. In the near term, extension educational and demonstration programs can provide irrigators the necessary confidence and knowledge to integrate SIS successfully into their total farming system. Equally important, such educational and demonstration programs will also help train consultants, conservation district staff, and electric utility and other agency personnel in climate-plant-soil-irrigation interactions and proper scheduling techniques and processes so they can work more effectively with growers. In addition, an increasing number of farmers and their children are college-educated, many with advanced degrees, and these individuals are more open to technological approaches to farming than earlier generations.

The technical approaches to SIS are complex because they must be based on many factors related to crops, soils, climate, irrigation method and management objectives as well as local experience with constraints imposed by the water delivery system. In addition, generalized SIS procedures must be tailored to each situation since many of these factors are site-specific. SIS services must adequately integrate and support other farm management decisions perceived by growers to be more important than the irrigation decisions. To be successful in the long term, educational SIS programs must demonstrate the increased value of a range of improved farming practices, such as precision agriculture, that are supported by scheduling. This complexity generally requires consultants and others (e.g., specific employees of large corporate farms) to provide tailored SIS services since most agricultural producers do not have the time or expertise. Unfortunately, many consultants also lack the necessary knowledge to advise irrigators properly on these subjects. Nevertheless, large farming enterprises are more likely to adopt SIS practices because they are often better capitalized and generally more willing to make long-term investments in technology and training.

Remarkable progress has been made in recent years on sensor technologies and automation suitable for SIS, and the diversity is enormous. The economic and environmental incentives as well as the educational level of the farmer will dictate which technologies will be adopted for more accurate scheduling. These devices and tools must be tested and evaluated for use in specific situations, and the new information made available to growers, utilities, private consultants, and other interested parties for inclusion in on-farm SIS programs.

It is estimated that more than 300,000 acres in Washington currently use some aspects of SIS. The successes of past SIS education and demonstration efforts in the region have added to the general perception that SIS may actually be a beneficial and requisite practice rather than an inconvenience. The future availability of low-cost soil/plant sensors, currently unavailable, are crucial to expanding SIS adoption.

4.2.2 Weather Networks

Successful implementation of SIS requires the availability of a network of weather stations that provide timely climatic data for predicting crop water use. Two agricultural weather networks in the Pacific Northwest currently have fully instrumented stations. These networks must be maintained to support both SIS and integrated pest management programs that reduce agrichemical usage. Because of significant microclimate differences between the larger scale stations and farms, some growers have installed their own weather stations to assist in frost protection and pest/disease control programs.

AgriMet is a satellite communications-based network operated by the USBR out of Boise, Idaho. AgriMet provides climatic data at 4-hour intervals from sites near the Washington communities of George, Odessa, Lind, Goldendale, Harrah, LeGrow (on the Snake River near Burbank), and Omak, and in Oregon near Hermiston, Hood River, and Echo).

The second weather network is the PAWS operated by WSU Cooperative Extension out of WSU-Prosser. It is a network of 59 real-time weather stations primarily located in the irrigated areas of the Columbia Basin and Yakima Valley. Stations are also located in the Wenatchee and Omak drainages and a few stations are on the west side of the Cascade Mountains. All of these stations collect 15-minute data and communicate these data to the base station either once an hour over an rf transmission network or over the Internet. During the spring and fall, some of these stations transmit data at half-hour intervals to assist growers in frost protection.

4.2.3 Self-Propelled Center Pivot and Linear Move Irrigation

A center pivot or lateral move system basically consists of a pipeline (lateral) mounted on motorized structures (towers) with wheels for locomotion. A center pivot machine rotates around a "pivot" point in the center of the field, whereas a lateral move machine travels along a straight path and has a separate guidance system. Sprinkler outlets are installed on the top of a pipe supported by steel trusses between adjacent towers. The towers are usually from 30 to 60 m (90 to 200 ft) apart, and each tower has a 1-hp motor and sits on two large rubber or steel tires.

In the United States, approximately one-third of all irrigation, or about 60% of all sprinkler-irrigated lands, is by self-propelled irrigation systems, mostly center pivots. This is about 125,000 machines on approximately 7.9 million hectares (19.5 million acres), or about 29% of the total irrigated area., In Washington, center pivots account for more than 25% (about 190,000 out of 810,000 hectares) of the total irrigated lands, mostly in the Columbia Basin. These sprinkler irrigation systems have allowed agricultural development of "marginal" lands in central Washington unsuitable for surface irrigation, because of their mostly light sandy soils and large variations in field topography. These conditions are also typical of much of the potentially irrigable lands of the Hanford Site.

Worldwide use of these very adaptable water application methods has grown in recent years due to their 1) potential for highly efficient and uniform water applications, 2) high degree of automation requiring less labor than most other irrigation methods, 3) large areal coverage, and 4) ability to apply water and water-soluble nutrients economically over a wide range of soil, crop, and topographic

conditions. For these reasons, center pivot irrigation in the United States increased by more than 50% from 1986 to 1996.A standard 50-hectare(125-acre) center pivot system will cost from $35,000 to $45,000, excluding land and water supply development costs. Water development costs depend on the source of water and power (i.e., electric, diesel or natural gas). Generally, the largest annual costs for these machines are for power or fuel to pump water.

Because center pivot and lateral move systems operate semi-automatically, it is relatively easy to manage soil water levels carefully across a field. Almost all crops including sugar cane, orchard and vine crops, and more traditional field crops such as maize, potatoes, small grains, alfalfa, and vegetables have been successfully irrigated with center pivot water application systems under a wide range of conditions. Some center pivot irrigated crops require special cultural practices such as planting in circles or using small pits or reservoirs in the furrows to facilitate infiltration on heavy soils and prevent surface runoff. Application efficiencies higher than 80% are possible depending on management and a properly designed installation for the site. Center pivot and lateral move systems have the potential to be more than water application devices. They also provide an excellent vehicle to apply some chemicals and many fertilizers to match plant requirements exactly. In some areas of south-central Washington that have very light soils, as much as 80% of all nitrogen fertilizer used is applied through the center pivot system. Substantial crop quality and pest control benefits may accrue when using this method for applying chemicals.

In addition, center pivot systems provide an especially suitable platform on which to mount various types of sensors since the lateral system potentially passes over every part of the field every day. Color video and infrared and reflected wavelength specific sensors could be combined and coupled with pattern recognition software and GPS for early detection of stresses due to lack of water or nutrients, disease, and insects as well as potentially identify various weeds and other problems.

4.2.4 LEPA Systems

A special adaptation of self-propelled technology is the Low Energy Precision Application (LEPA) method that can be installed on both center pivot and linear move systems. LEPA has "drop" tubes spaced about every meter that extend to the soil surface where a low pressure bubbler is attached in place of a sprinkler. Water is applied directly to the furrow, minimizing evaporation losses because the canopy is not wetted. Although initial capital costs are higher than standard systems, with the right soil, topography, and management, these systems can be very efficient (e.g., 95-98%). Soil evaporation is generally less than 2% with alternate row irrigation, although runoff may be as much as 50% with poorly designed and operated systems. Wind drift losses also are eliminated. The best results with LEPA have been obtained on heavier clay soils, and use has been limited in the Pacific Northwest (used mostly on mint and alfalfa with shallow furrows) because of the light soils with poor lateral spreading.

Crops are usually planted in a circle so that the drops do not damage plants. Sometimes a canvas "sock" or other fabric energy dissipation device is used to prevent soil erosion in the furrows. A machine such as the Dammer-Diker™ is often used with both LEPA and regular center pivot and linear move application techniques to create small reservoirs that store water until it has infiltrated on heavy or steeply sloping soils. Typical quarter-mile-long (400 m) LEPA systems have from 350 to 450 heads. These systems could also be improved using precision irrigation technologies.

4.2.5 Precision Irrigation with Self-Propelled Irrigation Systems

The goal of irrigation designers is to have the most uniform water application pattern possible along the entire length of the center pivot or linear move, which is not necessarily ideal for crop quality and the environment. For example, our research and that of others (Evans and Han 1994; Han et al. 1995; Mulla et al. 1996; Mallawatantri and Mulla 1996) has shown that, in grossly simplified terms, about 75% of leaching occurs in about 25% of the area in many center pivot irrigated fields in the central Pacific Northwest.

Self-propelled irrigation systems such as center pivots and linear moves are particularly amenable to site-specific approaches because they are automated and cover a large area with a single lateral pipe. Microprocessor-controlled center pivot and linear move irrigation systems provide a unique control and sensor platform for economical and effective precision irrigated crop management. These technologies have made it potentially possible to vary agrichemical and water applications to meet the specific needs of a crop in each unique zone within a field to optimize crop yield and quality. There is less impact to the environment and reduced costs for input water and chemicals. The criteria for managing precision water and chemicals with these self-propelled systems is currently being developed by numerous universities, government research groups, and industry, and is expected to be commonly available within five years.

Despite the inherent high-frequency and fairly uniform applications of self-propelled center pivot irrigation systems, considerable yield variations still exist that are often attributed to spatial variability in soil water holding capacities and related nutrient availability. Variations in water availability across a field result in a farmer needing to 1) ensure that areas with the lowest water holding capacity maintain adequate water levels, 2) manage the whole field based on average soil water depletions, or 3) avoid overirrigation in wettest areas. All of these cases will cause overirrigation or underirrigation of some areas because current center pivot systems cannot differentially irrigate based on varying soil and plant factors within a single field. Some chemical leaching below the root zone, surface runoff, and potential yield decreases may occur in different areas under each management practice.

Thus, it is obvious that having high water application uniformities across an entire field is not necessarily the best in terms of crop quality and the environment. For example, research at WSU and the research of others has shown that, *in grossly simplified terms*, that about 75% of the leaching occurs in about 25% of the area in many center pivot irrigated fields in the central Pacific Northwest. It is evident that the ability to more precisely manage small areas of the field will be necessary to reduce groundwater degradation. *Therefore, the next advances in center pivot and lateral move irrigation will involve being able to vary water and chemical applications along the length of the pipe depending on its position in the field* (Evans and Harting 1999).

Center pivots are especially suitable for site-specific water application because one pipeline and 100+ sprinklers can irrigate 50+ hectares (125 acres). Automating a sprinkle irrigation system for precision water applications requires the ability to control the net application rate from each head individually depending on its location in the field. In addition to improved water management and reduced leaching, another obvious advantage of automating individual heads is that the very high application depths near the pivot point can be reduced to levels matching the rest of the system by using larger, non-plugging

heads with better water distribution characteristics. Reducing water applications near the pivot point would also reduce the incidence of fungal diseases. With appropriate sensors, software, feedback, and control systems, irrigation efficiencies of 85 to 95% are possible with precision irrigation using center pivots. Most water losses would be from evaporation and wind drift. Including precision irrigation hardware and control software adds about $250 per hectare ($100 per acre) to the cost of the machine. Agronomic input and monitoring equipment to support management decisions also will increase costs.

4.2.6 Microirrigation Technologies

Drip irrigation, also called trickle irrigation, bubblers, and localized small microsprinklers, micro-spinners and microsprayers are collectively referred to as microirrigation. Microirrigation includes any localized irrigation method that slowly and frequently provides water directly to the plant root zone. Applying water slowly at discrete locations at low pressure and irrigating only a portion of the soil volume in the field can result in relatively low-cost water delivery systems that divert less water than other irrigation methods. Drippers and bubblers are designed to apply water at atmospheric pressure, whereas microsprinklers apply water from about 50 to more than 250 kPa (7-40 psi).

Microirrigation has the potential for precise, high-level management and is an extremely flexible irrigation method to design. It can be adapted to almost any crop and climatic zone. Microirrigation can be used over a wide range of terrain conditions, and it has allowed irrigated crop production to expand into areas with problem soils (either very low or very high infiltration rates) and poor water quality that could not be used with other irrigation methods. It can be installed as either a surface or subsurface water application system. Application efficiencies above 90% are readily possible under good management with well-designed systems. These systems can cost from $1200 to $3700 per hectare (from $500 to $1500 per acre) depending on the field size and crop.

Microirrigation can be used on most agricultural crops, although it is most often used with high- value specialty crops such as vegetables, ornamentals, vines, berries, olives, avocados, nuts, fruits, and green-house plants. In many cases, it can also be used economically for field crops, golf greens and fairways, cotton, and sugar cane. Microirrigation is used almost exclusively on wine grapes in central Washington because of its potential to control soil water levels and influence winter hardiness.

Microirrigation is being used increasingly around the world and in the Pacific Northwest, and it is expected to continue to be a viable irrigation method for future agricultural production. With increasing demands on limited water resources and the need to minimize the environmental consequences of irrigation, microirrigation technology will undoubtedly be even more important in the future. Micro-irrigation provides many unique agronomic, water, and energy conservation benefits that address many of the challenges facing irrigated agriculture, now and in the future. Farmers and other microirrigation users (i.e., landscapers and golf course managers) are continually seeking new applications to microirrigation technologies, such as waste water reuse, that will continue to provide new challenges for designers and irrigation managers.

Microirrigation inherently offers tremendous benefits for chemical injection and application. Consistent soil water contents and wetted soil volumes tend to increase the efficiency of plant uptake of many

chemicals. Water-soluble nutrients can be injected to match crop requirements closely, increase efficiency of nutrient use, and reduce costs. Labeled systemic pesticides and some soil fumigants also may be injected with high efficacy.

Any irrigation system must be compatible with the cultural operations of a specific crop. Using microirrigation may require adapting to new or innovative cultural practices and even the development of new harvest and tillage equipment. For example, surface lateral lines can hinder traditional harvest operations by requiring pre-harvest removal of the tubing or development of a new harvester and harvesting techniques. Lateral lines can be buried, but this generally requires moving to minimal-tillage or permanent-bed systems for perennial crops.

An in-depth understanding of the unique benefits and limitations of microirrigation systems is needed to design and manage these systems successfully. As with all other irrigation methods, there are definite tradeoffs that impact irrigation scheduling, efficiency, uniformity, ecology, crop responses and economics.

4.2.7 Frost Protection in Orchards and Vineyards

In some years, many plants require at least some level of protection from cold temperature injury (frost protection) in Pacific Northwest fruit growing areas. Cold weather can occur during spring, fall or winter, although most cold protection activities for tree crops occur in the spring to keep buds, flowers, and small fruitlets above the critical temperatures at which they can be killed. On the other hand, it is often necessary to protect Pacific Northwest *vinifera* vineyards from frost in the fall to prevent leaf drop so sugar will continue to accumulate in the berries. Sometimes frost protection is needed on perennial trees (i.e., peaches, apricots) and vine crops. Very often only a few degrees rise in air temperature is sufficient to minimize cold damage. Applying water using under-tree and over-crop sprinklers to protect crops from cold temperature injury is common practice in central Washington.

Protecting orchards and vineyards from frost in spring and fall can require large volumes of water to be available for short periods of time, often creating major physical and legal problems for growers. Typical frost protection with under-tree sprinklers requires about 6.25 l s^{-1} ha^{-1} or 2.3 mm hr^{-1}. Over-tree sprinkling is more effective but requires about twice that amount.

Frost protection requires water to be delivered before it is normally required for irrigation, and many canal systems are not ready when frost occurs. In addition, most of the canal and on-farm delivery systems in the western United States are generally designed to deliver water at rates too slow to provide frost protection. They are designed to satisfy the requirements of surface furrow (rill) irrigation (max. delivery 1-1.5 l s^{-1} ha^{-1} [6-9 gpm/ac] continuous flow to farms based on total cropped area), which is also adequate for standard sprinkle systems. These flows are usually combined and used to irrigate smaller areas ("sets"), often at rates above 6.3 l s^{-1} or 5.3 mm hr^{-1} (100 gpm /ac or 0.21 in/hr). Water use is rotated over several days to cover the entire cropped area. For frost protection, many growers are drilling wells and building large ponds to hold supplemental water or unused allocations.

Water may be required for frost protection over 4 to 6 weeks in the spring. Growers may operate their systems from 20 to 30 nights for 6 to 10 hours per night in a frost protection season. As much as 250 to 500 mm of water can be applied during a single frost protection season.

Because the water is applied in large amounts at times when trees are using very little, groundwater contamination can result by leaching of chemicals and nutrients from saturated soils. Most of the applied water from frost protection is either runoff or deep percolation.

4.3 Economic Impacts of Irrigated Crop Production

The economic impacts of irrigated agriculture are large. It is well documented that irrigation increases yields and provides stability in food production over rainfed agricultural systems. Irrigated lands constitute less than 17% of the world's cultivated farmland but produce 40% of the total food and fiber.

Table 4.2 presents approximate net returns per hectare for some typical crops grown in the area surrounding the Hanford Site. For example, if 50,000 hectares (125,000 acres) were equally split between potatoes, apples, and wine grapes, the gross return based on representative current prices would be more than $430 million per year. When the economic income/employment multipliers are used, the annual value easily exceeds $1 billion.

Income/employment multipliers of 1.7 are commonly used for irrigation sector impacts. At the state level (1997 data), the total direct agricultural industry employment multiplier generated per job ranges from 1.4 to 2.5 with about 5.4 jobs generated per food processing job. By comparison, the total employment multiplier for the aerospace industry is about 2.3, for the computers and electronics industry from 2.4 to 2.7, for business services 1.7, and for fisheries 1.2.

4.4 Future Pressures for Expanded Agricultural Development

By 2050, world wide demands for increased production of animal/fish protein, food, and fiber are anticipated, despite advancements in crop breeding, genetic engineering, and other technologies. World population is projected to double to more than 12 billion people, straining already stressed agricultural resources. Current world surpluses in many commodities will not last when faced with increasing population, decreasing ocean fisheries, and the rapid loss of productive lands from soil salination and erosion. The production of pharmaceuticals from bioengineered plants and animals will undoubtedly add more pressure on the already limited (and declining) arable land base. In addition, there will be pressure to produce crops that can help reduce the world's dependence on petroleum and be used for chemical plant feedstock.

These external, formidable pressures to increase productivity will necessitate increased investments in irrigation infrastructure in many areas of the world. Intensive greenhouse culture and aquaculture also will be greatly expanded. There will be large economic and social pressures to expand production in areas such as the Pacific Northwest. Agricultural exports will continue to be important.

The most likely large areas for expanded irrigation in the Pacific Northwest are the undeveloped East High areas of the CBP and non-restricted areas within the Hanford Site. Both of these are potentially highly productive food and export capital producing areas. The environmental concerns will be large; however, the favorable growing conditions, high-quality (low-salinity) abundant water supplies, and low soil salinity make the Pacific Northwest, from a world perspective, a very desirable region for economically sustainable expansion of agriculture.

The economics of developing each area will have to be assessed. The Hanford Site may be less expensive to develop, even though much of the infrastructure is already in place for the East High area, because of easy access to water (surface and groundwater) and power. However, [public? local? regional?] pressure to develop both areas will mount as existing agricultural resources are stretched in the future. Much of any new agricultural development in these areas probably would be private rather than public.

Table 4.2. Estimated Current Yields and Value Received for Selected Irrigated Crops That Could be Produced on Hanford Site Lands Based on Approximate State Averages of Yields (Metric), Prices Paid, and Net Returns Based on Washington Agricultural Statistics Data (Chase et al. 1993)

Crop	Yield/ha	Unit Price, $	Gross, $/ha	Net, $/ha
Alfalfa	13.5 M Tons	97	1,310	230
Apples	100 bins[a]	116	11,600	1,110
Asparagus	4,000 kg	1.25	5,000	680
Sweet Cherries	15.7 M Tons	1,260	19,780	1,490
Concord Grapes	22.4 M Tons	198	4,435	715
Irrigated Wheat	6.8 M Tons	110	750	52
Onions	53.3 M Tons	88	4,690	860
Potatoes	62.3 M Tons	88	5,480	445
Sweet Corn	18 M Tons	92	1,660	198
Wine Grapes	9 M Tons	1,012	9,110	1,560
Average Return			6,382	734

(a) A bin of apples is approximately 450 kg (1000 lbs).

5.0 Viability of Agriculture on the Hanford Site

This section presents the procedures and results of evaluating the potential for agricultural development of the Hanford Site. In general, the site's semi-arid desert steppe climate offers deep soils, long summer days because of the northern latitude, low altitude and its attendant long growing season, good drainage, mild winters, and the easy proximity of high quality, dependable water in the Columbia River.

Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge are significant sources of cold air drainage that will have considerable impact on agronomic and horticultural crops selected to be grown in the Hanford Site because of the danger of cold temperature injury to orchard and vine crops. However, the general winds from the Pacific Ocean coming up the Columbia River Gorge to the southwest during the spring and fall have a large moderating effect on low temperatures throughout a substantial part of the region, making it a very desirable location for high-value orchard, vineyard, and vegetable crops.

The area's suitability to produce high-value crops is evident in the irrigated areas around the Hanford Site, which are primarily devoted to producing high-value, high-yielding fruit and vegetable crops. According to the 1997 Census of Agriculture, 4% of the crops produced in the United States are fruits and vegetables, but they account for more than 30% of the total farm income. Lands released for irrigated agriculture in the Hanford Site undoubtedly would also produce high-value crops that would have a major impact on the region's economy since soils and climatic conditions are similar.

Any irrigated agricultural development of the Hanford Site will undoubtedly be integrated with wildlife and ecosystem reserves and permanently restricted disposal or old reactor sites. However, making the very big assumption that water rights and environmental concerns will not be overpowering issues, three different scenarios may be envisioned for future irrigated agricultural development of the Hanford Site. These are: 1) small acreages (< 10 hectares [20 acres]) primarily used for pasture and small home gardens with most of the income from off-site sources, 2) large-scale intensive commercial agricultural developments similar to the privately developed large corporate farms that pump water directly from the Snake and Columbia rivers, or 3) a combination of the two. The large scale agriculture might also be integrated with highly intensive production in greenhouses (irrigated) and/or aquaculture.

The small farms and ranchettes near Benton City and the West Richland area probably would be typical of the types of small acreage (suburban) farming operations on the Hanford Site, if permitted. Currently, these 0.5 to 10-hectare (1 to 20-acre) operations are mostly devoted to pasture, small gardens, and landscaping, with a few small vineyards and orchards. Irrigation efficiencies are generally quite low because of poor water management due to a number of factors, but mostly due to the lack of time by the owners because of other commitments and the fact that their livelihood does not depend on the production efficiency or profitability. The poor irrigation efficiencies tend to result in excessive water moving toward the groundwater and the leaching of chemicals from septic tanks, fertilizers, and other soluble materials used on the properties.

The national trend in commercial agriculture is toward larger farms and vertical integration of farming operations with processing and marketing due to rising input costs, declining commodity prices,

and the cost of environmental regulations. Global competitiveness and the regional economics of agriculture suggest that this pattern would also be the norm for future large-scale commercial agriculture at the Hanford Site.

If the Hanford Site was developed for irrigated agriculture today, it would likely consist of large, vertically integrated farming enterprises using center pivots and microirrigation techniques. Based on current trends, the most probable crops grown on the Hanford Site would include:

1. Alfalfa, pasture, and forage crops
2. Premium varietal wine and juice (Concord) grapes
3. Tree fruits such as apples, pears, and sweet cherries
4. Field crops such as dry beans and feed corn
5. Sugar beets
6. Vegetables crops such as potatoes, asparagus, sweet corn, carrots, and onions.

Groundwater flow direction under the Hanford Site is predominately from west to east. As water is removed from the unconfined aquifers (Hanford and Ringold), groundwater flow velocities may decline in some regions of the acquifer and perhaps reverse, greatly slowing or even reversing the migration rate of various contaminant plumes, possibility allowing more time for treatment and/or radioactive decay before they reach the river systems. Excessive groundwater pumping in the interior of the Hanford Site and/or locating pumps near the river could enable surface water to be drawn directly from the Columbia River into the acquifer and the wells.

Groundwater development will require careful management and implementation of specific water withdrawal strategies (spatial and temporal distribution of the volume of pumped water) with water applied to agricultural crops. Carefully managed groundwater use potentially can be part of the contaminant control and treatment programs. Irrigation diversions should probably be a mix of surface and groundwater supplies. One scenario is that areas directly above contaminant plumes and between the plumes and the river would use river water (or deep wells in the confined aquifers), while areas to the sides could use shallow groundwater to manage hydraulic gradients. The mix of surface water and shallow groundwater pumping might avoid potential contamination of crops and keep contaminated groundwater plumes away from the river. This type of program would need to be supported by monitoring and sophisticated computer modeling of the system.

A realistic potential development scenario involving contaminated groundwater will depend on: 1) stewardship or security of the waste disposal sites, 2) health and environmental considerations to protect people in the area, and 3) use of the water in unconfined aquifers in light of contaminant movement for domestic, industrial or irrigation uses. Based in these criteria and the undesirable consequences of poor irrigation efficiencies common to most small farms/ranchettes, it was decided to base most of this analysis on only the second option of large commercial agriculture (no greenhouses) that is typical of the region.

5.1 Analysis

Determination of reasonable future agricultural uses was based on review and analysis of existing data, maps, reports and observations from DOE, Pacific Northwest National Laboratory (PNNL), WDOE, USBR, USDA-Natural Resources Conservation Service, WSU Cooperative Extension, local governmental agencies, and other sources. No new data were collected as part of this study. The analysis of potential agricultural land use patterns for the Hanford Site was generated using a GIS to collect and compare existing data.

Existing electronic digital elevation maps (DEM), digital line graphics (DLG), digital orthoquads (regional satellite and aerial photographs that have been processed to include coordinates) and other available data on soils, crops, field sizes, climate, and housing information were entered into a GIS data base. Topographic data were based on digital elevation maps in the GIS to extract information (layers) on slope, aspect, and elevation (see Figure 2.2).

Land use data were collected by viewing the orthoquads, digitizing, and entering them into the GIS data base on current land use. Land use data were somewhat verified by limited field inspections to check crop types. A 1996 baseline was selected for the land use comparisons because it was the latest date for which many data were available including orthoquads and the 1997 U.S. Census of Agriculture information.

The orthoquads covering the study area were either purchased from the U.S. Geological Survey-Earth Resources Observation Systems (USGS-EROS) Data Center or obtained from the USDA-NRCS and entered into the ArcView GIS program. Crop types and other types of land use were digitized from the orthoquads although some ground verification of crops was required. Some land use information on Franklin and Grant Counties was provided in ArcView format by the Franklin Count Conservation District and the Grant County Conservation District, respectively. The land use data were used to help create GIS layers on existing land use.

Soils data were entered into the GIS using digital copies of the existing Hanford soil survey (Hajek 1966) and USDA Soil Surveys for Grant (1984) and Franklin Counties (draft information 1999). Parts of Adams and Benton County soil surveys (1967 and 1971, respectively) were digitized and entered into the GIS. The soil classifications were merged, and a GIS soils layer was developed.

The GIS data bases were used to develop the summary of characteristics of irrigated and rainfed agriculture in the surrounding area from Royal Slope, Wahluke Slope, Cold Creek, the north slope of Rattlesnake Mountain, the southwest corner of Adams County, and the western portions of Franklin County. GIS layers of soils, slope, aspect, topography, land use, etc. were used to generate areas of common characteristics. These characteristics were used in conjunction with other reported data and observations to evaluate various land use scenarios for the Hanford Site based on comparisons from surrounding agricultural areas.

Comparisons of land use by soil classification and topography were made by overlaying the GIS layers. The information was then sorted by crop type, soil classification, aspect, slope, and elevation.

Slope is given in percent gradient as a length (i.e., meters) per 100 of the same unit lengths. Aspect, also often called exposure, is the direction is which the land is primarily facing. This is normally presented as a circle in degrees from true north (0 to 360). For example, an area that has a southern exposure, would have an aspect of approximately 180 degrees, whereas a northern exposure would be 0 or 360 degrees.

No information was directly collected on the types of irrigation systems used. However, the assumptions and much of the discussion is based on experience and current published data on the various types of irrigation systems used in central Washington and is not specific to the study area. It was assumed that the types of irrigation systems in the study area followed the regional distributions.

5.1.1 Selection of Lands for Comparison

It was assumed that basing future land use on the Hanford Site and other areas in central Washington on current agricultural development was reasonable and appropriate. It was also assumed that the current trend toward large field sizes will continue, and the management capability of growers will be substantially improved in 50 years.

Yakima Project lands were not used for comparisons in this study because the relatively small field sizes, exposures (slope, topography, and aspect) and cropping patterns are not representative of expected potential agricultural situations in the Hanford Site. CBP lands were used as the major source of data for developing land use scenarios for this project due to cropping patterns and other physical similarities to the Hanford Site. In addition, much of the CBP irrigation development is more recent than the Yakima Basin Project lands and reflects modern agricultural development strategies: they are highly capitalized with large fields and professional managers.

The Royal Slope area of the CBP has similar aspect, topography and slopes common to many areas of the Yakima Valley, but its more recent development is probably more indicative of the types of development that would occur in the Hanford Site. The Wahluke Slope (Mattawa) is a particularly appropriate example of the expected types of development because of its proximity and recent irrigation development. In addition, the Wahluke Slope has similar geology and pumps from the same unconfined aquifers. Consequently, the South District of the CBP contains most of the lands used for comparison in this study to predict likely potential future agricultural land use patterns on the Hanford Site.

5.1.2 Summary of 1996 Land Use

Land use was summarized by broad categories related to crop type as presented in Table 5.1. Some, such as the round center pivot irrigated fields were obvious from the aerial photography and were known to produce field crops although the exact crop was unknown. Center pivots are used for field crops such as potatoes, sweet corn, and alfalfa. They are very seldom used on tree and vine crops in the inland Pacific Northwest although center pivots are used on orchards and vineyards in other areas of the world. Orchards and vineyards could be distinguished from the orthoquads, but whether they were apples or cherries, wine (vinifera) or Concord grapes could not be determined. Field visits were made to verify crops in certain situations. For example, it was necessary to determine whether a vineyard was wine grapes or Concords because of the substantial water use differences (2X) between these crops.

Table 5.1. Summary of Study Area Statistics on 1996 Agricultural Land Use

Category	Acres	Hectares
Center Pivot Irrigated Field Crops	139403	56416
Other Field Crops	148252	59998
Wine Grapes	5632	2279
Orchard	51311	20765
Feedlots	511	207
Concord Grapes	578	234
Towns (Urban)	23271	9418

Field crops are irrigated by center pivots and other sprinkler systems and some are surface irrigated. Orchard and vine crops are typically irrigated by sprinkler and microirrigation methods. Microirrigation and other pressurized water application techniques are more appropriate for vine and tree crops, in fact, the rigorous water management requirements of wine grapes in this region make microirrigation the system of choice of most growers. Figure 5.1 shows current land use on the Hanford Site and surrounding agricultural areas. It is evident that center pivot irrigation is a major water application method.

Analysis of crops based on soil type, aspect, and percent slope shows a consistent pattern of most irrigated production occurring on silt loams, sandy loams, and loamy sands. Because of the regional stratigraphy, the majority of crops are produced on southwest, south, and west sloping lands (a factor that makes the region so suitable for orchard and vineyard crops). In addition, most crops are grown on slopes of less than three percent, although a substantial portion of the orchard crops are on slopes of 10% or less because of cold air drainage concerns. Much of the lands within the Hanford Site have the same characteristics and would be expected to produce similar crops with similar yields to the surrounding lands.

As noted, the majority of irrigated agriculture in the study area is located on loamy sand, sandy loam, fine sandy loams, and silt loam soils. These soil types are common on the Hanford Site (Figure 2.1). Table 5.2 summarizes land use by soils for the study area. Some relatively small areas of cobbles and stoney soils occur on the Hanford Site; however, as seen in Table 5.2, these are seldom farmed because of the very low water holding capacities.

Slope and aspect are important considerations in the long-term production of orchard and vineyards in central Washington. Center pivot irrigation systems are not recommended for use on general slopes exceeding 15%. Figures 5.2 and 5.3 show the slope and aspect characteristics of lands within the study area that includes the Hanford Site. As can be seen, numerous similarities exist between slope and aspect conditions on the Hanford Site and the surrounding agricultural lands. Soil types are also similar.

Figures 5.4 and 5.5 graphically summarizes the percent slope of the study area and the Hanford Site, respectively. While the study area includes the Hanford Site, there is substantially greater area in the study area. The Hanford Site has lower general slopes, which is desirable for irrigated agriculture because it reduces soil erosion and decreases pumping costs.

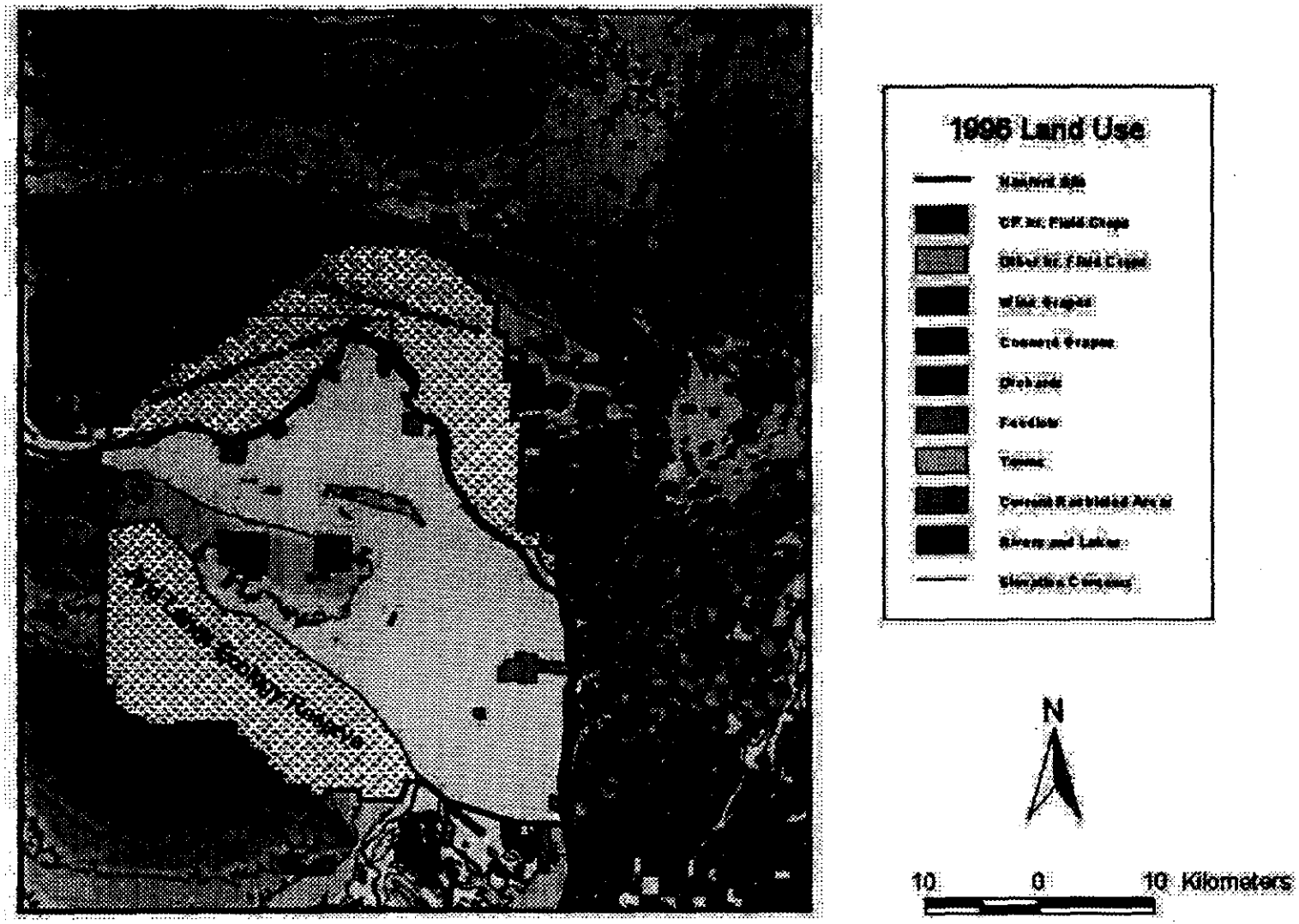

Figure 5.1. Land Use on the Hanford Site and the Surrounding Area in 1996. The white areas are range land in dry land wheat production.

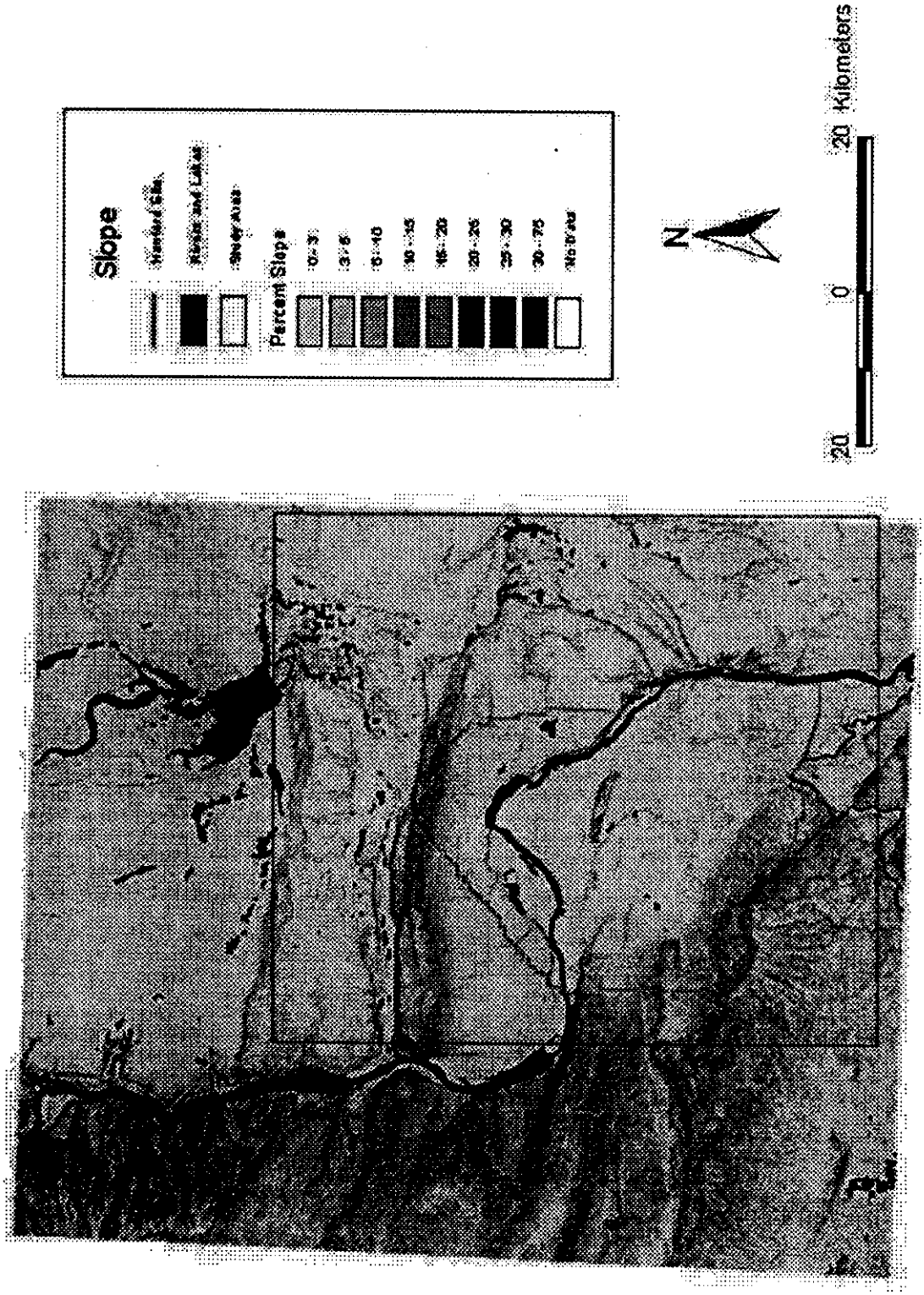

Figure 5.2. Map Showing the Slope Analysis of the Study Area Including the Hanford Site

Table 5.2. Summary of Irrigated Agricultural Land Use in the Surrounding Areas by Soil Types Found Within the Hanford Site

Soils	Hectares				
	Center Pivots	Trees	Wine Grapes	Concord Grapes	Field Crops
Loamy Sand	33403	4588	189	48	6433
Sand	6077	580	8	0	836
Fine Sandy Loams	12486	320	10	0	146
Sandy Loam	28612	6750	342	185	25940
Silt Loam	7953	5530	1048	0	15666
Cobbly Loam	74	15	0	0	3
Cobbly Sandy Loam	619	165	114	0	484
Stony Silt Loam	32	22	0	0	92
Cobbly Silt Loam	103	149	77	0	10
Stony Loam	242	0	0	0	28

Figures 5.6 and 5.7 graphically summarize the aspect characteristics of the study area and the Hanford Site, respectively. When examined in conjunction with Figure 5.3, it is obvious that aspect would not deter future agricultural development of the Hanford Site. For example, the Hanford Site has numerous similarities to the very productive Wahluke Slope area.

5.1.3 Recharge Rates

Under irrigation, recharge to the groundwater depends on the application efficiencies of each irrigation and the uniformity of water applications, which are largely functions of system design, management, and environmental conditions (e.g., wind). Recharge is greatly affected by soil texture and soil chemical properties as well as crop cover and rooting extent. Deep percolation losses (artificial recharge) will vary by crop because of management and ancillary uses of the irrigation systems such as for frost protection or agrichemical applications applied for cultural reasons even though soil water levels may already be high.

Application efficiency is defined as the ratio of the average depth of irrigation water infiltrated and stored in the root zone available for plant use to the average depth of total irrigation water applied, expressed as a percentage. Application efficiencies will change during the irrigation season, and calculated values may even exceed 100% under soil water deficit conditions. Dividing the required depth of water to be applied to refill the root zone by the decimal value of the application efficiency will give the required diversion of water to the field.

Applied water may be lost by surface runoff, deep percolation, and soil evaporation (typically 2-5%). Surface runoff may be as much as 50% of the applied water with poorly designed and managed systems. However, surface runoff from a field often collects in small off-site depressions and drainage ways, and some of the runoff returns to the rivers and streams. Much of it infiltrates the soil and contributes to the

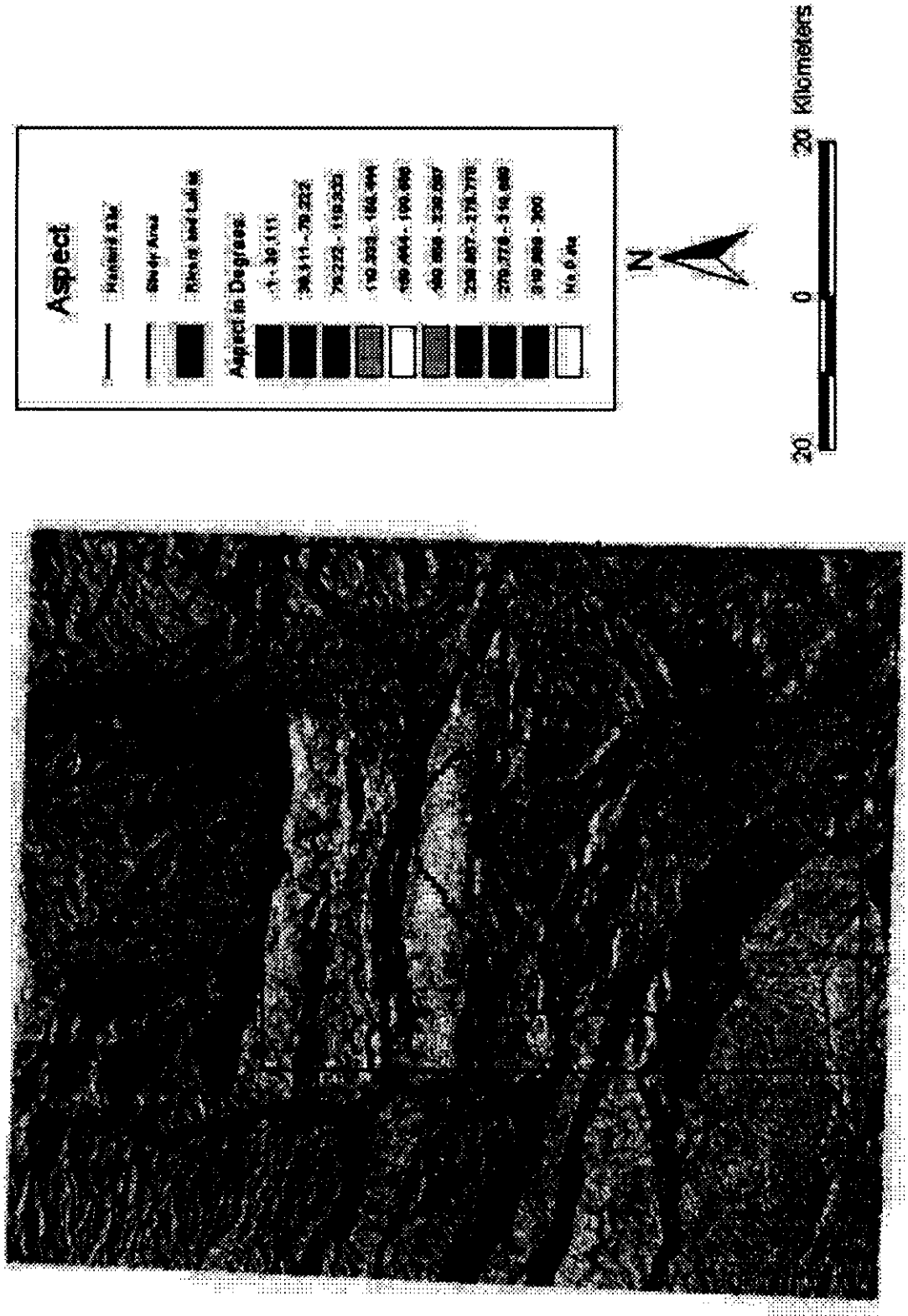

Figure 5.3. Map Showing the Aspect Analysis of the Study Area Including the Hanford Site

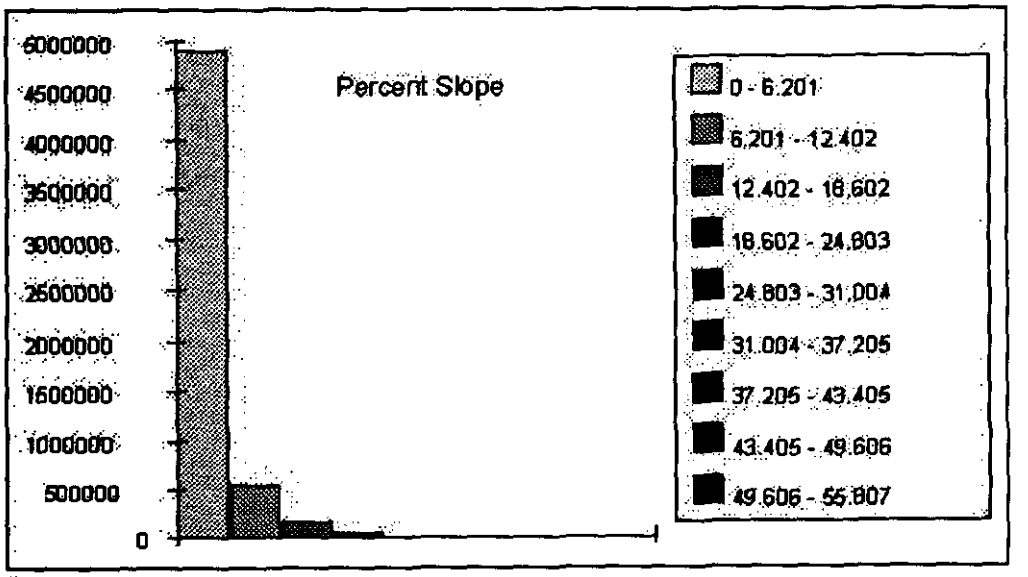

Figure 5.4. Summary of the Slope Characteristics in Percent Slope for the Study Area

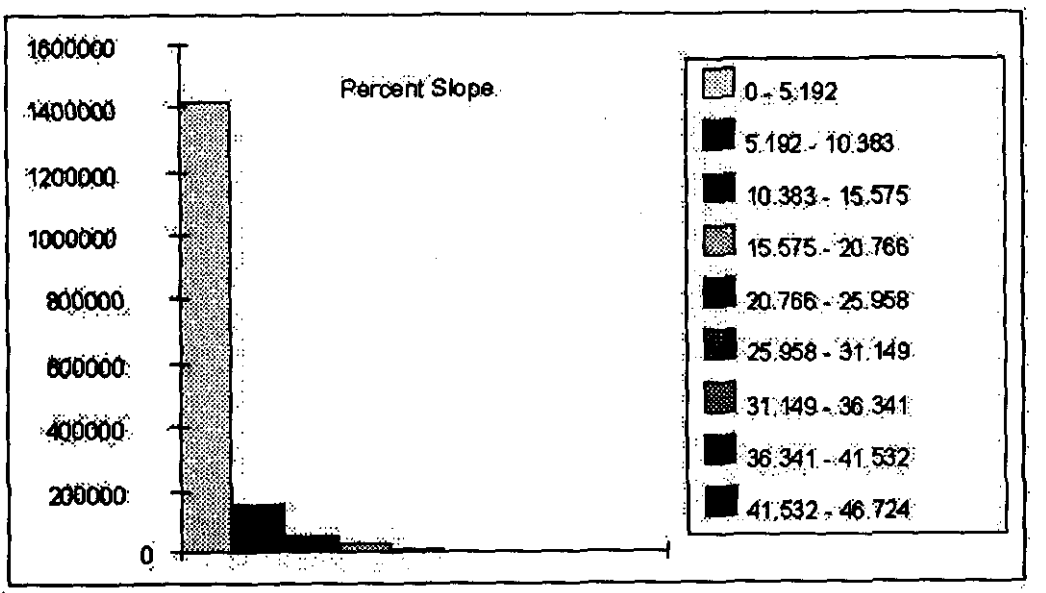

Figure 5.5. Summary of the Slope Characteristics in Percent for the Hanford Site

deep percolation towards the groundwater in the locale. Small wetland areas are often indications of where sustained runoff has percolated towards the water table. Consequently, estimates of deep percolation from irrigation over a broad areas often combine much of the runoff into the recharge calculations (i.e., 80% of losses). Since little surface runoff would be expected to return directly to the river on the light, sandy soils on the Hanford Site, this is a reasonable assumption for irrigated development in that

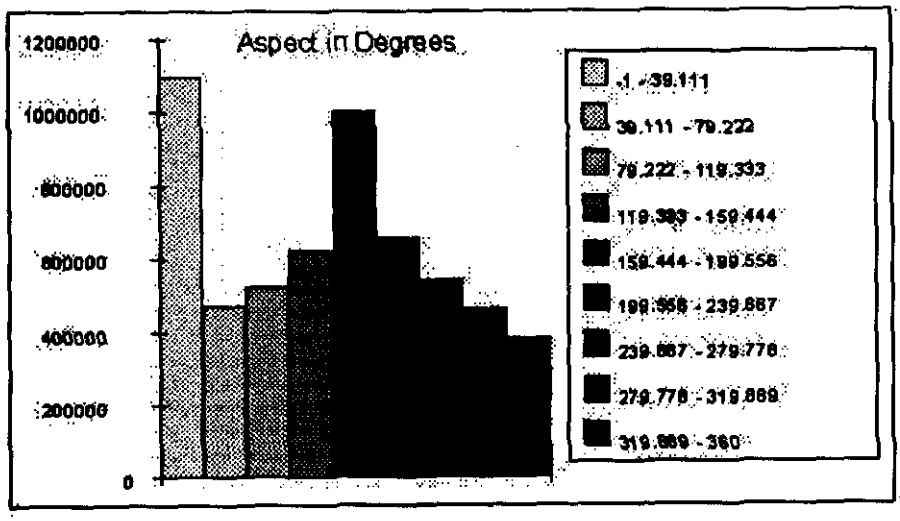

Figure 5.6. Summary of the Aspect Characteristics in Degrees for the Study Area

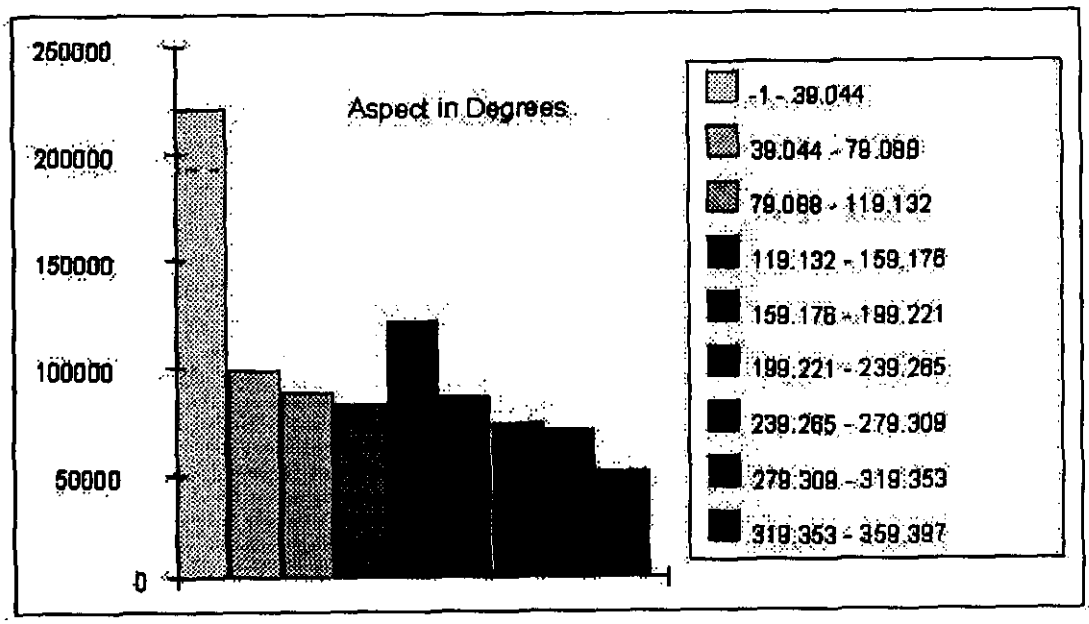

Figure 5.7. Summary of Hanford Site Aspect Characteristics in Degrees from North

area as well. However, estimates of deep percolation losses based on current irrigation practices will probably be higher than what will be the case in 2050 because of growers assumed increased management capability and improved technology.

Some deep percolation is always necessary (generally less than 2% of total annual water application in central Washington) under irrigated conditions to prevent salination of soils (leaching requirement). However, excessive amounts of deep percolation also carry fertilizers and other chemicals towards the groundwater and is a cause for concern.

It is highly probable that any future irrigation development on the Hanford Site would be with pressurized irrigation systems because of the very sandy soils and undulating topography Water supply to fields would be by pressurized pipelines rather than canals or ditches. Thus, any deep drainage losses from the water delivery system would be extremely small and not a major factor except in the infrequent and brief event of a pipeline structural failure.

The average on-farm delivery is about 1.13 ha-m/ha (3.7 acre-feet/ac) to all crops in the CBP. Average annual crop irrigation requirements are estimated at 0.83 ha-m/ha (2.71 af/a) (Montgomery Water Group 1997). This is a difference of about 305 mm (12 in.) in losses, but the percentage of this approximate value that is runoff compared to deep percolation (recharge) is not known since much of the surface runoff is captured and reused.

It is extremely difficult to obtain reasonable values for deep percolation because this is the only value in the water balance that cannot be measured or calculated accurately. Consequently, deep percolation is the term that contains all the errors from the other parameters. Estimates of deep percolation range from less than 25 mm (1 in.) to more than 250 mm (10 in.) per growing season depending on the crop and water management practices. It is known, however, that most of the deep percolation losses occur early and very late in the growing season with very little during peak water use periods in between. Nevertheless, the values for irrigation in Table 5.3 are probably fairly typical for current central Washington conditions during the growing season. These values do not including chemigation, frost protection, crop cooling or other ancillary water applications.

Current estimates of seasonal deep percolation (water lost below the plant's root zone) depend on soils, crop, soil and water salinity, type of irrigation system used, and the level of water management. Deficit irrigation strategies can reduce deep percolation within the growing season whereas using water for frost protection in orchards and vineyards can be a major source of water loss. Properly managed overcrop sprinklers used for crop cooling will have almost no impact on deep percolation; most water is lost by evaporation by design and intent.

Depending on management, center pivot irrigated potatoes tend to have most of their deep percolation occur in the early spring or late fall with very little, if any, during the middle of the summer. Because of the necessary strong emphasis on water management of wine grapes for winter hardiness, wine grapes will have almost no deep percolation (background rates), unless overcrop sprinkling is used for frost protection in the spring and fall.

Table 5.3. Comparative Average Seasonal Application Efficiencies for Various Irrigation Methods and Estimates of a Reasonably Attainable Percent of the Applied Water Resulting as Deep Percolation With Current Technology on Sandy Loam Soils in Washington (assuming irrigation systems are not also used for other purposes)

Method		Application Efficiency		Estimated % of Applied Water as Deep Percolation	
		Range	Average	Range	Attainable[a]
Surface:					
	Furrow (rill)	35 - 60	45	10 - 50	25
	Furrow w/land leveling	50 - 65	60	10 - 40	15
	Furrow w/automation[b]	75 - 80	75	10 - 20	15
	Furrow w/tailwater re-use	75 - 90	85	10 - 20	15
Sprinkle:					
	Hand-move	60 - 70	65	20 - 30	25
	Wheel-move	60 - 70	65	20 - 30	25
	Center pivot/Lateral Move	60 - 85	75	10 - 30	10
	Precision System	80 - 95	90	2 - 10	2
	LEPA	85 - 98	90	2 - 10	5
	Traveling gun	55 - 70	60	20 - 35	20
	Solid set	60 - 80	70	10 - 30	20
Microirrigation:					
	Drip/trickle	80 - 98	90	2 - 20	5
	Micro-sprayers	80 - 90	85	2 -15	8

(a) Percentage of deep percolation attainable under reasonably good current management practices.
(b) Automated surge flow furrow irrigation.

The owners of future suburban-type developments in the Hanford Site would likely insist on irrigation using groundwater sources for at least small portions of their properties. It is highly probable that irrigation efficiencies would still be low. In addition, use of shallow groundwater for domestic purposes, which is typical for such developments, may be difficult because of real or perceived contaminant problems. Water use requirements and distribution are extremely difficult to estimate for this option. If these developments were fully irrigated, recharge rates would be expected to be at least twice that of large-scale agricultural developments.

Deep percolation under furrow (gravity surface) irrigation on the sandy soils and topographic conditions in the Hanford Site will be much larger than presented in Table 5.3. These losses could be reduced somewhat with short runs and surge flow techniques, but these options are not economically competitive with pressurized sprinkler or microirrigation methods.

6.0 Discussion

The current high-value irrigated agricultural production on neighboring lands near Mattawa and east of the Columbia River in Grant and Franklin counties with similar slope, aspect, and soil textures s have clearly demonstrated that a considerable portion of the Hanford Site would likewise be quite valuable for large-scale farming of crops such as potatoes, fruit trees, and wine grapes. Some sloping areas would be especially suitable for orchard and vineyard crops whereas many of the lower elevation areas are appropriate for multi-year rotations of vegetable crops. The high value of these crops (see Table 4.2) would provide the economic ability to adopt advanced technologies and high-level management. Based on current trends and conditions, economics dictate that farm sizes would be large.

It is highly likely that precision agriculture and precision irrigation (center pivots and microirrigation) technologies will be standard operating practices in large-scale agriculture in the future. Portions of these advanced technologies are currently in development but have already demonstrated it is possible to greatly minimize chemical use and deep percolation. However, they will require excellent management, sophisticated control systems, and other resources available in highly capitalized, professional operations. Scientific irrigation scheduling and a supporting network of weather stations must be included.

New advances in microirrigation and self-propelled linear move and center pivot systems will probably have the most promise for future irrigation of field and vegetable crops on new lands like the Hanford site that have light soils and undulating topography. Microirrigation would be most appropriate for tree and vine crops.

The dry climate, long daylight hours, and the ability to control soil water levels throughout the season, make cultivation of specialty crops (e.g., pharmaceuticals, seed crops, herbs, special oil crops) highly likely. The capability to implement exact water and agrichemcial management scenarios to achieve specific quality parameters in a particular crop will allow growers to better respond to economic conditions and produce high-quality crops for niche markets. Pharmaceuticals from bioengineered plants and animals likely will be an important part of the future of agriculture in the region. Likewise, aquaculture may be important considering its intensive nature (small area required), the abundant water supply from the Columbia River, and the potential to apply wastes to nearby agricultural areas economically.

Potential exists to integrate confined livestock feeding and irrigated crop production. With careful management, livestock wastes could be applied to the land as a nutrient source.

Irrigated crops also would be a potential winter food source for migratory water fowl. Other wildlife (e.g., deer and elk) may feed all year on crops and may cause substantial damage to orchard and vine crops. Thus, it may be necessary to compensate growers for some level of damages from wildlife feeding as an incentive for development. Leasing hunting rights to private groups would also help offset crop loss due to wildlife.

Salination of the irrigated soils is not expected to be a problem, but soil erosion could be significant without proper management. Based on a large body of research and experience in the CBP, leveling fields to improve irrigation uniformities is not generally recommended for Hanford Site lands because it would cause long-term soil fertility problems.

Figure 6.1 shows the potentially irrigable lands within the Hanford Site, excluding the wildlife refuges on the north side of the Columbia River, and probable types of crops. Land use is indicated as either most probably field crops or most probably orchard and vineyard based on the land use patterns surrounding the Hanford Site. The areas defined as field crops would probably be irrigated with center pivots and could produce a wide variety of crops. Orchards and vineyards would likely be microirrigated and could be intermixed within the center pivot areas. Likewise, the designated orchard/vineyard areas also could be planted to field crops irrigated with center pivots. The crops produced under center pivots would most likely be part of multi-year potato cropping rotations and not trees and vines.

Analysis of the land use data shows that the total irrigable area (not including buffers) including both the north (wildlife refuge areas) and south side of the river is about 120,380 hectares (297,442 acres). The total (entire site) classified as suitable for field crops is 78,570 hectares (194,143 acres) whereas orchard and vine crops are 14,665 hectares (36,236 acres). Near the northern boundary, 8360 hectares (20,660 acres) is ideally suited for orchard and vine crops. Over the entire site, 27,160 hectares (67,116 acres) was classified as unsuitable for irrigation, not including buffer areas. One kilometer-wide buffers were excluded from all rivers and lakes (20,100 hectares [49,681 acres]) and current restricted areas (16,280 hectares [40,239 acres]). The state and federal wildlife reserves account for 35,740 hectares (88,315 acres).

If the wildlife areas are excluded and just the south side of the Hanford Site is opened for agricultural development (as shown in Figure 6.1), 6300 hectares (15,576 acres) are classified for tree and vine crops and 62,640 hectares (154,775 acres) for field crops. The 25,950 hectares (64116 acres) on the side of Rattlesnake Mountain are classified as unsuitable for irrigation and are totally within the Arid Lands Ecology Reserve (30,910 hectares [76,380 acres]).

6.1 Impacts of Development

A number of unresolved issues will have a large impact on future land use for the Hanford Site. Population growth in the western United States is projected to increase by 30% by 2020 (Western Water Policy Review Advisory Commission 1998). The populations of Washington, Oregon, and Idaho are expected to increase by more than 30% by 2020, which will place additional pressures on the region's water resources for industry, domestic use, agriculture, recreation, and power generation.

A crisis in water demand that continues to worsen has been created by unhealthy trends in aquatic ecosystems and water quality, endangered species regulations, sharp population growth in the region, international and interstate agreements on water allocations, unfilled Native American water claims, and an agricultural economy in transition. Global warming may have a large affect on the availability of future water resources.

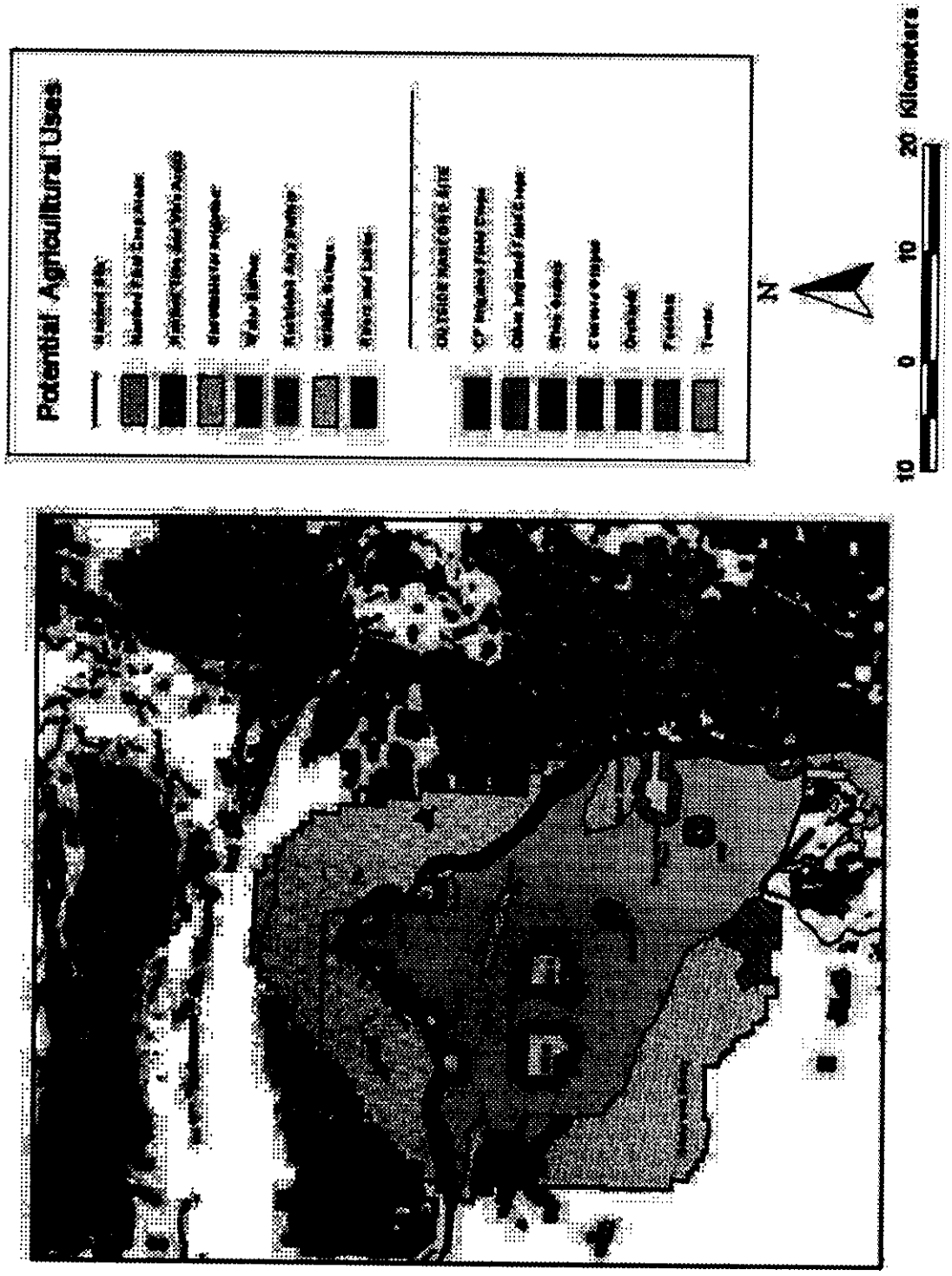

Figure 6.1. Map Showing Potential Agricultural Land Uses on the Hanford Site

Several salmon and steelhead fisheries in the Columbia River system are listed as endangered by the federal government, which will have a huge impact on current and future development of regional water resources. Reduced flows in the river system caused by irrigation withdrawals may have a negative impact on hydropower generation. Any additional future development must consider these and other environmental issues that will arise as well as potential mitigating measures.

Based in the CBP experience, irrigation can increase wetland areas, which would benefit migrating birds and local wildlife. However, increased wetlands would probably not occur under more precise and improved irrigation management. Nevertheless, large-scale agricultural activities would provide a considerable food source and foraging area for migratory and local birds during the fall and winter months.

The Hanford Site is part of the oldest and largest old-growth desert ecology community in eastern Washington. However, the future status of the Arid Lands Ecology Reserve or the wildlife refuge areas were not considered in this study. Ecosystem issues could have a significant impact in which lands might be developed for agricultural uses such as livestock grazing and crops such as wine grapes and orchards.

Migration of deer and elk herds on the Hanford Site will probably not be compatible with irrigated agriculture. They and smaller wild animals and birds would certainly suffer under a small farm/ranchette scenario because of the potential large number of fences as well as abundant dogs and cats, based on the current model. Large-scale agriculture would be more compatible, although it is likely growers would request compensation (under current state laws and regulations) for crop damages caused by the large herds. It is probable that critical areas, defined by county law under the state Growth Management Act as wetlands, areas prone to landslides, and fish and wildlife conservation areas, would be kept as permanent wildlife habitat.

It is assumed groundwater contaminants resulting from past industrial activities on the Hanford Site will still be a problem if and when the site is opened for agricultural or other development in the future. In addition to radioactive materials (i.e., tritium, iodine-129, uranium, technetium-99, strontium-90), significant problems are toxins and other chemicals (heavy metals, trichloroethylene, chloroform, carbon tetrachloride, or any exotic persistent organics such as PCBs, dioxin, etc.) that shouldn't be deposited on agricultural lands. If these contaminants cannot be kept from the applied water, then soil filtration, biological treatment, or other appropriate specific treatment processes may be required before the water is applied to crops. If these industrial contaminants cannot be removed, they must not be applied to any agricultural crop because the perceived implications of unhealthy foods could be transferred to all Northwest crops and result in huge financial consequences. It is entirely likely that water sources would be limited to upgradient unconfined groundwater, the Columbia River, and deep confined aquifers.

6.2 Water Rights

Wallace Stegner (1994) said that "water is the true wealth in a dry land." This is certainly the case in central Washington, with its high-quality, abundant flows of the Columbia River. The control over who gets water at what time for what use is a very emotional issue with huge environmental and economic

impacts. The issue of changing the control paradigm of water in the West is a priority of many environmental and conservation groups and is being bitterly challenged by pro-development and agricultural interests.

Water rights in Washington are a mix of prior appropriation and riparian doctrines depending on location. Arid areas east of the Cascades are primarily prior appropriation. Water rights are determined by the Superior Court and regulated (administered) by WDOE. WDOE is also responsible for developing regulatory programs and enforcing water quality laws and regulations.

However, the issue of water rights and the control of water in Washington is in a state of flux. There is little chance that the existing water rights structure will exist when, or if, the Hanford Site is developed for agriculture. The state government is currently proposing sweeping changes to existing water rights law in Washington. Regional water markets based on the true economic value of water will likely appear in many areas and influence water distribution. The federal government is rethinking its water policies and priorities in the western United States, which Congress will undoubtedly act on in the next decade. Endangered species regulations are accused of abrogating state's authority on water issues. Interstate and international agreements combined with societal needs for flood control, navigation, and electrical power will exert strong influences. The courts, politics, and public opinion will shape the final outcome and determine how we manage our precious water resources. Whatever the result, obtaining a reliable and adequate water supply will be crucial for any future economic development of the Hanford Site, agricultural or otherwise.

6.2.1 Hanford Site Water Rights

Section 4.3.3.1 of the Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement (DOE 1999) provided the following statement on water rights in the Hanford Site:.

"The DOE's past and present water withdrawals at the Hanford Site are based on the "Federal Reserved Water Rights" doctrine. This doctrine, developed as case law from U.S. Supreme Court rulings, holds that the Federal government, when it withdraws public domain lands for the purpose of the creation of a Federal reservation, necessarily withdraws unappropriated water rights sufficient to meet the needs for which the reservation was created. The date of priority of these rights is the date of creation of the reservation. In the case of the Hanford Site, this date is 1943. It is the general rule that Federal reserved water rights cease to exist when the Federal reservation ceases to be used for the purposes for which it was created. The limited exception to the rule is reflected in the U.S. v. Powers, 305 U.S. 527 (1939), wherein the Court allowed that a purchaser of agricultural land on an Indian reservation may be entitled to a portion of Federal reserved water rights where the use of the property did not change.

The Federal government has not established its own water rights regulation. Instead, it uses the regulatory procedures outlined in the State water rights laws to document the extent of its rights. There has been no general adjudication in the State of Washington of the water rights in the Columbia River and, therefore, the reserved water right of the Hanford Site has not

been documented. The quantity of that right, however, would be equal to the maximum amounts used at Hanford during its operation, up to the amount of unappropriated water in the Columbia River as of 1943.

In a report titled, Hanford Land Transfer (Washington Department of Ecology 1993), Ecology indicated that if water rights were attached to privately owned parcels of land acquired in fee by the Federal government for the creation of Hanford in 1943, those water rights may continue to be attached to these parcels of land. Ecology has indicated that it has not taken action to extinguish these rights, although under Washington law appropriative water rights are subject to be extinguished if unused for a period of five years.

Further complications exist regarding non-Federal water rights claims at the Hanford Site. The first is the issue of groundwater contamination at Hanford. The second is that the date for filing a water rights claim in the Hanford sub-basin, for both Columbia River water and groundwater, expired in 1992. No claims for water rights under state law appear to have been filed within the required time period (NPS 1994).

7.0 Conclusions

The area known as the Hanford Site in south central Washington has all of the components that favor successful irrigated farming. Environmentally, it has good soils, a mild climate and abundant high-quality water supplies. Economically, the Hanford Site benefits from the excellent transportation systems (roads, rail, and barge), extensive power systems, and the already well developed agricultural processing, supply and service infrastructure that supports the regions agriculture. Constraints to agricultural development of the Hanford Site are political and social.

In the event that irrigated agricultural land use is permitted, it is anticipated that only parts of the Hanford Site will likely be developed as irrigated agriculture in conjunction with wildlife and ecosystem reserves and the permanently restricted areas. A staged development scenario that integrates all uses may be the best process.

Potential land use and economic scenarios favor intensive large-scale agricultural development growing orchard and vegetable crops. Irrigation technologies would be limited to highly efficient methods such as center pivots and microirrigation. Precision agriculture techniques are likely to be more efficiently applied on large fields under limited ownership/management with resulting ecological benefits. These scenarios produce the fewest environmental problems with groundwater contamination and the flexibility to fit within eventual DOE operational strategies for groundwater management.

If portions of the Hanford Site are ever developed for irrigated agriculture, future development probably would focus on large-scale commercial enterprises that can afford to import clean water and employ high levels of water management to minimize deep drainage. Any suburban or small ranchette developments should be carefully examined in light of water safety concerns (real or imagined) and their generally poor levels of water management.

Numerous future advances in irrigation and resource conservation techniques are anticipated. Improved systems will be the norm in 50 years. Scientific irrigation scheduling and a network of supporting weather stations must be part of the total system for water and pest management of any future agricultural development on the Hanford Site. Because of the light soils and widely variable topography, new advances in microirrigation and self-propelled irrigation (i.e., linear move and center pivot systems) will probably have the most promise for future irrigation of new lands such as the Hanford Site.

A reasonable estimate of deep percolation in 50 years would be the current best achievable levels of the best technology: from 2% to 15% of the applied water not including water applied for frost protection or other non-irrigation uses. However, because of lack of uniformity in water distribution, soil types, topography, and imperfect management decisions, the deep percolation loss (recharge) is almost always larger than the required leaching fraction to prevent soil salination (about 2% of annual water delivery to the farm). Recharge from irrigation would probably range from 50 to 500 mm/yr compared to historical estimated natural recharge rates ranging from 0.1 to 10 mm/yr, even with the expected improved technologies and systems. Wine grapes would have the least recharge while field crops would potentially have the greatest deep percolation losses.

Extreme care must be exercised to avoid even the appearance that crops are irrigated with or otherwise exposed to toxic and radioactive substances, even at very low concentrations scientifically considered safe for humans. Agriculture is a large portion of the economy of Washington and a major source of exports. The delicate national and international trade balances would be easily upset by even unfounded rumors of contamination, resulting in huge economic consequences for agriculture throughout the Pacific Northwest.

The economic and political drivers can be anticipated to expand irrigated crop production in the Pacific Northwest. The most likely areas for future irrigated agriculture expansions are the undeveloped East High areas of the CBP and non-restricted areas within the Hanford Site. If environmental, water supply, and other concerns are met, it is probable based on current trends that both areas would be developed using private funding sources rather than public sources.

Obtaining adequate water rights for any irrigated development will be a major issue. Many of the salmon and steelhead fisheries in the Columbia River system are listed as endangered by the federal government. Thus, ecological consideration will have a significant impact on current and future development of regional water resources.

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Appendix

Summary of Current Agricultural Production in Grant, Adams, and Franklin Counties

Appendix

Summary of Current Agricultural Production in Grant, Adams, and Franklin Counties

Franklin County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	105,400	69.9	7,365,000	9
Wheat, Spring (bu)	15,600	59.6	929,000	9
Wheat, All (bu)	121,000	68.5	8,294,000	9
Barley (bu)	4,900	25.7	126,000	13
Corn for Grain (bu)	19,700	188.0	3,706,100	3
Corn for Silage (tons)	1,400	30.5	42,700	7
Potatoes (cwt)	42,500	620	26,360,000	1
Hay, Alfalfa (tons)	57,000	7.30	418,500	2
Hay, Other (tons)	2,400	5.80	14,000	18
Hay, All (tons)	59,400	7.30	432,500	2
Dry Beans (cwt)	2,700	24.80	67,000	3
Alfalfa Seed (cwt)	1,000	7.50	7,500	3
Kentucky Bluegrass Seed (cwt)	1,600	6.30	10,000	5
Other Grass Seeds (cwt)	900	6.90	6,200	2
Asparagus (cwt)	11,600	36.4	422,000	1
Carrots - Fresh (cwt)	300	460.0	138,000	3
Carrots - Proc (cwt)	2,200	27.7	61,000	1
Green Peas - Proc (cwt)	550	3.1	1,700	9
Onions, Storage (cwt)	3,900	515.0	2,008,000	2
Sweet Corn - Proc (cwt)	14,500	9.2	133,000	2
Source: Washington Agricultural Statistics Service				

Franklin County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	189	9,846	7
Apples	121	5,347	7
Apricots	7	105	6
Cherries, All	44	1,473	6
Grapes, All	40	2,328	3
Nectarines	9	94	5
Peaches	11	200	3
Pears	16	215	10
Plums & Prunes	5	(D)	-
Source: 1992 Census of Agriculture. (D) = Not disclosed.			

Grant County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	207,300	69.0	14,301,000	5
Wheat, Spring (bu)	39,600	75.8	3,000,000	1
Wheat, All (bu)	246,900	70.1	17,301,000	5
Barley (bu)	7,900	83.9	663,000	8
Corn for Grain (bu)	34,300	160.0	5,488,000	2
Corn for Silage (tons)	6,300	27.6	173,600	3
Potatoes (cwt)	40,500	590	23,895,000	2
Hay, Alfalfa (tons)	126,000	6.20	775,000	1
Hay, Other (tons)	8,900	4.10	36,500	7
Hay, All (tons)	134,900	6.00	811,500	1
Dry Beans (cwt)	12,900	23.20	299,000	1
Alfalfa Seed (cwt)	4,500	7.30	33,000	2
Peppermint (lbs)	6,000	100	600,000	3
Spearmint (lbs)	1,150	123	142,000	2
Asparagus (cwt)	1,900	36.8	70,000	3
Carrots - Proc (cwt)	1,400	32.9	46,000	2
Green Peas - Proc (cwt)	14,700	2.6	37,500	1
Onions, Storage (cwt)	4,000	515.0	2,060,000	1
Sweet Corn - Proc (cwt)	39,100	9.2	358,000	1
Source: Washington Agricultural Statistics Service.				

Grant County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	292	29,337	2
Apples	243	24,154	3
Apricots	36	332	1
Cherries, All	87	1,945	4
Grapes, All	20	1,389	4
Nectarines	23	166	3
Peaches	26	154	5
Pears	52	1,034	4
Plums and Prunes	9	136	3
Source: 1992 Census of Agriculture.			

Adams County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	286,000	58.7	16,787,000	4
Wheat, Spring (bu)	31,700	44.9	1,422,000	5
Wheat, All (bu)	317,700	57.3	18,209,000	4
Barley (bu)	6,900	58.0	2,552,000	3
Corn for Grain (bu)	5,900	157.0	926,400	6
Corn for Silage (tons)	1,600	30.0	48,000	6
Potatoes (cwt)	16,000	570	9,120,000	4
Hay, Alfalfa (tons)	19,500	6.50	126,500	4
Hay, Other (tons)	2,400	4.00	9,500	20
Hay, All (tons)	21,900	6.20	136,000	6
Dry Beans (cwt)	4,400	22.30	98,000	2
Kentucky Bluegrass Seed (cwt)	2,300	8.70	20,000	4
Peppermint (lbs)	7,000	104	730,000	2
Asparagus (cwt)	800	35.0	28,000	5
Onions, Storage (cwt)	1,000	500.0	500,000	4
Source: Washington Agricultural Statistics Service.				

Adams County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	31	2,343	9
Apples	28	2,247	9
Cherries, All	4	(D)	-
Pears	5	(D)	-

Source: 1992 Census of Agriculture.
(D) = Not disclosed.

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