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Special Analysis of Transuranic Waste in Trench T04C at the Area 5 Radioactive Waste Management Site, Nevada Test Site, Nye County, Nevada
Revision 1.0

May 2008

Prepared by

Greg Shott, Vefa Yucel, and Lloyd Desotell
National Security Technologies, LLC

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U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office
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EXECUTIVE SUMMARY

This Special Analysis (SA) was prepared to assess the potential impact of inadvertent disposal of a limited quantity of transuranic (TRU) waste in classified Trench 4 (T04C) within the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada Test Site (NTS). The Area 5 RWMS is a low-level radioactive waste disposal site in northern Frenchman Flat on the Nevada Test Site (NTS). The Area 5 RWMS is regulated by the U.S. Department of Energy (DOE) under DOE Order 435.1 and DOE Manual (DOE M) 435.1-1.

The primary objective of the SA is to evaluate if inadvertent disposal of limited quantities of TRU waste in a shallow land burial trench at the Area 5 RWMS is in compliance with the existing, approved Disposal Authorization Statement (DAS) issued under DOE M 435.1-1. In addition, supplemental analyses are performed to determine if there is reasonable assurance that the requirements of Title 40, Code of Federal Regulations (CFR), Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes,* can be met. The 40 CFR 191 analyses provide supplemental information regarding the risk to human health and the environment of leaving the TRU waste in T04C.

In 1989, waste management personnel reviewing classified materials records discovered that classified materials buried in trench T04C at the Area 5 RWMS contained TRU waste. Subsequent investigations determined that a total of 102 55-gallon drums of TRU waste from Rocky Flats were buried in trench T04C in 1986. The disposal was inadvertent because unclassified records accompanying the shipment indicated that the waste was low-level. The exact location of the TRU waste in T04C was not recorded and is currently unknown.

Under DOE M 435.1-1, Chapter IV, Section P.5, low-level waste disposal facilities must obtain a DAS. The DAS specifies conditions that must be met to operate within the radioactive waste management basis, consisting of a performance assessment (PA), composite analysis (CA), closure plan, monitoring plan, waste acceptance criteria, and a PA/CA maintenance plan. The DOE issued a DAS for the Area 5 RWMS in 2000. The Area 5 RWMS DAS was, in part, based on review of a CA as required under DOE M 435.1-1, Chapter IV, Section P.(3). A CA is a radiological assessment required for DOE waste disposed before 26 September 1988 and includes the radiological dose from all sources of radioactive material interacting with all radioactive waste disposed at the Area 5 RWMS.

The approved Area 5 RWMS CA, which includes the inventory of TRU waste in T04C, indicates that the Area 5 RWMS waste inventory and all interacting sources of radioactive material can meet the 0.3 mSv dose constraint. The composite analysis maximum annual dose for a future resident at the Area 5 RWMS was estimated to be 0.01 mSv at 1,000 years. Therefore, the inadvertent disposal of TRU in T04C is protective of the public and the environment, and compliant with all the applicable requirements in DOE M 435.1-1 and the DAS.

The U.S. Environmental Protection Agency promulgated 40 CFR 191 to establish standards for the planned disposal of spent nuclear fuel, high level, and transuranic wastes in geologic repositories. Although not required, the National Nuclear Security Administration Nevada Site Office requested a supplemental analysis to evaluate the likelihood that the inadvertent disposal of TRU waste in T04C meets the requirements of 40 CFR 191. The SA evaluates the likelihood of meeting the 40 CFR 191 containment requirements (CRs), assurance requirements, individual protection requirements (IPRs), and groundwater protection standards. The results of the SA indicate that there is a reasonable expectation of meeting all the requirements of 40 CFR 191.

The conclusion of the SA is that the Area 5 RWMS with the TRU waste buried in T04C is in compliance with all requirements in DOE M 435.1-1 and the DAS. Compliance with the DAS is demonstrated by the results of the Area 5 RWMS CA. Supplemental analyses in the SA indicate there is a reasonable expectation that the TRU in T04C can meet all the requirements of 40 CFR 191. Therefore, inadvertent disposal of a limited quantity of TRU in a shallow land burial trench at the Area 5 RWMS does not pose a significant risk to the public and the environment.

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ABBREVIATIONS and ACRONYMS

ac	acre
AHP	analytic hierarchy process
ANPP	aboveground net primary productivity
BLM	Bureau of Land Management
BN	Bechtel Nevada
Bq	Becquerel
CAU	corrective action unit
CCDF	complementary cumulative distribution function
Ci	Curie
CFR	Code of Federal Regulations
cm	centimeter
CR	containment requirement
DAF	Device Assembly Facility
DAS	Disposal Authorization Statement
DASH	Deep Arid System Hydrodynamic
DOE	U.S. Department of Energy
DOE/HQ	U.S. Department of Energy/Headquarters
DOE M	U.S. Department of Energy Manual
DOE/NV	U.S. Department of Energy/Nevada Operations
DOE O	U.S. Department of Energy Order
DoD	Department of Defense
EIS	environmental impact statement
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
FACE	Free-Air-Carbon dioxide Enrichment
FEP	feature, event, or process
FFACO	Federal Facility Agreement and Consent Order
FFCACT	Federal Facility Compliance Act and Consent Order
ft	feet
FY	fiscal year
gal	gallon
gbm	generalized boosted model
GCD	greater confinement disposal
GCDT	Greater Confinement Disposal Test

GTG	GoldSim Technology Group
ha	hectare
HC	hazard category
HDP	heat dissipation probe
ICMP	Interim Closure and Monitoring Plan
ICP	Idaho Closure Project
in.	inch
IPR	individual protection requirement
kg ha^{-1} yr^{-1}	kilogram per hectare per year
km	kilometer
km^2	square kilometer
LFRG	Low-Level Waste Disposal Facility Federal Review Group
LHS	Latin hypercube sample
LLW	low-level waste
LLWMU	low-level waste management unit
LOESS	locally weighted polynomial regression
LWIS	low-level waste information system
m	meter
mm	millimeter
m^2	square meter
m^3	cubic meter
Ma	million years ago
MAP	mean annual precipitation
MAT	mean annual temperature
MCA	mutual consent agreement
MCDA	multicriteria decision analysis
mi	mile
mi^2	square mile
mSv	millisievert
MWDU	mixed waste disposal unit
NAFR	Nellis Air Force Range
NAS	National Academy of Sciences
nCi g^{-1}	nanoCurie per gram
NDEP	Nevada Division of Environmental Protection
NEPA	National Environmental Policy Act
NLFB	no-liquid flux boundary
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NRC	U.S. Nuclear Regulatory Commission

NTS	Nevada Test Site
NTSWAC	Nevada Test Site Waste Acceptance Criteria
NTTR	Nellis Training and Test Range
NSTec	National Security Technologies, LLC
NWAR	nuclear weapon accident residue
PA	performance assessment
PCC	partial correlation coefficient
pdf	probability density function
PET	potential evapotranspiration
pmf	probability mass function
RCRA	Resources Conservation and Recovery Act
REECo	Reynolds Electrical and Engineering Co. Inc.
RTR	real-time radiography
RWMC	Radioactive Waste Management Complex
RWMS	Radioactive Waste Management Site
SA	special analysis
SI	sensitivity index
SLB	shallow land burial
SME	subject matter expert
SND	State of Nevada Demographer
SNL	Sandia National Laboratories
SQAP	Software Quality Assurance Plan
SRC	standardized regression coefficient
TBq	teraBecquerel
TDR	time domain reflectrometry
TEDE	total effective dose equivalent
TRU	transuranic
TRW	Thompson Ramo Wooldridge
TSCA	Toxic Substances Control Act
UGTA	underground testing area
WAC	waste acceptance criteria
WEF	Waste Examination Facility
WIPP	Waste Isolation Pilot Plant
WMD	waste management database
YMP	Yucca Mountain Project
yrs	years
1-D	one-dimensional

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1.0 Introduction

This report describes the results of a special analysis (SA) of the consequences of burial of small quantities of transuranic (TRU) waste in a low-level waste (LLW) disposal site on the Nevada Test Site (NTS). NTS is a 3,561-square kilometer (km^2) (1,375-square mile [mi^2]) U.S. Department of Energy (DOE) National Nuclear Security Administration, Nevada Site Office (NNSA/NSO)-operated, restricted-access facility currently used for hazardous chemical spill testing, emergency response training, nonnuclear weapons testing, radioactive waste management, and environmental technology studies. NTS is surrounded on most of its boundaries and further isolated by U.S. government-controlled land used as a military gunnery range and a wildlife refuge. NNSA/NSO operates two LLW disposal facilities at NTS.

1.1 Site Description

The Area 5 Radioactive Waste Management Complex (RWMC) is a 296-hectare (ha) (732-acre [ac]) site allocated for LLW disposal in northern Frenchman Flat of NTS. The Area 5 Radioactive Waste Management Site (RWMS) is the operationally active area, located on approximately 58 ha (144 ac) in the southeast corner of the RWMC. The Area 5 RWMS includes the 37-ha (92-ac) low-level waste management unit (LLWMU) and an approximately 21-ha (52-ac) northern expansion area where new disposal trenches have been developed since 2002. This SA addresses a small quantity of TRU waste buried in the LLWMU within the Area 5 RWMS.

1.2 Operational History

Disposal of LLW generated by NTS operations began at the Area 5 RWMS in 1961. Classified materials have been accepted at the Area 5 RWMS since 1961. Most classified waste has been buried in shallow land burial trenches or deep boreholes. In 1978, the site began to accept unlimited quantities of LLW from offsite generators. Most LLW has been disposed by shallow land burial in unlined pits and trenches 6- to 9-meters (m) (20 to 30-feet [ft]) deep and closed with 2.4-m (8-ft) operational covers.

The Area 5 RWMS accepts LLW generated by DOE operations and classified radioactive materials generated by U.S. government agencies. Categories of waste currently accepted for burial include classified materials, unclassified LLW, *Resource Conservation and Recovery Act* (RCRA)-regulated waste, and *Toxic Substances Control Act* (TSCA)-regulated waste.

In 1983, the Greater Confinement Disposal Test (GCDT) was initiated at the Area 5 RWMS to demonstrate the feasibility of disposal of high specific activity wastes in deep augered boreholes. The following year, operational disposal of waste began in 36-m (120-ft) deep, 3- to 3.6-m (10- to 12-ft) diameter, uncased greater confinement disposal (GCD) boreholes. From 1984 to 1988, eight GCD units received high specific activity wastes.

Although NTS waste acceptance criteria (WAC) have always prohibited disposal of TRU waste, in 1984 NTS was requested by DOE/Headquarters (DOE/HQ) to accept classified nuclear weapon accident residue (NWAR) TRU waste for national security purposes. The NWAR wastes were placed in classified GCD boreholes 1, 2, and 3 (U5RWMS01C, U5RWMS02C, and U5RWMS03C). Subsequent to the NWAR disposals, additional classified TRU wastes from Rocky Flats were disposed in GCD borehole 4 (U5RWMS04C) from July 1985 to October 1987. During this period, classified TRU waste from Rocky Flats, misidentified as LLW, was buried in classified Trench 4 (T04C). This SA evaluates the suitability of permanently disposing of these materials in T04C. Although for consistency with other documents this report may use the term "waste" to describe these materials, it should be recognized that from a security perspective this material must be managed as classified material.

1.2.1 DOE Regulation/Authorization Basis

Waste disposal units at the Area 5 RWMS are regulated under at least six different regulations, agreements, or DOE orders. Individual disposal units are subject to different regulatory requirements based on the types of waste present and agreements between federal and state agencies.

Radioactive waste disposed after 26 September 1988 is regulated by the DOE under DOE Order (DOE O) 435.1 and the accompanying DOE Manual (DOE M) 435.1-1 (DOE 2001a, b). Wastes disposed before 26 September 1988 are subject to the DOE M 435.1-1, Chapter IV, Section P.(3) composite analysis process, which requires an assessment of the radiological dose from all sources of radioactive material interacting with DOE LLW. Waste disposed before the 1987 opening of the RCRA-regulated Pit 3 (P03U) mixed waste disposal unit (MWDU) is managed under the *Federal Facility Agreement and Consent Order* (FFACO), a joint agreement among DOE, the U.S. Department of Defense (DoD), and the state of Nevada that specifies a process for characterization, corrective action selection, and closure. Eleven disposal units at the Area 5 RWMS comprising Corrective Action Unit (CAU) 111 are managed under the FFACO. Wastes disposed in P03U are regulated under RCRA. Pits 7 and 6 (P07U and P06UA) contain asbestiform waste regulated under TSCA. TRU waste disposed in GCD boreholes is regulated under Title 40, Code of Federal Regulations (CFR), Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes*.

LLW disposal facilities must maintain a waste authorization basis under DOE M 435.1-1 (IV.D), which consists of physical and administrative controls that ensure the protection of workers, the public, and the environment. The Area 5 RWMS waste authorization basis consists of a performance assessment (Shott et al. 1998; Bechtel Nevada [BN] 2006a), a composite analysis (BN 2001a), a disposal authorization statement (DOE 2000), a closure plan (BN 2005a), waste acceptance criteria (NNSA/NSO 2003), and a monitoring plan (BN 2005a).

The TRU in T04C is regulated by DOE under the composite analysis process. The existing Area 5 RWMS composite analysis, which includes the inventory of TRU waste in T04C, indicates that the Area 5 RWMS waste inventory and all interacting sources of radioactive material can meet the 0.3 mSv dose constraint (BN 2001a). The composite analysis maximum annual dose for a future resident at the Area 5 RWMS was estimated to be 0.01 mSv at 1,000 years (BN 2001a). TRU waste components were not an important contributor to the dose. A disposal authorization statement for the Area 5 RWMS was issued on 5 December 2000 after review and approval of the Area 5 RWMS composite analysis (DOE 2000). Therefore, the Area 5 RWMS with the TRU in T04C is in compliance with DOE M 435.1-1 and its DAS.

1.2.2 Management Options for Buried TRU Waste

TRU wastes were first segregated from other low-level radioactive waste in 1970 when the Atomic Energy Commission issued an Immediate Action Directive requiring retrievable storage until a geologic repository was available for final disposal. At that time, TRU waste was defined as waste containing transuranic alpha emitters above 10 nanoCuries per gram (nCi g^{-1}). The TRU waste definition was later changed to waste containing transuranic alpha emitters above 100 nCi g^{-1} with half-lives greater than 20 years. In 1986, TRU wastes were regulated under DOE O 5820.2, whose intent was to require retrievable storage of TRU waste until a geologic repository was available for permanent disposal (DOE 1984). Multiple DOE sites used shallow land burial for retrievable storage of TRU during this period. The TRU waste in T04C is different because it was most likely intended for disposal in the GCD boreholes and was accidentally buried in T04C. Therefore, there never was any plan to retrieve the waste for disposal at the Waste Isolation Pilot Plant (WIPP). In addition these wastes are classified and at the time of disposal would not have been eligible for disposal at WIPP. Since then WIPP has begun accepting classified TRU.

The TRU waste in T04C has unique characteristics that should be considered in selecting an appropriate management option, including:

- Unplanned disposal in an authorized low-level waste disposal facility
- Burial in a shallow land burial trench rather than in a geologic repository
- Exact location of disposal is uncertain
- TRU inventory is a minor component of the low-level waste disposal facility inventory
- Costs and hazards of retrieval are high
- Involves classified materials

Multiple management options for the TRU in T04C have been considered (Crowe 2006) including:

(1) Retrieve, characterize, and certify the waste for disposal at WIPP
(2) Close in-place under a DOE-regulated process
(3) Close in-place using a risk informed process to establish an exemption for limited quantities of TRU as envisioned by the National Research Council (National Academy of Sciences [NAS] 2005)
(4) Close in-place under the alternative disposal provisions allowed by 40 CFR 191.16
(5) Delay final closure until management options for disposal of buried TRU waste are identified at a national level.

The SA evaluates option 2. The previous section demonstrates that the disposal of TRU waste in T04C is in compliance with the composite analysis requirements, DAS, and all 435.1-1 requirements. As a supplemental assessment of the impacts of the TRU waste, the SA evaluates the likelihood that this disposal can meet all the requirements of 40 CFR 191. The analysis is considered supplemental because of the factors listed above (i.e., unplanned disposal, small quantity, near-surface disposal), which are inconsistent with the intent of 40 CFR 191. 40 CFR 191 has been used in the past to regulate TRU disposal in GCD boreholes at the Area 5 RWMS

1.2.3 History of TRU Waste in T04C

In 1989, NTS waste management personnel were requested by DOE to identify sources of classified materials sent to NTS waste management facilities. The review was conducted by examining the classified DOE/U.S. Nuclear Regulatory Commission (NRC) Form 741, "Nuclear Material Transaction Reports", which accompanies any shipment of source material or special nuclear material subject to international safeguard agreements. During the review it became apparent that some classified materials previously buried were TRU waste. Subsequent investigations determined that a total of 102 55-gallon (gal) drums of TRU waste were buried in T04C. The unclassified paperwork accompanying the shipments indicated that the materials were LLW. Waste management personnel receiving and disposing the waste did not review the classified DOE/NRC Form 741 because it was sent to a security area and not readily available for review.

The buried TRU wastes were shipped from Rocky Flats on two occasions. The first incident occurred on 27 February 1986 when two shipments containing 76 55-gal drums were received. On 12 June 1986, an additional 26 55-gal drums of classified TRU waste were received from Rocky Flats. During this period, classified TRU wastes were received from Rocky Flats and disposed in GCD boreholes. However, because these materials were shipped as classified LLW, they were placed in T04C. Several photographs from July 1986 confirm that the portion of Trench 4 west of the intersection with Classified Trench 9 (T09C) was operationally active at this time (Figure 1.1). The exact location of the TRU waste in T04C was not recorded and is currently unknown. The volume of TRU waste in T04C represents approximately 0.5 percent of the total disposal unit volume.

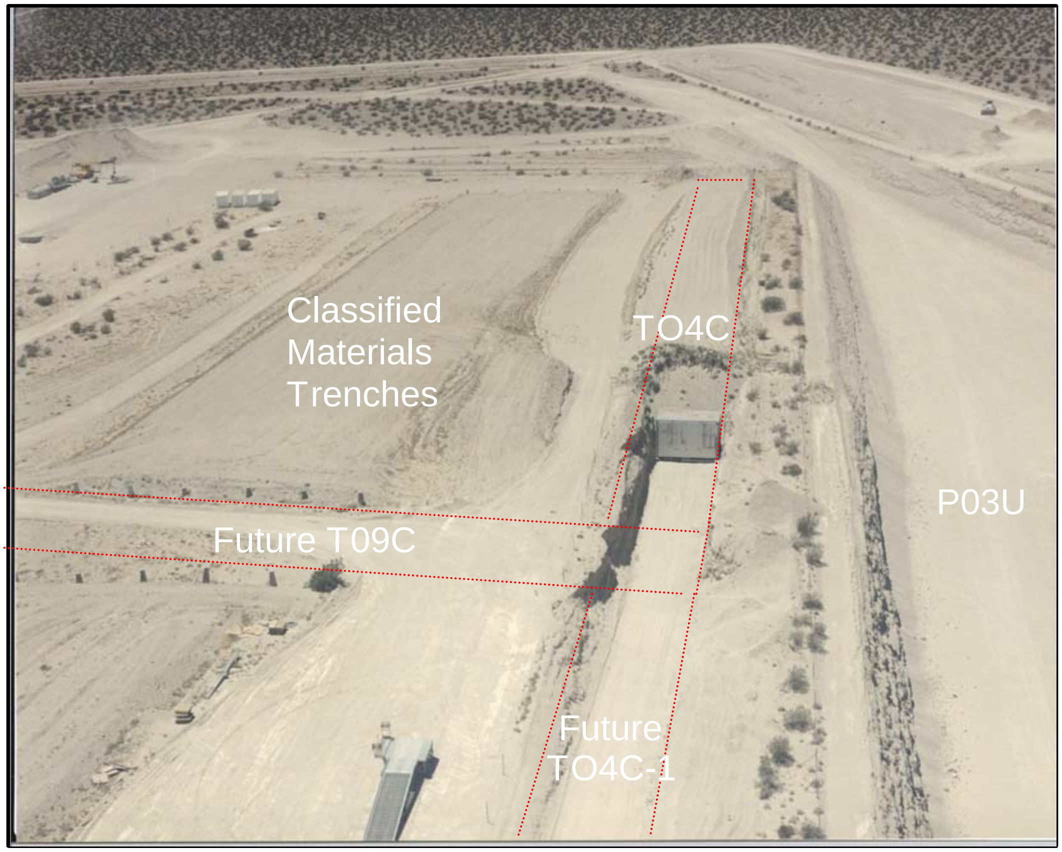


Figure 1.1 July 1986 photo showing partially filled western arm of T04C (photo WB 593).

1.3 Special Analysis Approach

The SA approach consists of 1) determining that the TRU in T04C complies with the requirements of 435.1-1, which are the composite analysis requirements, and, although not required it is used as supplemental information, 2) determining the likelihood that the requirements of 40 CFR 191 can be met.

1.3.1 Applicable Version of 40 CFR 191

Two versions of 40 CFR 191 have been promulgated, requiring that a version be selected for the SA. Portions of the regulation were remanded by the First Circuit Court in 1987 and in 1993 Parts 191.15 and Subpart C were revised and reinstated. The 1993 Part 191.15 individual protection requirements (IPRs) reduced the member of public dose limit from 0.25 to 0.15 milliSievert (mSv) in a year, increased the compliance period from 1,000 to 10,000 years, and changed the dose calculation method. The Subpart C groundwater protection standards were changed to broaden the definition of groundwaters protected, to move the point of compliance to the accessible environment, and to increase the compliance period from 1,000 to 10,000 years.

Although the 1985 version could be applicable to the TRU waste in T04C, several arguments support using the 1993 version.

- The 1993 version is more restrictive than the 1985 version with respect to the IPRs and groundwater protection standards.
- The 1993 version uses dosimetric quantities that are consistent with quantities currently used to regulate radiation exposure in the U.S.
- DOE/HQ has issued guidance to DOE, Nevada Operations (DOE/NV), requiring the GCD performance assessment (PA) show compliance with the 1993 version of 40 CFR 191 (DOE 1999a, 2002; Cochran et al. 2001).

Therefore, the special analysis will use requirements from the 1993 version of 40 CFR 191.

1.3.2 Containment Requirements

The CRs in Part 191.13(a) require that:

> *"Disposal systems for spent nuclear fuel, high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events shall:*
> *(1) Have a likelihood of less than one chance in 10 of exceeding quantities calculated according to Table 1 (appendix A); and*
> (2) *Have a likelihood of less than one chance in 1,000 of exceeding 10 times the quantities calculated according to Table 1 (appendix A)."*

As stated in Part 191.13(b), absolute proof that the CRs can be met is not required or obtainable due to uncertainties in estimating the performance of the disposal system over 10,000 years. A reasonable expectation of meeting the CRs is provided by repeatedly simulating the cumulative radionuclide release of the disposal system and determining the frequency of realizations that exceed the release limits. Each simulation represents an alternative stochastic realization of the system representing uncertainty (i.e., lack of knowledge) contributed by model parameters and the number and timing of human intrusion events. Reasonable expectation is provided if the frequency of realizations exceeding the release limits is less than the likelihood limits in Parts 191.13(a)(1) and 191.13(a)(2) above.

The accessible environment is defined as:

(1) "The atmosphere;
(2) Land surfaces;
(3) Surface waters;
(4) Oceans; and
(5) All of the lithosphere that is beyond the controlled area."

The phrase "*beyond the controlled area*" is assumed to apply only to the lithosphere, as in previous 40 CFR 191 PAs conducted at NTS (Cochran et al. 2001). The controlled area is defined as:

> *(1) "A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and*
> *(2) The subsurface underlying such a surface location."*

The controlled area is assumed to describe the area within the 100-m (330-ft) RWMS boundary as assumed in previous NTS 40 CFR 191 PAs (Cochran et al. 2001). The distance through the subsurface to the 100-m (330-ft) boundary is much greater than the distance to the land surface above the disposal unit. Therefore, the cumulative release is calculated as the release to the land surface and atmosphere directly above T04C. Releases by drilling intrusion are also included in the cumulative release. These cumulative releases are calculated as the cumulative release over 10,000 years normalized by the 40 CFR 191, Table 1 quantities in Appendix A or:

$$R = \sum_{i=1}^{n} \frac{Q_i}{RL_i}$$

where R is the normalized cumulative release (dimensionless), Q_i the cumulative release of nuclide i, and RL_i the release limit of nuclide i (Table 1.1). The 40 CFR 191, Appendix A, Table 1, release limits are scaled based on the type and quantity of waste. The applicable waste type for T04C is TRU waste described in Note 1(e) as alpha-emitting transuranic radionuclides with half-lives greater than 20 years. Under Note 1(e), the release limits are scaled per 1×10^6 Curies (Ci) of TRU waste.

Table 1.1 Release limits for the 40 CFR 191.13(a) containment requirements

Radionuclide	Release Limit per 1×10^6 Ci of TRU Waste
^{241}Am or ^{243}Am	100
^{14}C	100
^{135}Cs, ^{137}Cs	1,000
^{129}I	100
^{237}Np	100
^{238}Pu, ^{239}Pu, ^{240}Pu, or ^{242}Pu	100
^{226}Ra	100
^{90}Sr	1,000
^{99}Tc	10,000
^{230}Th or ^{232}Th	10
^{126}Sn	1,000
^{233}U, ^{234}U, ^{235}U, ^{236}U, or ^{238}U	100
Any other alpha-emitting radionuclide with a half-life greater than 20 yrs	100
Any other radionuclide with a half-life greater than 20 yrs that does not emit alpha particles	1,000

1.3.3 Assurance Requirements

The regulation includes assurance requirements in Part 191.14 to "*provide the confidence needed for long-term compliance with the requirements of 191.13*." Six different types of assurance are required including:

- Active institutional controls
- Monitoring
- Passive institutional controls including markers and records
- Multiple barriers including natural and engineered barriers
- Selecting a site without significant attractive resources
- System design that does not preclude waste retrieval

Active institutional controls are defined as: *"(1) controlling access to a disposal site by means other than passive institutional controls; (2) performing maintenance operations of remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance*." Active institutional control is explicitly limited to 100 years. Institutional control is assumed to begin at the time of final site closure when all closure barriers are installed based on previous DOE guidance (DOE 1999a).

Passive institutional controls are defined as: *"(1) permanent markers placed at the disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of the disposal system.*"

A barrier is defined as: "*any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment*." Although many alternative barrier systems are conceivable, the regulation does not identify any criteria or process for barrier selection. During its regulation of the WIPP, EPA proposed that the DOE select barriers using cost-benefit analysis (EPA 1995). Therefore, the best engineered barrier is assumed to be the most cost-effective barrier that meets the requirements of the regulation.

The assurance requirements differ from the other requirements because they do not require technical analyses to demonstrate compliance. Therefore, the SA demonstrates that the assurance requirements can be met by describing the planned site control and features that meet each specific requirement. The SA model is used to identify potentially cost-effective engineered barriers.

1.3.4 Individual Protection Requirements

The 1993 version of the regulation states in Part 191.15(a) that:

> *"Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 0.15 mSv."*

"Any associated radioactive material" is not defined by the regulation. The SA interprets the associated radioactive material to be any waste disposed in the same disposal unit, T04C. The same disposal unit interpretation is consistent with the 40 CFR 191 PA for the GCD boreholes (Cochran et al. 2001). T04C is close to or contiguous with adjacent disposal units. At the time of disposal, the northernmost east-west oriented disposal unit in the classified materials area was designated T04C. A perpendicular trench, T09C, was subsequently excavated, intersecting the ramp into T04C. After this date, a disposal unit following the trend of T04C, designated T04C-1, was excavated eastward from the northern end of T09C. The SA assumes that the TRU disposal unit is T04C, which is delineated as the northern most east-west trending trench in the classified area. The eastern boundary of T04C is contiguous with T09C. The delineation of the disposal unit affects the volume of low-LLW associated with the TRU waste, but will have no affect on the estimated individual dose. The response of the dose assessment models used in the SA are linearly proportional to waste concentration. The waste concentrations of surrounding disposal units are similar and the dose would not change significantly if additional disposal units where included in or excluded from the associated waste.

The SA demonstrates that the IPRs are met by calculating dose using Monte Carlo simulation. Appendix C of the regulation states that when uncertainties are considered, the best estimate should be compared with the regulatory limit. A reasonable expectation of meeting the dose limit is assumed to be provided if the mean and median of the result is less than 0.15 mSv in a year.

Undisturbed performance is defined in Part 191.12 as:

> *"…the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events."*

Undisturbed performance clearly does not include human intrusion. Climate change over the next 10,000 years is considered likely and included in the definition of undisturbed performance.

Based on guidance in 40 CFR 191, Appendix B, the annual committed effective dose equivalent is assumed to be equivalent to the total effective dose equivalent (TEDE) calculated using dose conversion factors published in Federal Guidance Reports 11 and 12 (Eckerman and Ryman 1993; Eckerman et al. 1998). The TEDE is calculated as the sum of the annual effective dose equivalent from external irradiation and the 50-year committed effective dose equivalent resulting from a year of intake. The dose from internally deposited radionuclides is assumed to exclude the dose from inhalation of ^{222}Rn and its short-lived progeny in air based on guidance provided by NNSA/NSO (2007a). The ^{222}Rn inhalation dose is excluded because it (1) is explicitly excluded from DOE performance assessments, (2) dominates the individual's dose, but is not produced by the regulated TRU waste component, and (3) is not specifically included in the 40 CFR 191 IPRs.

The regulation contains no details or guidance on selection of the exposure scenario except that the member of public is located in the accessible environment. The accessible environment is interpreted to include the land surface and atmosphere above the disposal unit. The member of public is assumed to be located directly above the disposal unit because this is the location in the accessible environment with the highest expected radionuclide concentration and dose.

Alternative exposure scenarios are possible. One approach is to evaluate alternative exposure scenarios and calculate a mean dose weighted with the probability of each scenario. Estimating the probability of exposure scenarios is problematic and the requirements for the 40 CFR 191 IPRs are not probabilistic. A single scenario was selected consistent with the exposure scenarios used in other PAs. Assessments conducted under DOE M 435.1-1 are required to evaluate potential doses to representative critical groups receiving the highest doses assuming average living habits and exposure conditions. For the Area 5 RWMS, the critical group receiving the highest doses is interpreted as those members of the public residing on the disposal unit. Members of the public residing at the disposal unit are assumed to have average living habits and exposure conditions. Average residents of southern Nevada are not engaged in agriculture and the exposure scenario does not include agricultural pathways.

1.3.5 Groundwater Protection

Subpart C of 40 CFR 191 includes standards for groundwater protection. The regulation specifically states that the groundwater protection standard "*does not apply to waste disposed before the effective date*" which is 19 January 1994. The 1985 version of the regulation applies to a special source of groundwater. Groundwater below the Area 5 RWMS does not meet the definition of a special source of groundwater (Chapman 1994) and this interpretation was accepted for the regulatory review of the GCD 40 CFR 191 PA (Cochran et al. 2001).

If the regulation were applied to groundwater below the Area 5 RWMS, there is ample evidence that the travel time to groundwater exceeds 10,000 years (Shott et al. 1998). Therefore, the SA does not evaluate a groundwater pathway.

2.0 Disposal Facility Characteristics

Environmental conditions at NTS and the Area 5 RWMS have been reported extensively (Carr et al. 1975; Winograd and Thordarson 1975; Beatley 1976; DOE 1997; Shott et al. 1998; Ostler et al. 2000; BN 2001a). The geologic and hydrologic setting of the Area 5 RWMS has been extensively characterized (Reynolds Electrical and Engineering Company 1993, 1994; Istok et al. 1994; Blout et al. 1995).

2.1 Site Characteristics

2.1.1 Disposal Site Location

NTS is in southern Nevada approximately 105 kilometer (km) (65 miles [mi]) northwest of Las Vegas. The Area 5 RWMS is located in northern Frenchman Flat, a large closed basin in the southeast corner of NTS. Counties falling within an 80-km radius of the Area 5 RWMS include portions of Nye, Lincoln, and Clark Counties in Nevada, and Inyo County, California. The closest major metropolitan center is Las Vegas. Closer, but much smaller rural communities include: Indian Springs (42 km [26 mi]), Amargosa/Lathrop Wells (52 km [32 mi]), Pahrump (80 km [50 mi]), and Beatty (82 km [51 mi]).

The Area 5 RWMC is a 296-ha (732-ac) operational area set aside for LLW disposal. The Area 5 RWMS describes the operationally active area within the RWMC, encompassing approximately 58 ha (144 ac) in the southeast corner of the RWMC (Figure 2.1). For closure planning purposes, the Area 5 RWMS is divided into an older 37-ha (92-ac) disposal area referred to as the LLWMU, that is planned to be closed first, and a more recent northern expansion area. The TRU waste is buried in T04C within the LLWMU.

2.1.2 Disposal Site Description

The Area 5 RWMC consists of five operational areas, the Area 5 RWMS, the Real-Time Radiography (RTR) system, the TRU Waste Storage Pad and TRU Pad Cover Building, the S02C classified area, and the Waste Examination Facility (WEF) (Figure 2.2). The RTR is a radiography cell used for verification of mixed waste generated off site. The TRU Waste Storage Pad and Pad Cover Building are hazard category 2 (HC-2) facilities used for storage of TRU waste. The S02C Classified Area is a HC-2 facility consisting of seven cargo containers used for the storage of classified TRU waste. The WEF is a HC-2 facility used to examine and repackage TRU waste for shipment to WIPP.

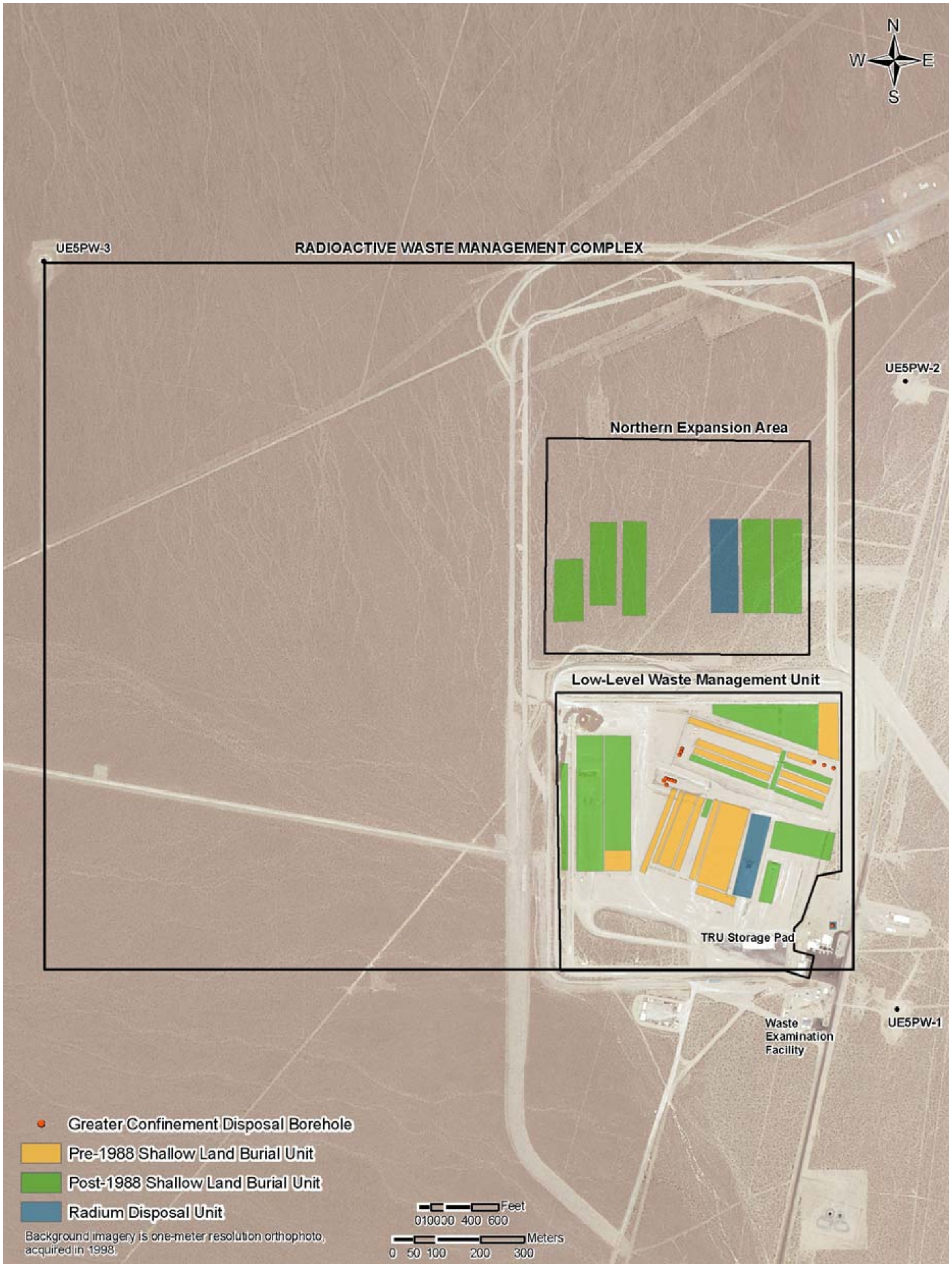


Figure 2.1 Location of the Area 5 RWMS and other features within the Area 5 RWMC

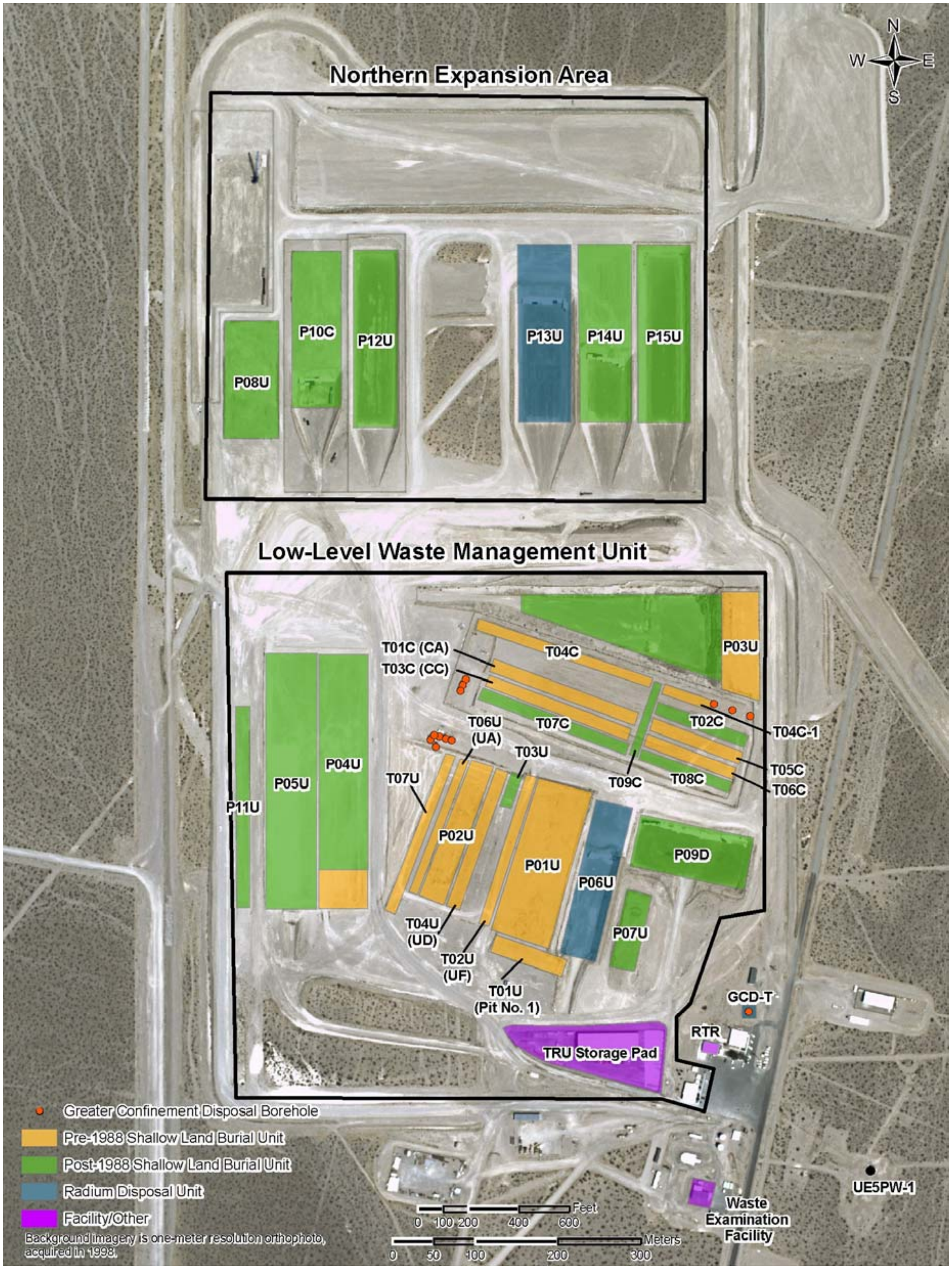


Figure 2.2 Operational areas, disposal units, and support facilities at the Area 5 RWMS

The active Area 5 RWMS is bounded on the north, west, and east by a flood protection system consisting of berms, levee extensions, and flood control channels. The flood protection system was designed to provide protection from a 25-year, 24-hour storm as required under RCRA. Three pilot wells (UE5PW-1, UE5PW-2, and UE5PW-3), located outside of the Area 5 RWMS, are used for groundwater monitoring.

T04C is located in the classified area within the LLWMU. It is an approximately 221 m (725 ft) long and 6.4 m (21 ft) wide unlined shallow land burial trench. T04C was excavated to 6.1 m (20- ft) below grade. Wastes are typically stacked to within 1.2 m (4 ft) of grade, allowing a maximum waste thickness of 4.9 m (16 ft). This is sufficient to allow stacking of 55 gal drums four high on end. The total disposal unit volume is approximately 6,907 m^3 (2.44E5 ft^3). Assuming a 0.6 facility design factor, approximately 4,100 m^3 (1.45E5 ft^3) of waste could be disposed in the unit. The unit is currently operationally closed with a 2.4 m (8 ft) alluvium cover.

2.1.3 Population Distribution

Permanent settlements in southern Nevada are clustered around a few relatively rare sites with access to water or important mineral resources. Nevada's population is predominantly urban, with most of the population living in the Las Vegas and Reno metropolitan areas. Intervening areas are undeveloped arid shrublands or forested mountains, giving Nevada one of the lowest population densities in the U.S.

Communities near NTS are growing, with large urban centers experiencing the most rapid and consistent increases. The Las Vegas metropolitan area (composed of Las Vegas, North Las Vegas, Henderson, Boulder City, and Mesquite) is one of the fastest-growing metropolitan areas in the U.S., increasing from 4 to 8 percent per year. In 2006, the population of the Las Vegas metropolitan area and Nye County were estimated to be more than 1.9 million and 44,795, respectively (State of Nevada Demographer [SND] 2007). Pahrump, a rural community in Nye County continues to grow rapidly with a 2006 population of 36,645 (SND 2007). Long-term population trends for smaller rural communities near NTS such as Amargosa, with a 2006 population of 1,435, and Indian Springs, with a 2006 population of 1,907 indicate slower, less consistent increases, with small decreases occurring in some individual years. By 2024, the approximate time of site closure, the population of Clark County is expected to increase to 2.7 million and Nye County to 57,665 (SND 2007).

2.1.4 Land Use

The arid valleys and mountains of NTS comprise some of the least hospitable lands in the U.S. With the exception of the brief-lived Wahmonie mining camp, the 1,375 square mile NTS has probably never supported a population greater than 100 persons (Fehner and Gosling 2000). Native American populations have waxed and waned over the last 10,000 years as climatic conditions have varied. In the late 1800s, NTS was reported to be the home of approximately 40 Native Americans subsisting by hunting and gathering in the Pahute Mesa area. During the second half of the 1800s, European immigrants began to traverse the area and to use the site for mining and grazing. These activities were sparse and small scale except for the mining boom town of Wahmonie which supported a peak population of 1,500 on the margin of Jackass Flats for approximately 2 years. NTS range is suitable for grazing sheep and cattle, but lacks water resources. Most ranchers using NTS have lived at nearby communities with permanent water resources. Before DOE use, there was no evidence of settlement within Frenchman Flat. The closest site with evidence of past human habitation is Cane Spring 14.3 km (8.8 mi) west of the Area 5 RWMS.

Public access to NTS area has been restricted since at least the 1940s, when the land was part of a bombing and gunnery range under the jurisdiction of Nellis Air Force Base. In 1951, NTS became the continental nuclear testing site. In the 1950s and 1960s, the U.S. Atomic Energy Commission withdrew the land within NTS boundaries under four Public Land Orders.

The site continues to be protected from public access and development by government control. Current land uses at NTS include hazardous chemical spill testing, emergency response training, nonnuclear weapons testing, radioactive waste management, and environmental technology studies. Active DOE facilities in Frenchman Flat include the Device Assembly Facility (DAF), the Nonproliferation Test and Evaluation Complex, the Free-Air-Carbon dioxide Enrichment (FACE) facility and the Radiological/Nuclear Countermeasures Test and Evaluation Complex. The FACE facility is an outdoor environmental research experiment investigating the long-term effects of atmospheric carbon dioxide on desert ecosystems. FACE is located south of the Frenchman Flat playa. The Radiological/Nuclear Countermeasures Test and Evaluation Complex is a research and testing facility for instrumentation for the detection of weapons of mass destruction located south of the DAF.

The NNSA/NSO plans to restrict access to NTS in perpetuity (DOE/NV 2000). The primary national security mission of NTS requires restriction of public access. Residual radioactivity from past activities, including aboveground and underground nuclear testing, precludes release of large areas of NTS. Restoration of some areas contaminated by nuclear testing may not be economically or technically feasible. Such areas will be closed in place with permanent land-use restrictions. The NNSA/NSO land-use plans for NTS includes prohibiting construction and drilling within the Area 5 RWMS in perpetuity.

2.1.5 Meteorology and Climatology

The present-day NTS climate is considered a dry interglacial period dominated by the Westerlies. The climate is extremely arid due to the rain shadow created by the Sierra Nevada mountains to the west. Conditions are characterized by a large number of cloudless days, low precipitation, and high daily temperatures, especially in the summer. Precipitation varies with elevation with valley bottoms receiving the least precipitation. The mean annual precipitation (MAP) for Frenchman Flat is 12 centimeters (cm) (4.7 inches [in.]). Most rain falls in the winter months during long-duration, low-intensity storms. A second smaller precipitation peak, characterized by brief but intense local thunderstorms, occurs in the late summer months. Meteorology data indicate that annual potential evapotranspiration (PET) calculated using the radiation based method of Doorenbos and Pruitt (1977) greatly exceeds annual precipitation. From 1994 through 2004, PET averaged 15 times annual precipitation (Figure 2.3).

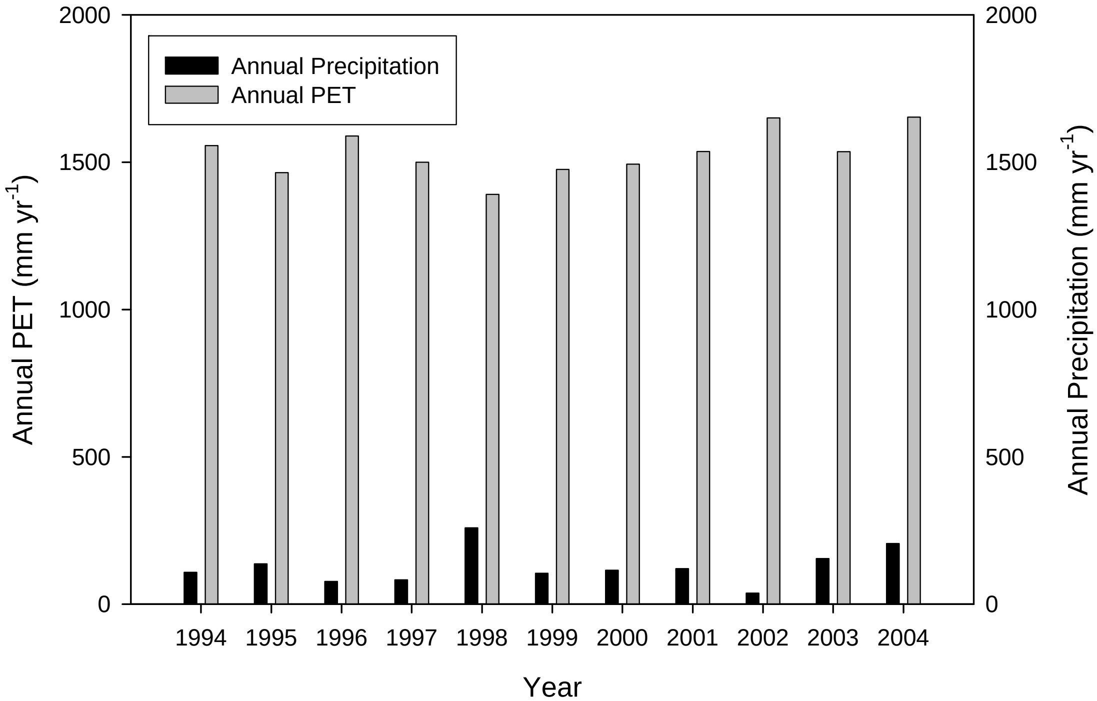


Figure 2.3 Annual potential evapotranspiration (PET) and annual precipitation at the Area 5 RWMS

2.1.6 Ecology

The flora and fauna of NTS and their role in bioturbation of soils have been investigated by both literature reviews and site characterizations efforts (Hooten et al. 2004; Hansen and Ostler 2003; Shott et al. 1998; BN 2006a).

Two major ecoregions occur on NTS: the Mojave Desert to the south, and the Great Basin Desert to the north, with a transitional desert separating the two regions (BN 2001b; Ostler et al. 2000). The Area 5 RWMS, which lies within the northern fringe of the Mojave Desert, is surrounded by a *Larrea tridentata-Ambrosia dumosa* (creosote bush-white bursage) Shrubland Alliance. The plant community has a comparatively low rate of aboveground net primary productivity (ANPP), ~300 kilograms per hectare per year (kg ha^{-1} yr^{-1}). Plant roots are rare below the near-surface zone (~2.5 m [8.2 ft]) where infiltrating precipitation is available.

A diverse assemblage of invertebrate and vertebrate fauna occurs within the Mojave Desert. Insects and fossorial rodents are the most numerous and diverse groups present and are thought to be the most important in terms of burrowing. Site characterization studies have identified two harvester ants (*Pogonomyrmex rugosus* and *Messor pergandei*) as the most important burrowing insects at the Area 5 RWMS. While several termite species occur, no species has been identified that transport significant amounts of soil upward to the land surface. Rodents move the largest amounts of soil at the site, but the depth of their burrows is shallow. Larger mammals, such as badgers, excavate to greater depths, but are rare at the site.

2.1.7 Geology, Seismology, and Volcanology

Geology

Frenchman Flat is a closed basin bounded by the Halfpint Range to the north, the Ranger Mountains and the Spotted Range to the east-southeast, and Mount Salyer to the west. Elevations range from approximately 1,600 m (5250 ft) above mean sea level in the surrounding mountain ranges to 940 m (3080 ft) at its lowest point on Frenchman Flat playa.

The Frenchman Flat basin is filled with alluvial sediments, which are 360- to 460-m (1180- to 1500-ft) thick below the Area 5 RWMS. The uppermost aquifer occurs at approximately 236-m (774-ft) depth in the alluvium. Beneath the alluvium lies a thick sequence of interbedded Tertiary welded and non-welded tuff and local lava flows. The volcanic section is estimated to be over 550-m (1,804-ft) thick and thins southeast across the basin. The lower part of the volcanic section is zeolitized and forms a confining aquifer throughout most of the basin (BN 2006b). The alluvial and volcanic sequences are underlain by an undetermined thickness of Paleozoic carbonate rocks with increased thickness of clastic rocks near the Paleozoic-Precambrian boundary (Laczniak et al. 1996).

Seismic Activity

There is a significant potential for future seismic activity in NTS area including Frenchman Flat during the next 1,000 years (Shott et al. 1998). The revised conceptual model of Frenchman Flat relates the origin of the Frenchman Flat basin to strike-slip faulting along the Rock Valley fault system that terminates in an extensional imbricate fan structure in the eastern margin of the basin (BN 2006b). Observational data suggest that this structure is still active. Relatively large-magnitude earthquakes (> magnitude 5.0) are expected events in the NTS region over time frames of 10,000 to 15,000 years.

A formal seismic risk assessment has not been conducted for the Area 5 RWMS. However, multiple lines of evidence support the conclusion that future seismic activity is unlikely to significantly degrade the isolation capability of shallow land pits and trenches.

1. There are no observed offsets in alluvial deposits within the vicinity of the Area 5 RWMS. The active parts of the Rock Valley fault system and related imbricate fault systems are > 5 km (3 mi) from the facility. A buried fault beneath the facility strikes northwest, a fault orientation that is not seismogenic in the current stress field (Carr 1983). Future ground ruptures from earthquake activity are not expected to disrupt the facility.

2. The most likely effect of seismic activity is ground shaking associated with a distant earthquake event. The primary concern with seismic activity ground shaking is

disruption of engineered components (geomembrane barriers, leachate collection system) that can lead to increased infiltration and/or enhanced vapor-phase transport. Closure plans for the Area 5 RWMS include construction of a thick (> 3-m [9.8-ft]) monolayer-evapotranspiration (ET) closure cover composed of alluvial soil. This closure cover does not contain engineered components that could fail or be disrupted by seismic events. The only anticipated effect of ground shaking is enhanced and/or accelerated compaction/subsidence.

The important infiltration, water storage, and water removal characteristics of a monolayer-ET cover are not expected to be adversely affected by minor compaction. Kemnitz (1999) completed a seismic hazard assessment for the U3ax/bl monolayer closure cover at the Area 3 RWMS. Model parameters and site response assessments were performed for a bounding analysis to assess damage to a monolayer closure cover at the U3ax/bl disposal cell. The controlling earthquake for the analysis is an earthquake event on the Yucca fault with a peak horizontal acceleration of 0.79 g, where g is the acceleration of gravity. The maximum predicted deformation of the closure cover is between 2 and 8 cm (0.8 and 3 in.) (lateral and differential deformation). These deformations are insignificant compared to the expected subsidence in the closure cover (Kemnitz 1999). The effects of future seismic events are not important for the Area 5 RWMS monolayer-ET closure cover.

Potential for Volcanic Activity

The volcanic record of NTS was summarized in the Area 5 RWMS PA (Shott et al. 1998). Silicic volcanism in the region ceased following eruptions associated with the Black Mountain caldera about 8.5 million years ago (Ma) (Sawyer et al. 1994). Small-volume basaltic volcanism persisted in the region following cessation of silicic volcanism. All Quaternary basaltic volcanic activity in the NTS region is confined to the western and southwest parts of the region, including the basalt of Sleeping Butte, the Quaternary basalt of Crater Flat, and the Lathrop Wells volcanic center (Crowe 1990; Fleck et al. 1996; Heizler et al. 1999). Basaltic volcanism in the Frenchman Flat basin includes buried basalt encountered in the alluvial section in multiple drillholes, including the underground testing area (UGTA) northern drillhole cluster (Carr et al. 1975; BN 2005b). The age of these buried basalt lavas is about 8.5 Ma (RSN 1994). Local vents for the buried basalt are present in Scarp Canyon, immediately north of Frenchman Flat (Crowe 1990). The youngest basalt centers in the basin vicinity are the basalt of Nye Canyon. This volcanic unit consists of three basalt centers aligned along a north-northeast trend and the centers have been dated at about 7.3 Ma (RSN 1994).

The absence of nearby Pliocene or Quaternary basaltic volcanism in the Frenchman Flat area is the primary basis for an assessment of minimal risk to the Area 5 RWMS from the recurrence of future volcanism. The nearest site of Quaternary basaltic volcanism is the Lathrop Wells center, over 50 km (31 mi) from the Area 5 RWMS. The absence of young volcanic centers in the area classifies the facility as removed from zones of active volcanism and in a setting of background volcanic rates for the southern Great Basin. Background volcanic rates for the southern Great Basin region have been estimated by multiple researchers. Crowe et al. (1998) calculated a Quaternary recurrence rate of 3.7×10^{-6} events yr^{-1} for post-caldera basaltic volcanism within an area encompassing the NTS region and including Frenchman Flat. The likelihood of magmatic disruption of a 2.5-km^2 (1-mi^2) area equivalent to the dimensions of the Area 5 RWMS using this recurrence rate is 2 x 10^{-9} events yr^{-1}. Connor et al. (2000) calculated an event rate of 1.3 x 10^{-9} events yr^{-1} per km^2 for the last 2.0 Ma for the western Great Basin. Application of this rate to a 2.5-km^2 (1-mi^2) facility area gives a volcanic disruption probability of 3.2 x 10^{-9} events yr^{-1}. These event rates are equal to a disruption probability of about 1 in 300 million per year, a sufficiently low probability to dismiss volcanism as a concern for the Area 5 RWMS.

2.1.8 Hydrology

Surface Water Hydrology

Surface water occurs intermittently in Frenchman Flat in washes and on the playa after intense convective summer storms or prolonged winter rains. Cane Spring, a small spring issuing from a perched aquifer 14.3 km (8.8 mi) west of the Area 5 RWMS, is the closest naturally occurring source of surface water.

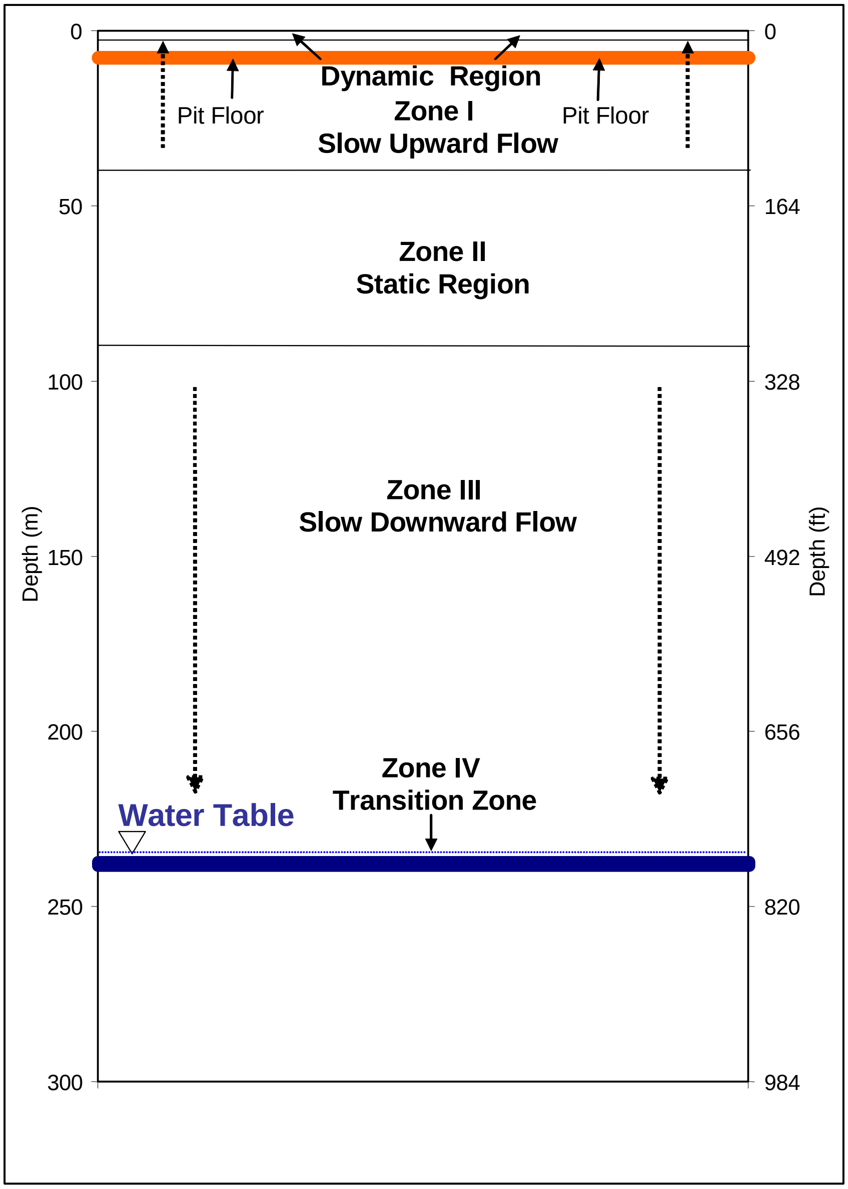
Vadose Zone Hydrology

The conceptual model of unsaturated flow in the vadose zone was developed to understand liquid fluxes capable of transporting radionuclides. The model, based primarily on observed water potential and chloride profiles, hypothesizes four regions of flow in the vadose zone (Figure 2.4). Zone boundaries are approximate and may vary from location to location within Frenchman Flat. In Zone I, a near-surface zone approximately 35 m (115 ft) thick, the water potential indicates a potential for upward liquid flux. Zone II, occurring from approximately 40 to 90 m (131 to 295 ft), is a static region with negligible liquid flux. Zone III, an intermediate region with downward liquid fluxes driven by gravity, occurs from approximately 90 m (295 ft) to within a few centimeters of the saturated zone. The final region, Zone IV, is a few centimeters thick transition zone between the vadose zone and the saturated zone where water potential and flow are negligible.

Zone I includes a dynamic and transitory region in the upper few meters of the vadose zone, where the water potential gradient periodically reverses as precipitation infiltrates and is returned to the atmosphere by ET. A strong upward potential for flow is maintained in Zone I by the roots of xeric desert plants. Although there is a potential for upward flow in Zone I, the soil is normally so dry that liquid advection is very slow. In the very near-surface, where plant roots maintain low moisture contents, upward water movement occurs predominantly in the vapor phase (and through plant roots) and the upward advection of soluble radionuclides may become negligible. The conceptual boundary where upward liquid advection rates approach zero is referred to as the no-liquid flux boundary (NLFB).

The large accumulation of chloride in Zone I below 2 m (6.6 ft) indicates that transient infiltration events are stopped above this depth and returned to the atmosphere by ET. Assuming a constant atmospheric chloride source and downward liquid advection, the observed near-surface chloride accumulation below the root zone is estimated to require from 10,000 to

15,000 years to form, which corresponds with the end of the last pluvial period, approximately 8,000 to 15,000 years ago (Tyler et al. 1996; Walvoord et al. 2002).



Dynamic Region-Magnitude and the direction of liquid fluxes are variable and determined by episodic infiltration, evapotranspiration, and processes of biotic transport. NLFB at mean depth of 2 m.

Zone I-Region of Slow Upward Flow: Region where the combination of low precipitation and high potential evapotranspiration leads to a dry zone, inducing upward flow of pore water in the unsaturated zone from as deep as about 35 m. Median upward flux: 0.003 mm yr^{-1}

Waste zone located in region of upward flow.

Zone II-Static Region: Region of no vertical liquid movement (balance of matric suction and gravitational forces). The thickness and the depth below the surface of this region changes with the physical/textural properties of alluvium and *in situ* water

Zone III-Region of Slow Downward Flow: region of steady downward flow (increased water contents allow downward drainage). Water in the vadose zone currently recharging the water table probably infiltrated during past pluvial climate cycles.

No aerially distributed recharge to the groundwater table under current conditions.

Zone IV-Transition Zone: Few centimeter thick zone between vadose zone and saturated zone.

Figure 2.4 Schematic diagram of vadose zone conceptual model of the Area 5 RWMS under present-day climatic conditions. Orange-shaded layer is the waste zone and the blue-shaded layer is the water table.

The chloride accumulated throughout the entire profile at pilot wells UE5PW-1 and UE5PW-3 suggest that infiltration at these locations has not reached the water table for 95,000 to 110,000 years (Tyler et al. 1996). The chloride profile at UE5PW-2 suggests that the sub-root zone chloride bulge was flushed from this profile at some time before 15,000 years ago, perhaps indicating that spatially variable recharge occurred during an earlier pluvial period. The chloride profiles in the vadose zone near the Area 5 RWMS suggests that recharge through the alluvium ended after the last pluvial period when the climate became drier and mesic vegetation was replaced by more xeric desert shrubs.

Using surface boundary conditions for infiltration and root-zone matric potentials based on a 110,000-year paleoclimate reconstruction for southern Nevada, Walvoord et al. (2002) were able to simulate matric potential and chloride profiles observed at the Area 5 RWMS pilot wells, UE5PW-1, UE5PW-2, and UE5PW-3. Sub-root zone upward liquid fluxes were estimated to range from 2×10^{-5} to 1×10^{-3} mm yr^{-1} under the current climatic conditions. The hydraulic response time, the time required for an e-fold $(1 - e^{-1})$ change in matric potential from the initial to steady-state profile, was estimated to be 300,000 years for Frenchman Flat, again suggesting that the pilot well profiles are not at equilibrium, but drying very slowly.

Wolfsberg and Stauffer (2003) have extended and refined the modeling of Walvoord et al. (2002) to estimate present-day upward liquid fluxes at the Area 5 RWMS. Varying the timing of the last pluvial period, pluvial infiltration rate, alluvium properties, and the interpluvial root-zone matric potential, Wolfsberg and Stauffer (2003) produced 32 simulation results matching chloride profiles for the Area 5 RWMS pilot wells. The simulations include realizations which used measured unsaturated hydraulic conductivities for Area 5 RWMS soils, rather than modeled conductivities. The upward near-surface liquid fluxes in their simulations ranged from 0 to 0.02 mm yr^{-1}. The transition from upward to downward liquid flux occurred from 20 to 70 m (66 to 295 ft). The estimated upward liquid fluxes were most sensitive to the timing of the end of the last pluvial period, which was assumed to be 26,000 or 13,000 years ago. Wolfsberg and Stauffer (2003) also conclude that solute diffusion in the liquid phase may be more important than upward liquid advection because of the low upward flux predicted by their simulations.

Groundwater Hydrology

Groundwater movement on NTS can be divided into intrabasin and interbasin flow. Intrabasin flow describes the downward flow of water through the alluvial and volcanic aquifers and aquitards to the underlying carbonate aquifer. Interbasin flow describes the lateral movement of groundwater within the lower-carbonate aquifer, confined by the lower-clastic aquitard on the bottom and either the upper-clastic or tuff aquitard above. Interbasin flow in the southeast corner of NTS is generally from the northeast to the southwest toward Amargosa Valley, Ash Meadows, and Death Valley.

Groundwater flow through Frenchman Flat Basin is driven primarily by areas of higher hydraulic head west of the basin and by recharge. Present-day recharge is estimated to be one percent or less of the total fluxes passing through the basin (Stoller-Navarro 2006). Head gradients are small suggesting slow groundwater flow. Flow is predominantly through three hydrogeologic units (Stoller-Navarro 2006):

1. Alluvial aquifer within saturated parts of the basin fill.
2. Welded tuff and vitric aquifers in the volcanic section.
3. Fracture and fault controlled sections of the lower-carbonate aquifer.

Faults are an important component of the Frenchman Flat flow system with the Rock Valley fault system probably controlling the general basin flow to the southwest. Hydraulic heads are higher in the alluvial aquifer than the lower-carbonate aquifer consistent with separation of the intrabasin flow in the alluvial aquifer from the regional interbasin flow system of the lower-carbonate aquifer (Stoller-Navarro 2006).

The three pilot wells (UE5PW-1, UE5PW-2, and UE5PW-3) have been used to monitor the uppermost alluvial aquifer below the Area 5 RWMS since 1992. Water table elevation measurements are performed quarterly at the pilot wells. Water table elevations indicate that the uppermost aquifer below the Area 5 RWMS is essentially flat with negligible lateral flow. Some vertical flow to the underlying regional lower carbonate aquifer is suspected to occur. Although the vertical flow is uncharacterized at this time, it is expected to be extremely slow.

In addition to water level monitoring, semiannual samples are collected for five contamination-indicating parameters (pH, specific conductance, total organic carbon, total organic halides, and tritium) and water chemistry parameters (major cations, anions, and alkalinity). Biennial samples are collected for the radiological monitoring parameters (gross alpha, gross beta, gamma-emitting radionuclides, and plutonium). All data indicate that Area 5 RWMS waste disposal operations have not had any measurable impact on the uppermost aquifer (BN 2005b).

2.1.9 Geochemistry

The water content of alluvium at the Area 5 RWMS is extremely low and aqueous phase transport of radionuclides is expected to be very slow. Dissolved solutes are assumed to precipitate and partition between the liquid phase and solid phase as described by the solubility constant (K_{sp}) and soil-water distribution coefficient (K_d).

2.1.10 Natural Background Radiation

Natural background radiation in the vicinity of the Area 5 RWMS has been previously described (Shott et al. 1998, BN 2001a). Although Frenchman Flat has been the site of 14 aboveground nuclear tests, 10 belowground nuclear tests, and 24 safety tests, surface soils at the Area 5 RWMS contain levels of man-made radionuclides typical of global fallout.

2.2 Future Site Characteristics

2.2.1 Future Climate

The climatic history of the southwest U.S. recorded in packrat middens, lake sediments, and calcite deposits indicates that climate change is likely over the next 10,000 years (Forester et al. 1999). Glacial and various glacial-transition climate regimes account for approximately 87 percent of the last 400,000 years and are likely to occur in the future. The monsoon climate regime has occurred frequently in the past. During the monsoon climate regime, the Subtropical Highs expand northward causing increased summer monsoon activity in southern Nevada (Bechtel SAIC 2004a). These monsoon periods are characterized by increased temperature and increased summer precipitation. Glacial-transition climates with increased Polar Low influence are also possible over the next 10,000 years. These climate regimes are characterized by lower temperatures and increased winter precipitation.

Predicting future climate is highly speculative. The SA adapts the Yucca Mountain Project (YMP) climate change forecast for use at the Area 5 RWMS. The YMP has developed a model of future climate using a climate forecasting method based on the earth's orbital cycles (Forestor et al. 1999; Bechtel SAIC 2004a). The climate forecast method attempts to establish the relationship between past climate states and periodic variations in the earth's orbital motion and to project these changes into the future.

The YMP climate forecast begins by reconstructing the sequence of past climates that have occurred over the last 500,000 years in the Southwest region (Forester et al. 1999). Descriptions of past climate states are based on present climatic conditions, stable isotope data from Devil's Hole, NV, the microfossil record from Owen's Lake, CA, and plant macrofossil records recorded in packrat middens. The next step in the climate forecast is to assume Milankovitch theory which holds that global climate is influenced by periodic variation in the distance of the earth from the sun and orientation of the earth's axis of rotation relative to the sun (Imbrie et al. 1993). These variations include at least three different orbital motions (orbital eccentricity, obliquity, and precession of the earth's axis of rotation) and are predictable and repeat approximately every 400,000 years. These periodic variations change solar insolation which influences global climate. The relationship between orbital variation and regional climatic conditions can be established, once the sequence of past climate states has been dated.

Since orbital variations repeat themselves over an approximately 400,000 year period, the future climate at the site can be forecast as the sequence of regional climate regimes observed approximately 400,000 years ago. A Southern Hemisphere precession maximum occurred approximately 1,000 years ago during the present-day interglacial period. This maximum has been matched with a precession maximum occurring 399,000 years ago. The future climate forecast is then based on the sequence of climate states observed starting at 398,000 years ago. Using this approach, movement away from the present-day interglacial conditions is expected to begin in approximately 400 to 600 years (Table 2.1) (Bechtel SAIC 2004a). The following period is forecast to be a 900 to 1,400-year monsoon period. The remainder of the 10,000 year period is expected to be a glacial-transition period.

Table 2.1 Summary of future climate states and their present-day analog sites as forecasted by the YMP (Bechtel SAIC 2004a).

Climate State	Duration	Analog Site
Inter-Glacial	400 – 600 years	Current Site Conditions
Inter-Glacial with Increased Summer Monsoon	900 – 1,400 years	Upper Limit: Sonoran/Chihuahuan Desert (Nogales AZ, Hobbs NM) Lower Limit: Current Site Conditions
Glacial Transition	Remainder of 10,000 year period	Upper Limit: Eastern Slope of the Cascades (Spokane, Rosalia, and St. John, WA) Lower Limit: Great Basin Desert (Beowawe, NV, Delta, UT)

During the monsoon period, the subtropical high is assumed to move northward, producing a warmer climate with a wetter summer monsoon season, similar to conditions currently observed in the Sonoran and Chihuahuan deserts of southern Arizona and New Mexico. The glacial transition period is expected to be wetter and colder than present-day conditions. Three sites on the eastern slope of the Cascade Mountains were selected as upper-limit analog sites for the glacial transition period. These sites are under greater influence of the polar front and in the rain shadow of the Cascades. The lower limit conditions for the glacial-transition period are based on Great Basin Desert sites.

The YMP future climate states are considered beliefs of subject matter experts based on observed data. Based on the speculative nature of the estimates and lack of credible alternative views, the YMP climate regime durations are adopted for use in the SA as ranges of a uniform distribution (Table 2.2).

Table 2.2 Duration of future climate states assumed for Frenchman Flat.

Climate State	Adopted Distribution
Inter-glacial (Present-Day Conditions)	Duration_IG U(400, 600 yr)[†]
Inter-glacial with increased summer monsoon	Duration_M U(900, 1400 yr)
Glacial-transition	Duration_GT = 10,000 y – Duration_IG – Duration_M

[†] - Uniform distribution(lower limit, upper limit)

Meteorological Conditions

Site meteorological conditions are inputs to infiltration process models used to evaluate potential changes to the hydrogeologic conceptual model under climate change and to estimate soil moisture contents. Meteorological conditions also guide selection of parameters describing future flora and fauna. The meteorological conditions at Frenchman Flat during future climate regimes were estimated by scaling present-day conditions using the relative changes predicted for Yucca Mountain. Relative changes were estimated by comparing analog sites with current Yucca Mountain conditions (Table 2.3).

Table 2.3 Mean annual precipitation and temperature for current and future climate conditions as assumed by the YMP (Bechtel SAIC 2004b)

Climate State	Location	Mean Annual Precipitation (mm)	Mean Annual Temperature, ºC[†]
Current inter-glacial mean	Yucca Mountain Region	188.5	15.1
Current inter-glacial upper limit	Yucca Mountain Region	265.5	18.2
Monsoon mean	Nogales, AZ; Hobbs, NM	300.5	17.2
Monsoon upper limit	Nogales, AZ; Hobbs, NM	412.5	17.3
Glacial-transition mean	Rosalia, Spokane, St. John, WA	316.1	9.8
Glacial-transition upper limit	Rosalia, Spokane, St. John, WA	431.1	10.2

[†] - Celsius

The relative changes were then used to scale the present-day Frenchmen Flat conditions to future conditions (Table 2.4).

Table 2.4 Mean annual precipitation and temperature for current and future climate regimes for Frenchman Flat

Climate State	Relative Change		Estimated Frenchman Flat Mean Annual Precipitation (mm)	Estimated Frenchman Flat Mean Annual Temperature, ºC
	Precipitation	Temperature		
Present-day	1X	±0	N(123.82, 8.11^2)†	N(15.2)
Monsoon	1.59X	+0.6	N(197, 32^2)	N(15.8, 0.04^2)
Glacial-transition	1.68X	-5.3	N(208, 32^2)	N(9.9, 0.17^2)

†- Normal distribution(mean, variance)

2.2.2 Future Hydrologic Conditions

Future hydrologic conditions are estimated from the results of hydrologic process models using the climatic conditions described above and site specific soil properties. Monsoon climate regime analog sites do not appear to currently have infiltration below the plant root zone (Scanlon et al. 1999). The Hanford Site, an analog site for the glacial-transition period, has been reported to have low recharge rates ranging from 0.2 to 5 mm yr^{-1} (Mann et al. 2003).

2.2.3 Future Ecology

Estimating the ecologic effects of climate change was approached by first attempting to understand the type of change expected for a parameter (i.e., increase, decrease, or no change) given the assumed change in climate. When a parameter was expected to change, the scientific literature was reviewed for data from appropriate analog sites, and quantitative estimates of the expected value and its uncertainty were made. When published literature supporting a new parameter value could not be identified, parameters were selected to bound the range of expected change.

Floral Community

Expected climate change impacts on the floral community are limited on a conceptual basis to the following areas:

- Plant community or species composition of plant associations
- Aboveground net primary productivity of plants (ANPP)
- Allometric structure of plants (i.e., root-to-shoot ratio, rooting depth, root depth distribution)

Primary productivity is the rate of production of plant biomass by the process of photosynthesis. Model plant-soil concentration ratios are generic and are assumed to be unaffected by climate change or changing plant communities. Climate change and ecosystem response are assumed to be instantaneous.

Monsoon Climate Regime

Monsoon climate analog sites with similar MAP and mean annual temperature (MAT) can be found on NTS, but these sites differ in the seasonal distribution of rainfall. Beatley (1974) has reported that *Larrea* is limited to a MAP less than 160 – 183 mm yr^{-1} on NTS. Beatley's data would suggest that a *Coleogyne* association is more likely for a MAP of 197 mm yr^{-1}.

Another source of analog sites for the monsoon period is the Sonoran and Chihuahuan Deserts. *Larrea* communities occur in the Sonoran Desert in areas receiving up to 300 mm yr^{-1} of precipitation (USDA 2007), suggesting that *Larrea* communities may persist at the site during the monsoon climate regime. The Chihuahuan Desert perhaps has a stronger monsoon signature with as much as 70 to 80 percent of annual precipitation falling between April and September (USDA 2007). In contrast, NTS Mojave Desert sites typically receive 40 percent of their precipitation from March to August (USDA 2007). *Larrea* communities also commonly occur at lower elevation sites in the Chihuahuan Desert. Sonoran and Chihuahuan Deserts analog sites indicate that a *Larrea* community may still be present during a monsoon climate regime.

The Sonoran and Chihuahuan Deserts differ most noticeably from Mojave Desert communities by the presence of deep rooted trees including *Prosopis* spp. (mesquite), *Cercidium* spp. (paloverde), and *Acacia* spp. (acacia). However, these trees are most commonly found in drainage ways with higher infiltration, and therefore are not expected on the bajadas near the Area 5 RWMS.

Under the monsoonal climate regime, *Larrea tridentata* is expected to remain as the dominant species surrounding the Area 5 RWMS. The plant community during the monsoonal period is assumed to have the same species compositions as present-day communities with increased primary productivity due to increased water availability.

Glacial-Transition Climate Regime

The glacial-transition climate is expected to be 5.3 degrees Celsius (ºC) colder than present-day conditions and precipitation is expected to increase 1.68 times. The precipitation pattern is also expected to be changed, with increased precipitation occurring in the Winter-Spring period when it can be used more effectively for plant production. A change in the dominant plant alliances and associations is considered likely for the glacial-transition climate regime.

The plant community assumed for the glacial-transition climate regime is based on present-day communities observed at analog sites with similar climatic and soil conditions. The upper limit analog climate sites selected by the YMP are sites in Eastern Washington in the rain shadow of the Cascade mountain range. The Pacific Northwest sites receive more precipitation than 1.68 times present-day Frenchman Flat rainfall, but may provide some indication of the types of plant communities possible. Low elevation areas in this region typically support shrub-steppe communities with Big Sagebrush (*Artemisia tridentata*) as the dominant species (Figure 2.5) or in the past supported the now rare Palouse Prairie, a bunchgrass community dominated by bluebunch wheat grass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*) (Figure 2.6). Lower limit analog sites are Great Basin Desert sites.

Figure 2.5 View of an *Artemisia spp.* shrub-steppe community on the Columbia Plateau of Central Washington (Ginko State Park).

Figure 2.6 View of a remnant of Palouse Prairie, a bunchgrass prairie, in eastern Oregon.

Great Basin Desert shrub-steppe communities occur on NTS, including the *Artemisia* spp. Shrubland Alliance and *Pinus monophylla/Artemisia* spp. Woodland Alliance which occur at colder, wetter, higher elevation sites. *Pinus monophylla* woodlands typically develop on steeper slopes with shallow soils (Ostler et al. 2000). Under wetter conditions, the deeper soils at the Area 5 RWMS will support the growth of grasses which can promote fire. If grass production is sufficient, periodic fires will remove large slow-growing woody species from these environments and favor faster-growing grasses and shrubs. Consequently, the *Pinus monophylla/Artemisia spp*. Woodland Alliance is considered unlikely to develop on the deep soils at the Area 5 RWMS, but might be expected on the steeper slopes and shallower soils of the Massachusetts Mountains to the north (Hansen and Ostler 2003).

No grassland communities currently occur on NTS, but if soil moisture conditions can support sufficient grass production, periodic fire may remove woody shrubs. Palouse Prairie develops on deep loamy soils of the Columbia Plateau and typically receives more precipitation (250 to 750 mm yr^{-1}) than expected for Frenchman Flat during the glacial-transition climate regime. Palouse Prairie seems an unlikely analog given the coarser NTS soils and more arid conditions, but development of a grassland community at the Area 5 RWMS is still considered possible, within the upper limit of precipitation in the glacial-transition climate regime. Over the last century, the sagebrush-steppe of the Great Basin Desert has seen an invasion of *Bromus tectorum* (cheatgrass) that has replaced native bunchgrasses and woody perennial shrubs (Knapp 1996). This trend is also observed on NTS. A grassland dominated by cheatgrass may be another possible future state.

Pearson (1965) found that the aboveground biomass of an *Artemisia tridentata* Shubland was partitioned as 65 percent *Artemisia tridentata,* 6.4 percent *Chrysothamnus viscidiflorus* (green rabbitbrush), and 29 percent grasses and forbs. Boindini et al. (1985) found that *Artemisia tridentata* comprised from 60 to 80 percent of the canopy of an *Artemisia tridentata* Shubland. Grassland communities are assumed to be 100 percent grasses and forbs. As no information is available on the relative probability of these two communities, the life-form composition of the glacial-transition plant community is simulated as a continuous gradation between the two communities. The glacial transition community is divided into three life-forms, sagebrush with *Artemisia tridentata* as the dominant species, other shrubs typified by *Chrysothamnus spp., Krascheninnikovia lanata* (winterfat), and *Grayia spinosa* (spiny hopsage), and grasses/forbs. The fraction of aboveground biomass that is *Artemisia tridentata* is assumed to vary uniformly between 0 (grassland) and 0.8 (pure *Artemisia tridentata* shrubland). The biomass fraction of other shrubs is assumed to be 0.1 times the *Artemisia tridentata* fraction. The grass and forb fraction is calculated as 1.0 minus the total shrub fraction. These distributions simulate a gradation of communities that includes the range of possible future states. The fraction of each life-form present is used to calculate the ANPP.

Primary Productivity

Monsoon Climate Regime

Primary productivity in desert plant communities is strongly limited by the availability of water (Hadley and Szarek 1981; Ehleringer et al. 1991). The seasonal timing of rainfall impacts its utilization by different species in the plant community. During the monsoon climate regime, late summer precipitation is expected to increase relative to Winter-Spring precipitation. Those plant species able to utilize summer rains will differentially benefit during this climate regime. Plants most susceptible to water stress, herbaceous species and shallow rooted woody species, appear most likely to respond to summer precipitation (Ehleringer et al. 1991; Lin et al. 1996). In the Mojave Desert as much as 37 percent of woody perennial ANPP can occur in the fall after late summer rains (Rundel and Gibson 1996). In addition, Mojave Desert communities typically include a summer annual community that is specifically adapted to utilize summer rains.

Aboveground net primary productivity in Sonoran and Chihuahuan Deserts which already experience a monsoonal climate regime is reported to range from 920 to 1,860 kg $ha^{-1}yr^{-1}$ (Whittaker and Niering 1975; Sims et al. 1978a). Conceptually, increasing summer rainfall will increase ANPP, but this increase is likely to be less than if the Winter-Spring rainfall was increased because a limited number of species respond to summer precipitation while nearly all species respond to Winter-Spring rainfall. Specific data to estimate the effect of summer rains on *Larrea* community productivity are not available. Therefore, ANPP and growing season (September to August) precipitation data are used. The range of these data is expected to bound the expected increase in primary productivity occurring during the monsoon climate regime.

Two data sets are available describing shrub ANPP in *Larrea tridentata-Ambrosia dumosa* Shrubland Alliance and growing season precipitation (Rundel and Gibson 1996; Thompson Ramo Wooldridge Inc. [TRW] 1996). Shrub ANPP is assumed to be correlated with growing season precipitation. The correlation between precipitation and shrub ANPP is maintained by using a Bayesian linear regression to probabilistically simulate ANPP.

Three data sets are available describing grass and forb ANPP in *Larrea tridentata-Ambrosia dumosa* Shrubland Alliances and growing season precipitation (Rundel and Gibson 1996; TRW 1996, and Beatley 1969). Grass and forb ANPP is assumed to be correlated with growing season precipitation. The correlation between precipitation and grass/forb ANPP is maintained by using Bayesian linear regression to simulate ANPP from precipitation

Glacial-Transition Climate Regime

The relationship between MAP and ANPP for the glacial transition climate regime was developed from 13 data points for eight sites with *Artemisia* spp. shrub-steppe communities or semi-arid grassland communities from the western United States (Pearson 1965; Webb et al. 1978; Sims et al. 1978a, b; Gholz 1982; Law and Waring 1994; Hansen et al. 2000; Knapp and Smith 2001). Selected grassland communities were limited to those with MAT from 8 to 12ºC and MAP less than 400 mm yr^{-1}. Data from grazed sites was not used. No relationship between precipitation and ANPP was observed for these data and the distribution of ANPP was estimated by resampling with replacement. The simulated mean ANPP data were well fit by a normal distribution with mean 1,130 kg ha^{-1} yr^{-1} and standard deviation of 171 kg ha^{-1} yr^{-1}.

Rooting Depth and Distribution

Monsoon Climate Regime

Precipitation falling during summer months, when PET is at its highest, would not be expected to infiltrate deeply into the soil before ET returns it to the atmosphere. Conceptually, plants utilizing summer rains would be expected to increase shallow roots or lateral roots to withdraw infiltrating water near the surface.

Statistical analysis of plant rooting data for arid ecosystems has shown that only shrub roots show a response to summer-dominated precipitation (Shenk and Jackson 2002). Shrubs (defined as shrubs > 1 m [3.28 ft] in height) growing in arid environments with summer-dominated precipitation tended to have shallower roots than shrubs in environments without seasonal precipitation variation or winter-dominated precipitation, while other life-forms including shrubs < 1 m [3.28 ft] in height were unaffected (Shenk and Jackson 2002). Given the apparently weak relationship between plant root depth distribution and summer-dominated precipitation, plant rooting depths are assumed not to change for the monsoon climate regime.

Root biomass can be expected to increase relative to aboveground biomass in environments where water or nutrients are limited. In a global study of major terrestrial biomes, Jackson et al. (1996) found that tundra, cold deserts, and grasslands had the largest root-to-shoot ratios. Tundra and cold deserts are environments with limited water and nutrient availability. Shenk and Jackson (2002) reviewed the relative size of roots to aboveground plants as reported in the literature and concluded that grass and forb root-to-shoot ratio decreases with increasing MAP and PET. The data for woody plants (i.e. shrubs, semi-shrubs, and trees) was equivocal with a weak increase in root-to-shoot ratio with increasing MAP.

Conceptually, increasing precipitation should increase water availability, which should reduce root-to-shoot ratio. However, the data for a broad range of environments appear weak. Therefore, root-to-shoot ratios are assumed not to change for the monsoon climate regime.

Glacial-Transition Climate Regime

Rooting depths are determined by plant genetics and environmental factors including water, oxygen, and nutrient availability. The glacial-transition climate regime is expected to change both the plant association and soil water content, so changes in rooting depths and distributions are possible. Maximum rooting depths were selected as the maximum value found in the literature for the three different life-forms. The selected values were 2.48 m (8.1 ft) for sagebrush (Hampton 2006), 2.93 m (9.6 ft) for other shrubs (Hampton 2006), and 2.7 m (8.8 ft) for grasses (Canadell et al. 1996).

The SA model describes the plant root density with depth using the fraction of plant roots below a given depth, F:

$$F = \left(1 - \frac{z}{z_{\max}}\right)^{b}$$

where z is the depth, z_{max}, the maximum root depth, and b a fitted parameter. The b parameter for *Artemisia* spp. was estimated by fitting 13 root profiles from the literature. The distribution of the mean of b was simulated by resampling with replacement. The simulated means were well fit by a $N(5.19, 0.71^2)$ distribution. The distribution was truncated at 1.0, which corresponds to a uniform distribution with depth.

The b parameter for other shrubs was fit for 10 profiles from the literature. The 10 b values were resampled with replacement. The means of the simulated data were well fit by an $N(10.03, 2.77^2)$ distribution. Only three depth profiles could be located for grasses. The b parameter for grasses was modeled as an $N(4.17, 0.18^2)$ distribution.

The data for *Artemisia spp.* and grass root-to-shoot ratio are sparse. The *Artemisia spp*. root-to-shoot ratio was modeled as a U(0.38, 1.8) distribution. The single grass value was modeled using the present-day distribution. The other shrubs root-to-shoot ratio was estimated by resampling with replacement using five data points from the literature. The data were well fit by a N(1.47, 0.55^2) distribution.

2.3 Facility Features Supporting Assurance Requirements

Under 40 CFR 191, the disposal system is required to include features that increase confidence in the long-term compliance with the containment requirements. This section describes features planned for the Area 5 RWMS which meet these requirements. Chapters 3 and 4 describe the results of analyses performed to assess the cost-effectiveness of alternative engineered barriers required to increase confidence in the isolation of waste.

2.3.1 Active Institutional Controls

Active institutional controls are defined by 40 CFR 191 to include access controls, site maintenance, remedial actions, control and clean-up of releases, and monitoring. NTS's national security mission, legacy of aboveground and below ground nuclear testing, and waste disposal operations, require access controls. Access controls are currently in place. Federal ownership of NTS lands and numerous commitments in DOE land-use planning and policy documents ensure that access controls will continue indefinitely. Closure planning documents for the Area 5 RWMS include provisions for inspections and maintenance of passive institutional controls, the landfill cover, and the environmental monitoring system. Closure plans also include provisions for detecting and responding to releases.

Access-Control and Site Security

Located in a remote and sparsely populated region, NTS is an ideal location for sensitive or hazardous national security activities. The U.S. government has committed to oversight and management of NTS into the foreseeable future for the purposes of national security. The NTS Environmental Impact Statement (EIS) (DOE/NV 1996) and Resource Management Plan (DOE/NV 1998a) state a primary mission of NTS is to "preserve the capability to resume underground nuclear testing . . . and accomplish stockpile stewardship and national security missions." Therefore, it is expected that public access will be restricted as long as NTS is an operational Defense Program facility.

Current access-controls and site security features are summarized in the following passage from the *Resource Management Plan* (DOE/NV 1998a):

> NTS is surrounded by government-controlled buffer zones and protected by Security Police officers, mobile patrols, and highly trained emergency response teams. Sensitive areas within NTS use chain-link fencing, protective alarms, closed-circuit television, and secure communications systems. The Nye County Sheriff's Department provides civil law enforcement.

> NTS is a controlled-access area with road access beginning at the Security Station on Mercury Highway, 5 miles (mi) from the U.S. Highway 95 Mercury turnoff. Although a security clearance is not required for entry, access is not allowed without proper identification and an identification badge. Personnel are issued dosimetry badges if entering areas where they might be exposed to radiation levels above background. Security areas within NTS have stringent personnel controls, requiring the appropriate security clearance and an operational need before access is allowed.
>
> The entire perimeter of NTS is not fenced, but it is posted as a restricted area; access is prohibited except at designated entrances. Beyond the perimeter, the BLM and NAFR (Nellis Air Force Range) (now NTTR [Nellis Test and Training Range]) provide buffer zones. Barricades and/or Security Stations control the few roads that access NTS boundaries. Perimeter barricades are checked by security force patrols. (DOE/NV 1998a, page 8-2)

As long as the NTS national security mission continues, access controls will ensure that the public does not have access to the Area 5 RWMS.

Post-Closure Inspections and Maintenance

Post-closure inspection and maintenance activities for the Area 5 RWMS are outlined in the Integrated Closure and Monitoring Plan (ICMP) (BN 2005a). The final inspection and maintenance strategy will be presented in the post-closure care plans for the Area 5 RWMS. Inspection and maintenance requirements for the 92-ac LLMU will require compliance with RCRA requirements for the closure of the Pit 3 MWDU.

The operational inspection program has requirements for environmental monitoring equipment, fire protection systems, safety and emergency equipment, security devices, and operating or structural equipment that are critical to prevent, detect, or respond to human health or environmental hazards. Records will be used by RWMS personnel to ensure inspections are conducted according to established schedules.

Post-closure inspection and maintenance will be minimized to the extent possible by the design of the disposal unit and closure cover system, and the additional site security measures. Post-closure inspections will include:

- General facility inspection
- Boundary monument inspection
- Warning sign inspection
- Cover inspection
- Run-on/runoff inspection

During each inspection, any changes in the condition of the closure cover, vegetation, or fenced area will be documented [Title 40 CFR part 265.310(b)(1)]. Specific changes noted on the current condition of the cover include, but are not limited to, trash and debris within the fenced compound, animal burrows or nesting activity, and erosion of the cover.

Maintenance activities will be based on inspection results. Custodial maintenance or repair actions may include: repair of fences; replacement of warning signs; re-establishment of location control monuments; removal of unwanted vegetation; reconstruction of slopes, cover, or embankments.

All repair work to the cover will ensure that the integrity of the cover and design is maintained "as built." For RCRA-regulated disposal units, if cover repair requires modifications of the closure cover design, NNSA/NSO will present a formal design modification request to the NDEP prior to making the design modification.

Closure and post-closure monitoring documentation will be maintained in the Area 5 RWMS files and at the NNSA/NSO Technical Library in North Las Vegas. The files will be available for public inspection and review upon request.

Emergency Response

Except for extraordinary events, the site access restrictions, closure cover design, post-closure inspections and preventive maintenance are expected to mitigate the need for emergency release response during the active control period. NTS environmental surveillance and site-specific monitoring programs are designed to detect conditions indicating a potential containment breach. After detection, further investigation may be necessary to confirm site conditions and to assess the scope and nature of the problem. The type and level of response will depend on the scope and nature of the problem and the hazards that must be addressed to implement the response safely. The response may include several phases of activity including quick containment measures and longer-term construction projects. NTS has on site capacity to address many types of emergencies rapidly and is likely to maintain such capacity while active DoD and DOE operations remain.

2.3.2 Monitoring

An integrated closure and monitoring plan has been developed for the Area 5 RWMS (BN 2005a).

The Area 5 RWMS monitoring system consists of a combination of direct monitoring of radionuclides released from the disposal system as well as monitoring transport mechanisms, which could lead to the release of radionuclides to the accessible environment. The monitoring system consists of the following elements:

- Vadose Zone Monitoring
- Groundwater Detection Monitoring
- Radon Monitoring
- Meteorology Monitoring

- Biota Monitoring
- Subsidence Monitoring
- Air Monitoring
- Soil Gas Monitoring at GCD borehole 5 (U5RWMS05U)

Current monitoring locations are shown in Figures 2.7 and 2.8. The monitoring program will be applied to the entire Area 5 RWMS including T04C.

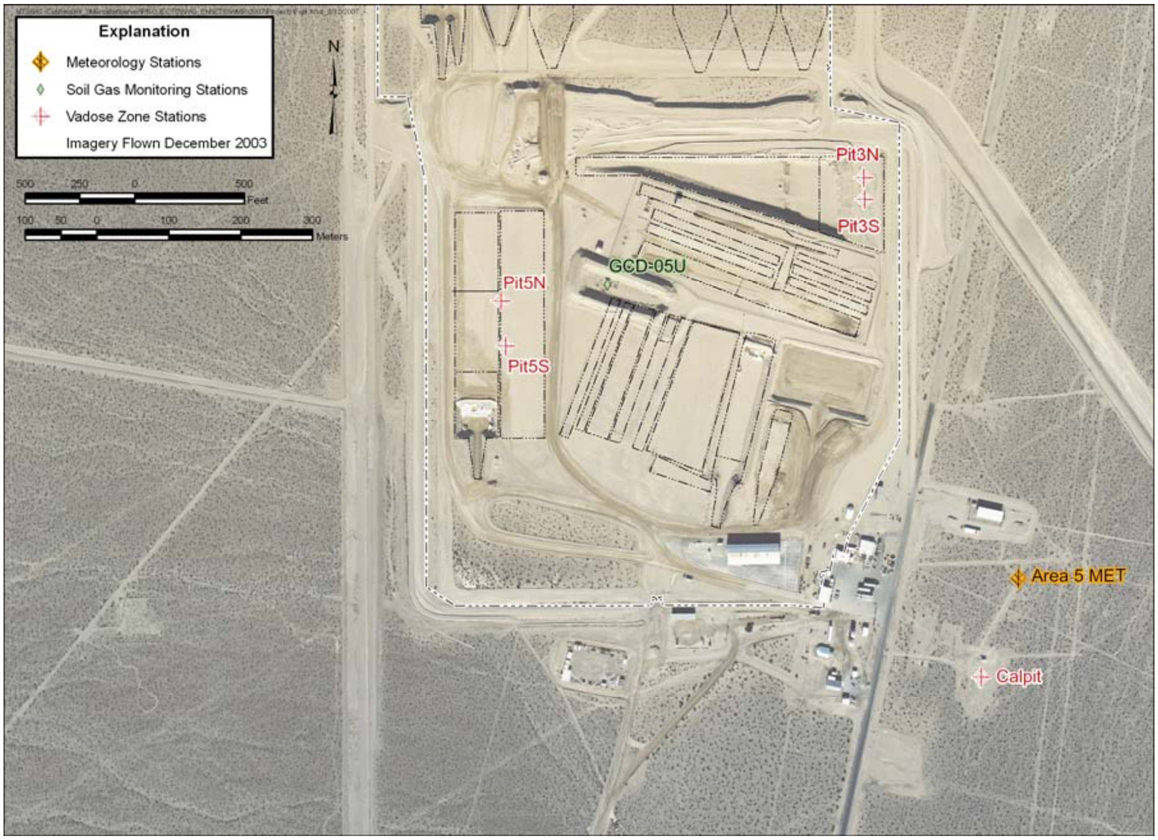


Figure 2.7 Meteorology, soil gas, and vadose zone monitoring stations at the Area 5 RWMS

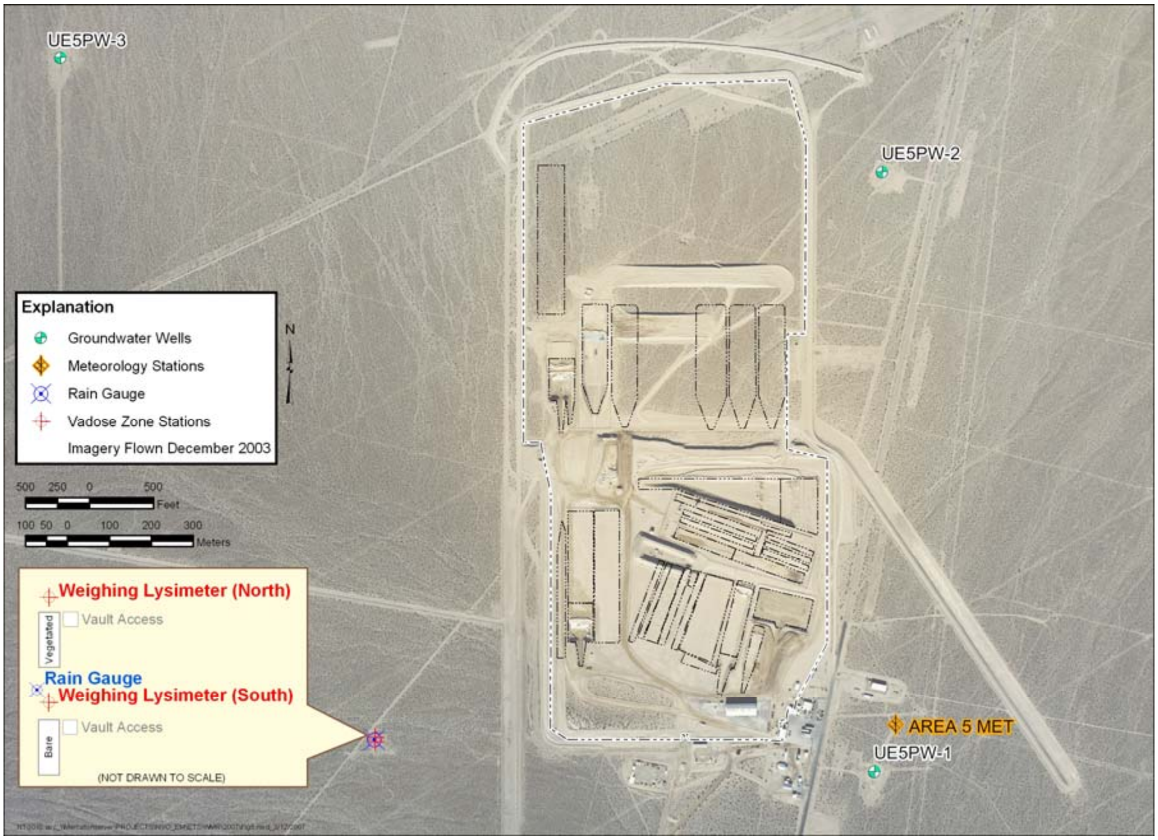


Figure 2.8 Groundwater wells, weighing lysimeters, rain gauge and other monitoring stations near the Area 5 RWMS

Vadose Zone Monitoring

Vadose zone monitoring is conducted to confirm the key assumption of no downward pathway, to detect changes in system performance, and establish baseline data for long-term monitoring. The vadose monitoring system consists of weighing lysimeters and instrumented operational covers. Two precision weighing lysimeters have been in continuous operation since March 1994. One lysimeter is vegetated with native plant species at the approximate density of the surrounding desert, and the other lysimeter is kept bare to simulate operational covers. The lysimeters are capable of measuring changes in storage of ±800 grams or ± 0.1 mm of water. Additionally, both lysimeter soil columns are instrumented with time domain reflectometers (TDR) for volumetric water content and heat dissipation probes (HDP) for matric potential and soil temperature measurements.

Three operational covers and one pit floor are instrumented with TDR probes. Sensors are installed throughout the cover profile to a depth of 1.80 m (6 ft). HDP arrays are also installed in two of the operational covers. Vadose zone sensors are typically read once a day.

Groundwater Monitoring

Groundwater monitoring has been conducted for a suite of radiologic and chemical constituents at the three wells surrounding the Area 5 RWMS since 1993. The wells have been sampled semi-annually for RCRA compliance and biennially as part of the site-wide groundwater monitoring program. Water table elevation measurements taken at the three wells surrounding the RWMS, as well as neighboring wells, indicate the uppermost aquifer is approximately 236 m (775 ft) below ground surface and is essentially flat, with little to no appreciable groundwater flow.

Meteorology Monitoring

Detailed meteorological data are collected at the Area 5 RWMS. Measurements include: precipitation, air temperature, relative humidity, wind speed and direction, barometric pressure and incoming solar radiation. Hourly data are recorded. These basic meteorological parameters are required to quantify the exchange of water and heat between the soil and atmosphere. Meteorological measurements are taken to (1) confirm the RWMS is sited in an arid environment (2) be used as input for process level models, and (3) refine PA/CA parameter distributions.

Subsidence Monitoring

Subsidence has been formally monitored since 2000. Subsidence occurs most commonly in recently filled disposal units, especially between the trench wall and the waste stack where soil backfill may not be completely compacted. Subsidence monitoring ensures subsidence features are repaired to maintain the integrity of the closure cover.

Air Monitoring

Air particulate samples are collected weekly at two stations surrounding the Area 5 RWMS using glass fiber filters. Air particulate samples are screened for gross alpha and gross beta activity weekly. Monthly composites are analyzed by gamma spectrometry for gamma-emitting radionuclides and by radiochemical analyses for americium (Am) and plutonium (Pu).

Atmospheric moisture is collected and analyzed for tritium (^{3}H) at two stations. Tritium samples are collected over a two week period. Tritium acts as a conservative tracer and therefore is an excellent indicator of volatile radionuclide migration from waste cells.

Soil Gas Monitoring

Soil gas sampling for ^{3}H has been conducted approximately annually at GCD borehole 5 since 1990. GCD borehole 5 has a large ^{3}H inventory (~ 8.1E4 teraBequerel [TBq] at time of disposal). GCD borehole 5 has the same approximate geometry and is located near the 40 CFR 191 regulated GCD boreholes and therefore is a direct performance analogue for the 40 CFR 191 regulated GCD units.

Biota Monitoring

Vegetation growing on and around waste disposal units is periodically sampled. Vegetation sampling provides a direct measure of radionuclide transport through plant uptake. Due to its high mobility, ^{3}H is the primary target analyte, although other radionuclides are often included in the analysis suite. Small burrowing animals also are collected periodically and analyzed for radionuclides.

Radon Flux

Although significant radon flux is not expected for T04C in the near-term, the dose from ^{222}Rn progeny is important for long-term performance. Radon flux measurements are taken at other locations within the Area 5 RWMS, which have the highest expected present-day fluxes, to provide supporting data for volatile radionuclide transport calculations.

Post-Closure Monitoring

Monitoring data will be evaluated and compared on an annual basis against PA/SA model assumptions to confirm conceptual and parameter assumptions are not changing.
Included in these evaluations will be recommendations for changes in frequency or addition/deletion of monitored parameters.

2.3.3 Passive Institutional Controls

Passive institutional controls are defined by 40 CFR 191 to include markers, public records and archives, government ownership, land- and resource-use policies. Land-use policies for NTS reflect the need to control residual radioactive contamination from past activities. Inactive facilities and areas known to be contaminated and require access controls are fenced and posted with warning signs. In remote areas where personnel rarely work, appropriate posting at the perimeter boundary as well as access roads to the contaminated area may be substituted for fencing. Further program enhancement is accomplished by following the Integrated Safety Management guiding principles and core functions (DOE/NV 1998c, page 9-8)

Markers, Signs and Fencing

Classified Trench 4 is already marked by concrete boundary markers at its four corners. Although these markers may be buried during final site closure, intruders may still detect their presence and be alerted to the potentially hazardous nature of the site. Concrete boundary monuments with metal placards warning of buried TRU wastes are planned for the four corners of T04C at final closure. GCD boreholes with regulated TRU waste in close proximity to T04C will also have monuments.

Fencing with warning signs every 100 feet will be installed around the Area 5 RWMS. Regulated units within the Area 5 RWMS that have specific posting requirements include FFACO-regulated units (CAU 111), TSCA-regulated asbestiform disposal units, and LLW disposal units which must be posted as buried radioactive materials areas. These controls will indicate the presence and hazardous nature of the site after the end of active institutional controls.

Land Ownership and Land Use

NTS occupies federally owned public lands that are administered by the Department of Interior and Bureau of Land Management (BLM). Most of the land surrounding NTS is also owned and controlled by various agencies of the federal government (Figure 2.9).

DOE has jurisdiction of NTS through withdrawals under public land laws, including mining and mineral leasing laws through the public land orders, and a memorandum of understanding (NNSA/NSO 2006). In 1983, BLM reviewed the four land withdrawals comprising NTS. BLM concluded the lands were still being used for the purposes withdrawn, but recognizing the potential end of testing, recommended another review in 100 years. (NNSA/NSO 2006, page 36). Although the agency with jurisdiction over NTS land may change, federal responsibility for NTS is expected to continue in perpetuity. There are currently no plans to remove institutional controls placed on lands within NTS boundary.

Public Records

NNSA/NSO has entered into the FFACO with the DoD and the state of Nevada (State of Nevada et al. 1996). This agreement specifies a process for the identification, remediation, and closure of CAUs on NTS. The FFACO land-use restrictions for CAUs near the Area 5 RWMS are part of the active institutional control strategy for the Area 5 RWMS. Anticipated FFACO land-use restrictions in Frenchman Flat have implications for future public access to the area for drilling water wells, and for the likelihood of human intrusion at the site.

The Area 5 RWMS is within the Frenchman Flat UGTA CAU. The UGTA CAUs are identified as Restricted Use Zones in local directives. The corrective action strategy for UGTA is based on a corrective action process where boundaries are identified for each CAU that encompass geographic areas containing groundwater that may be unsafe for domestic and municipal use. Each UGTA CAU will be evaluated through data collection, evaluation and numerical modeling leading to predictions of the maximum extent of groundwater flow and contaminant transport from underground testing of nuclear weapons. The vertical and horizontal extent of contaminant migration will be predicted for each CAU. The contaminant boundary will be used to negotiate a compliance boundary between NNSA/NSO and the Nevada Department of Environmental Protection (NDEP). With establishment of a regulatory compliance boundary, remedial actions will be evaluated and a 5-year monitoring plan will be developed to assess adequacy of CAU surveillance. If the monitoring plan is found acceptable, a closure plan for the CAU will be developed followed by a long-term closure monitoring program.

The expectation of the UGTA is that protection of human health and the environmental will be based on controlled access to areas of contamination (areas within the compliance boundary). As part of the FFACO process land use restriction forms and maps are approval by NDEP and become official records for documenting sites with remaining contamination after closure. NNSA/NSO, BLM and the U.S. Air Force will maintain use restriction records as long as the land is under their jurisdiction.

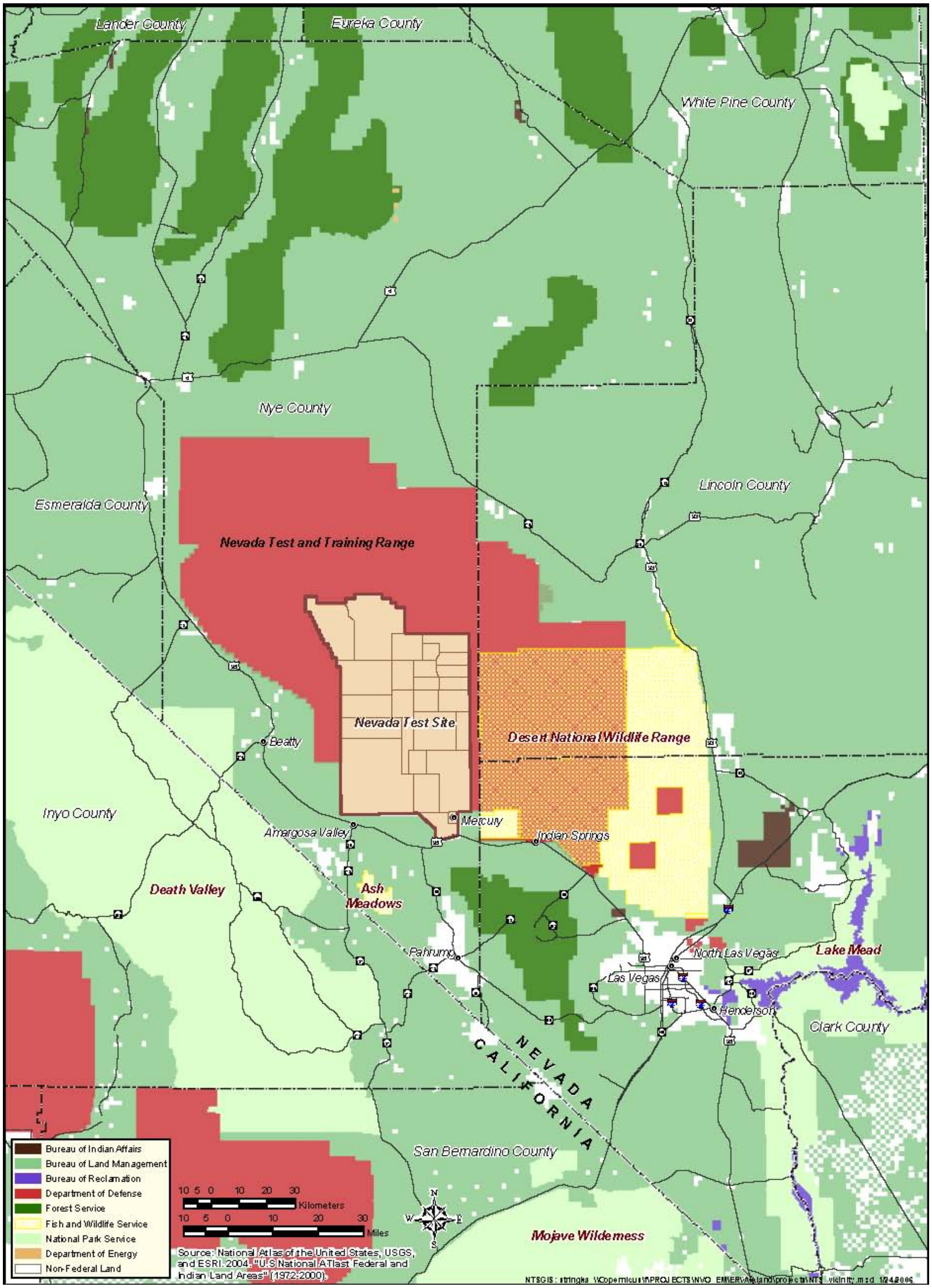


Figure 2.9 Ownership of lands surrounding NTS

Current results are inconclusive whether the Area 5 facility will be included in the contaminant and compliance boundaries associated with a cluster of underground tests in northern Frenchman Flat. The model boundaries are expected to be close to the Area 5 RWMS and the Assistant Manager for Environmental Management, NNSA/NSO, has administratively agreed that the facility will be included within the contaminant and compliance boundaries for the Frenchman Flat CAU 98.

The land-use restrictions will prohibit public access to contaminated groundwater within the NDEP compliance-negotiated boundaries for 1,000 years. Land-use restrictions will ensure that the member of public is farther than at the 100-m (330-ft) site boundary and will reduce the likelihood of releases caused by inadvertent intrusion.

Public records of T04C will be recorded as part of final closure of the site and compliance with the FFACO. Final closure of the Area 5 RMWS under the FFACO requires that a survey plat of the site include the location and dimensions of all disposal units be submitted to NDEP. Land-use restrictions for the site will also be recorded in the FFACO and the NTS Information Management Systems databases.

Federal Land Use and Long-Term Stewardship Policies

Numerous government policies for NTS land-use and long-term stewardship written to manage resources and provide protection from residual radioactive contamination provide another assurance of continuing institutional control. The NTS EIS (DOE/NV 1996) defined NTS land uses for planning purposes. The Area 5 RWMS is designated as a "Waste Management Site" and is managed through a comprehensive waste management program in accordance with pertinent DOE Orders, policies, and federal regulations. Closure requirements are designed to help protect future users of the property from exposure to the contaminants in waste.

The NTS Resource Management Plan indicates that the Area 5 RWMS is within a Restricted Use Zone (DOE/NV 1998a). Activities within a Restricted Use Zone must, among other criteria, be "compatible with NTS natural and manmade resources" and there must be a "compelling need (such as security, restricted access, remote location, physical characteristics) that drives the project to be located within the security boundary of NTS."

Processes and permits that ensure land-use plans are enforced during the period of active institutional control include:

- FFACO land-use restrictions for the CAU 98 (Frenchman Flat Underground Testing Area) and CAU 111 (Area 5 RWMS Shallow Land Burial Trenches).
- NTS excavation permits
- NTS radiological work permits
- State of Nevada groundwater well permits
- *National Environmental Protection Act* (NEPA) checklist reviews and compliance for planned NTS activities

The U.S. government's commitment to the long-term environmental stewardship of NTS while accomplishing agency missions has been stated in many planning and policy documents including:

- DOE Policy P 430.1 Land and Facility Use Planning (DOE 1996)
- Accelerating Cleanup: Paths to Closure (DOE 1998)
- Accelerating Cleanup: Paths to Closure, Nevada Operations Office (DOE/NV 1998c)
- From Cleanup to Stewardship (DOE 1999b)
- NTS Resource Management Plan (DOE/NV 1998a)
- Performance Management Plan (NNSA/NSO 2002)
- U.S. Department of Energy, Nevada Test Site, Environmental Management, End State Vision (NNSA/NVO 2006)

The DOE's policy is to manage its *"land and facilities as valuable natural resources, with stewardship based on principles of ecosystem management and sustainable development…The goal of NTS ecosystem management is to accomplish the DOE/NV missions of national security, EM (Environmental Management), technology diversification, energy efficiency and renewable energy, and NTS stewardship while at the same time, sustaining the health and biological diversity of NTS ecosystems."* (DOE/NV 1998c, page 4-1). Furthermore, "DOE will maintain a presence at NTS to ensure reduced risks to human health and the environment. This long-term stewardship will include passive and active institutional controls, the degree of which will be determined through negotiations between DOE/NV, regulators, Tribal Nations, and stakeholders" (DOE/NV 1998c).

The NNSA/NSO and DOE contractors at NTS must comply with DOE O 450.1, "Environmental Protection Program" (DOE 2003a). The principle objective of DOE O 450.1 is "To implement sound stewardship practices that are protective of the air, water, land, and other natural and cultural resources impacted by Department of Energy (DOE) Operations and by which DOE cost effectively meets or exceeds compliance with applicable environmental; public health; and resource protection laws, regulations and DOE requirements" (DOE 2003a).

The NNSA/NSO Performance Management Plan (NNSA/NSO 2002) is compliant with DOE Policy P455.1 Use of Risk-Based End States (DOE 2003b). Expected future land uses are a driver in selecting acceptable end state conditions and clean-up goals for NTS. NNSA/NSO EM's land management assumptions and framework for Environmental Management activities include:

> "The NTS will remain under federal control in perpetuity as an NNSA test site, and the large buffer zone surrounding the NTS (the Nevada Test and Training Range) is assumed to remain under the control of the U.S. Air Force. There are no plans for transfer of any NTS lands to other agencies or public entities. Access will continue to be restricted to the NTS and the surrounding areas.
>
> For management purposes, NNSA/NV EM activities have been established based on the source of contamination and type of waste requiring management. Environmental Restoration activities within the state of Nevada fall under the

> purview of a formal regulatory agreement, the FFACO. Waste Management activities are governed by the *Federal Facility Compliance Act and Consent Order* (FFCAct) and the *Mutual Consent Agreement* (MCA). A *Joint Low-Level Waste Oversight Agreement* is in place to allow State of Nevada representatives to participate in review and approval processes associated with waste receipt and disposal operations“ (NNSA/NSO 2002, page 5).

The DOE EM End State Vision for NTS (NNSA/NSO 2006) addresses contaminated sites controlled by NNSA/NSO EM. “The long-term end state vision of the NTS is to restore the environment to an extent that will allow the maximum continuation of the National security mission conducted by the NNSA/NSO, the national laboratories and contractors” (NNSA/NSO 2006, page ES-1).

DOE criteria for free release of land may result in an extended federal environmental stewardship role. Because of past activities, including both atmospheric and underground nuclear weapon tests, some land within NTS boundary cannot be released for unrestricted use without remediation. It may not be cost-effective to remediate residual contamination from underground nuclear testing and long-term land-use restrictions may be required.

The NNSA/NSO has programs to ensure compliance with DOE O 5400.5 that limits annual exposure of the public to 0.1 mSv in a year (DOE 1990). DOE O 5400.5 also contains conditions and requirements for unrestricted release of land. Because some of the residual contamination from past nuclear tests is likely to be closed in place, and will persist for many years, portions of NTS (e.g., Yucca Flat and Frenchman Flat) may not meet unrestricted release requirements. Therefore, use restrictions will preclude new rural development, mining permits, groundwater wells, and other intrusive uses, even after DoD and DOE activities cease.

DOE/NV (1998c) projects long-term federal stewardship: “Institutional control of the NTS is assumed in perpetuity at the existing boundaries.” If DOE ceases to exist, it is assumed that “another federal agency will become the landlord....as institutional control of the site is considered an obligation of the federal government and one that is expected to be maintained.”

Although the SA assumes institutional control only will last 100 years in accordance with 40 CFR 191.14 (a), federal stewardship of NTS is expected to last in perpetuity.

Control Effectiveness

Convening a panel of independent SMEs (Black et al. 2001), NNSA/NSO evaluated the effectiveness and probable duration of long-term institutional controls in Frenchman Flat. The SMEs unanimously agreed that a combination of active and passive institutional control would not last for 10,000 years (the elicitation’s target compliance period) because no human institution, government, or political civilization has lasted for this length of time. Instead the SMEs focused on the time frame in which institutional control might be lost. The consensus opinion was that institutional control would be lost within 1,000 years (90% probability), that institutional control has a reasonable chance of lasting about 250 years (50% chance), and that it was very likely to last at least 50 years (90% chance). The SMEs also suggested that 2,000 years is the longest period of time for which institutional control could reasonably be expected to last. The SMEs considered a time frame of 100 to 500 years for institutional control because they expected that it would take this long for sociopolitical will to erode sufficiently for institutional control to cease.

2.3.4 Natural and Engineered Barriers

Natural Barriers

Barriers are defined in 40 CFR 191 as "*any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment*." Previous PAs have identified numerous natural barriers at the Area 5 RWMS including:

- The thick dry vadose zone below the site. The extremely low hydraulic conductivity of the dry alluvium (approximately 1 x 10^{-10} cm s^{-1}) and thickness of the vadose zone (236 - 272 m [774 – 892 ft]) leads to extremely long travel times. The median travel time for water under current conditions has been estimated to be 51,000 years (Shott et al. 1998).
- The thick homogenous alluvium below the site. Contaminants must migrate through a tortuous porous medium rather than through rapidly flowing fractures in rock.
- The nearly flat groundwater table below the site. If any contaminants were to reach the saturated zone, lateral migration to the edge of the controlled area would be extremely slow because of the negligible gradient.
- The extremely dry cover soil conditions. Mean cover volumetric water contents range from 0.058 to 0.079. The low water contents are maintained by high PET and low precipitation.
- The alkaline soil conditions which retard the migration and reduce the solubility of most cationic metals.
- The adaptations of native plants to xeric conditions. Native Mojave Desert plants are able to efficiently withdraw water from cover soil and maintain extremely negative soil matric potentials.
- The low primary productivity of native plants. The present-day Mojave Desert assemblage has an ANPP of only approximately 300 kg ha^{-1} yr^{-1}.
- The shallow rooting depth of native plants. Native plants roots seldom penetrate below the dynamic range of infiltrating precipitation, 2 to 3 m (6.5 to 9.8 ft).
- The shallow burrowing depth of rodents, the most abundant burrowing animals.

Engineered Barriers

Engineered barriers are interpreted to be materials or structures intentionally placed at the site to increase the isolation of the waste from the accessible environment. Engineered barriers already present include the waste containers and the 2.4-m (8-ft) operational closure cover.

Previous PAs have identified a number of alternative barriers that might be expected to provide additional assurance that the requirements can be met (Black et al. 2001; National Security

Technologies [NSTec] 2007). Because all release and transport pathways are upward, barriers that block biointrusion, upward liquid advection/diffusion, gaseous diffusion, and deter human intrusion are obvious choices. Barriers can be categorized as subsurface resistive barriers which resist biointrusion and slow upward advection/diffusion, subsurface intrusion barriers, and surface intrusion barriers. Increasing cover thickness beyond the current 2.4-m (8-ft) operational cover is also considered an engineered barrier.

Chapters 3 and 4 describe evaluations that rank the cost-effectiveness of alternative engineered barriers. Cost-benefit analysis will be used in final closure planning to determine if additional engineered barriers are justified for T04C.

2.3.5 Natural Resources

Disposal systems regulated under 40 CFR 191 must be sited at locations where attractive natural resources are not present. Resources to be considered includes minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems.

Several assessments show that the Area 5 RWMS is not sited near any significant economic mineral deposits, viable petroleum or natural gas deposits, valuable geologic formations, or irreplaceable sensitive water supplies. The Area 5 RWMS is located on an alluvial fan, in an arid, remote, alluvium-filled basin, with deep groundwater. Biological studies show the Area 5 RWMS is not located near unique or sensitive ecosystems.

Gustafson et al. (2007) identified potentially exploitable resources near the Area 5 RWMS that could lead to inadvertent human intrusion after active institutional control ends. They considered sand and gravel, minerals, petroleum, and water. Quality, quantity, availability of better sources, transport costs, and limited local demand are likely to limit commercial extraction of geologic economic resources in the NTS region.

Gustafson et al. (2007) also reviewed examinations of rural land use potential (Case et al. 1984; Richard-Haggard 1983) and concluded "Alternative land uses such as agriculture, grazing, and hunting, do not appear to be potential causes for inadvertent human intrusion."

Sand and Gravel Resources

Although there are sands and gravels in the upper alluvium at the Area 5 RWMS, the quality of the material is poor and the location is far from the most likely sources of demand for roadways, building pads, and other fill structures. Samples of alluvium from excavations in the Area 5 RWMS indicate the shallow gravels are composed of fragments of predominantly pyroclastic volcanic rocks derived from nearby exposures in the Half Pint range. The pyroclastic volcanic rocks are too friable to be suitable for many typical commercial uses. Current existing population centers (Alamo, Beatty, and Pahrump) and major highways (I-95) are far from the Area 5 RWMS. If development were to occur in the Frenchman Flat region in the future, gravel resources are more likely to be extracted from the south side of the basin where the material may be higher quality because carbonate rocks are more prevalent (Gustafson et al. 2007).

Mineral Resources

There is no record of historic mining activities within Frenchman Flat. Four mining districts have been identified on NTS: Calico Hills, Wahmonie, Mine Mountain, and Oak Spring. The nearest recorded mineral deposits are 23 km (14 mi) northwest of the Area 5 RWMS in the Mine Mountain Mining District.

The economic mineral potential of these districts was summarized by Shott et al. (2000). Silver may be present in the Oak Spring District. Potentially economic mineral deposits may remain in the Wahmonie District. Commercial tungsten mining occurred in the Oak Spring District in the 1950s and early 1960s. NTS is considered to have a moderate potential for tungsten skarn deposits. Molybdenum is associated with these deposits. Although these sites may be developed in the future, they are relatively distant from the Area 5 RWMS.

Although there are natural zeolites in some of the volcanic tuffs underlying Frenchman Flat, the likelihood of the Area 5 RWMS being mined for zeolites is very low. Only one of the ten companies that mined natural zeolites in the U.S. in 2005 was located in Nevada, and the U.S. produced less than 3 percent of the world production in 2005. The main domestic uses for natural zeolites are for animal feed, water purification, and pet litter (Virta 2006). There are alternative materials for these products. Many commercial industrial applications use synthesized zeolites for their purity and unique characteristics. Most of U.S. foreign trade in zeolites is in synthetic zeolite products (Virta 2006).

Projections for growth in demand and production of natural zeolites in the U.S. are modest. New products and markets, such as lightweight aggregate for specialty concrete products are in development. Based on recent trends, the U.S. Geological Survey predicts U.S. production and sales of natural zeolites will increase by at least 4 to 5 percent per year for the next 2 to 3 years (Virta 2006).

Natural zeolite resources, however, are not unique to the Frenchman Flat area. There are existing operations in the U.S. extracting higher quality and more accessible material. In the unlikely event that a local market for zeolites would ever develop within NTS, the mid-fan location of the Area 5 RWMS is less likely to be a viable source than volcanic tuffs in alkaline lake deposits or surface outcrops of volcanic rocks with higher zeolite contents.

Petroleum Resources

Petroleum exploration in Nevada has been very limited. Petroleum had been produced from wells in Railroad Valley, approximately 150 km (92 miles) north of the Area 5 RWMS and in the Blackburn Field, Eureka County. The potential for oil and natural gas is rated low for Southern Nye County in two Nevada Bureau of Mines and Geology Reports (Garside et al. 1988; Castor et al. 1990). Four oil and gas exploration holes within 40 miles of the Area 5 RWMS developed before 1992, ranging in depth from 447 to 1,702 m (1,468 to 5,583 ft) depth, were dry holes.

Groundwater and Surface Water Supplies

Pilot wells at the Area 5 RWMS indicate depth to groundwater is about 236 m (775 ft) (BN 2005d). The results from the pilot wells indicate the groundwater is good quality in the immediate vicinity of the Area 5 RWMS. These wells tap the uppermost alluvial aquifer, which is not regionally extensive and is locally impacted by radionuclides in the vicinity of nearby nuclear tests which were conducted below or near the water table. Many corrective action units have been identified in Frenchman Flat. It is anticipated that the Area 5 RWMS will be included inside the boundary of a use restriction area to be established for the Frenchman Flat UGTA CAU 98.

Gustafson et al. (2007) identifies at least three potential uses for groundwater from the aquifer, assuming the aquifer is accessible and there is water in sufficient quantity: agricultural irrigation, commercial geothermal energy development, and human consumption. However, the cost of developing deep wells and pumping groundwater makes these uses unlikely. The nearest spring is Cane Spring, about 14.3 km (8.8 mi) southwest of the Area 5 RWMS. Future settlers are more likely to locate near such surface water resources.

Important Habitats

Unique and sensitive areas of NTS have been identified through biological studies. The Area 5 RWMS is not within an area identified as "important habitat" based on high species diversity, uniqueness, pristineness, or sensitive habitat that would be slow to recover from disturbances (DOE/NV 1998c). The floral community at the Area 5 RWMS is classified as a *Larrea tridentata-Ambrosia dumosa* assemblage, a common community within the Mojave Desert.

Large portions of NTS are within the range of the Western burrowing owl, which is protected by the state of Nevada. There is no evidence that the Area 5 RWMS operations have affected the owls, which often reside in culverts and abandoned conduit pipes. The Area 5 RWMS is also within the range of the desert tortoise, a threatened species protected under the Endangered Species Act, but in an area of relatively low abundance. Activities within tortoise habitat are conducted in accordance with a U.S. Fish and Wildlife Biological Opinion which includes provisions for surveys, relocations, and mitigation. The NTS Resource Management Plan (DOE/NV 1998a) and annual Nevada Test Site Environmental reports provide further information on monitoring and protection programs for flora, fauna, water supplies, and other critical resources of NTS.

Agriculture and Range

Site conditions do not appear to be favorable for intensive agriculture or livestock grazing. There are irrigable soils in Frenchman Flat, but the soils have poor water-retention characteristics. Although, it is technically feasible to produce hay crops such as alfalfa in the

Frenchman Flat basin, the demand for irrigable land in southern Nevada is currently low and likely to remain low in the future. Only 5 percent of the irrigable land in Nevada is in use (Richard-Haggard 1983) probably because the cost of infrastructure and power to extract water makes irrigation economically infeasible. Southern Nevada farming tends to be located near surface water or shallow groundwater supplies.

Mojave Desert plant communities are suitable for livestock grazing, but the low population density and productivity of forage shrubs and annual grasses limits the population of cattle that can be supported. Comparison of the average animal unit month for BLM grazing permits issued in Nevada to the estimated capacity of Frenchman Flat suggests that Frenchman Flat is less productive than average BLM controlled Nevada rangeland. The greatest obstacle to livestock grazing is the lack of surface water resources requiring that deep groundwater be used or water be trucked in. The costs of obtaining water and the low productivity of the Mojave Desert make Frenchman Flat an unlikely site for grazing.

2.3.6 Waste Retrieval

The TRU waste in T04C is packaged in steel 55-gal drums and buried below a 2.4-m (8-ft) operational cover. Final closure may require installation of additional engineered barriers. Nevertheless, the excavation of these materials from near-surface alluvium deposits is technically feasible. The waste containers may eventually degrade and loose their integrity. This may increase the required radiological controls, but containment technologies, remote handling equipment, and personal protective equipment exist that would allow safe retrieval. NNSA/NSO maintains a retrieval plan for wastes disposed at the Area 5 RWMS (NNSA/NSO 2007b).

2.4 Waste Characteristics

Waste characterization requirements have changed significantly since 1986 when TRU waste was buried in T04C. Unclassified records for these waste containers are limited to the generator, volume, and activity of nuclides subject to material controls, and accountability (i.e., fissionable radionuclides).

2.4.1 Regulated Waste Inventory

TRU Inventory

The T04C TRU waste inventory is limited to the 102 containers from Rocky Flats. The waste inventory for these containers is based on a memorandum summarizing a review of the disposal records (SNL 1992). The inventory in the memo has been revised to account for other radionuclides likely present in weapons-grade Pu and highly enriched uranium, but not reported. The Area 5 RWMS Inventory model, v2.021, was used to estimate the inventory at the assumed date of final site closure in 2028 (see Appendix A1).

The TRU inventory consists of 21 m^3 (741 ft^3) of waste containing approximately 5.7E12 Bq of long-lived radionuclides. The TRU inventory is predominately ^{239}Pu throughout the analysis period (Figure 2.10). The TRU waste in T04C is a minor component of the ^{239}Pu disposed at the Area 5 RWMS. The T04C ^{239}Pu inventory represents approximately 16 percent of the ^{239}Pu

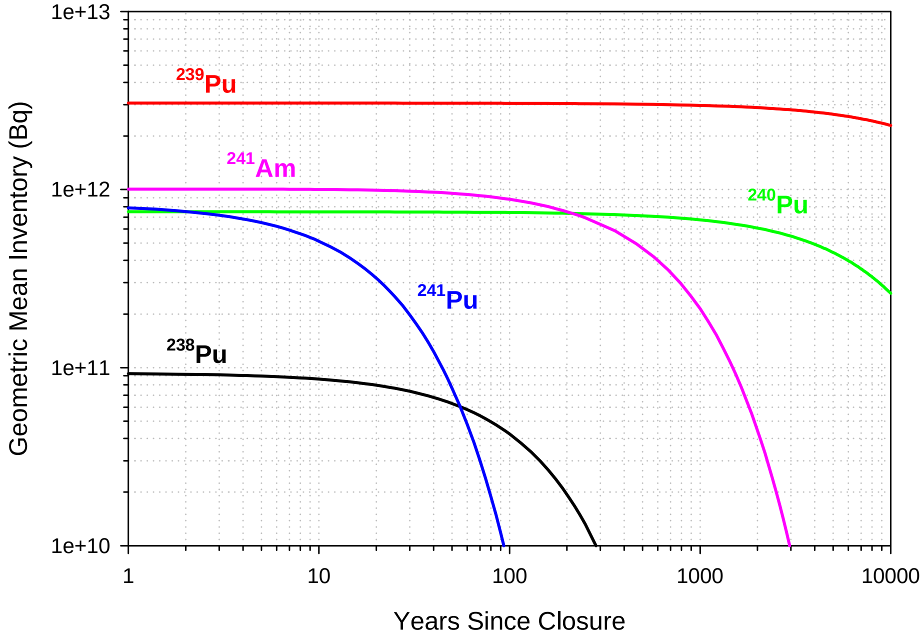


Figure 2.10 Inventory of TRU waste buried in T04C as a function of time.

expected to be disposed by shallow land burial at the Area 5 RWMS by closure and 19 percent of the inventory disposed in GCD boreholes.

Co-Located LLW Inventory

The dose assessment for the IPRs includes the dose from LLW disposed in T04C. This waste is referred to as the co-located low-level waste. Database records for T04C are incomplete. Therefore, the inventory is estimated as the product of the T04C trench volume, corrected for the TRU volume, and the mean activity concentration of pre-1988 low-level waste. The co-located waste inventory was also estimated with the Area 5 RWMS Inventory model (see Appendix A1).

The co-located low-level waste inventory consists of an estimated 4,126 m^3 (1.4E5 ft^3) of waste containing 8.2 x10^{14} Bq of long-lived radionuclides. The inventory is initially predominantly ^{3}H, strontium-90 (^{90}Sr) and cesium-137 (^{137}Cs) (Figure 2.11). After a few hundred years, uranium-238 (^{238}U), ^{234}U, technetium-99 (^{99}Tc), and ^{239}Pu are most abundant. The total TRU nuclide inventory in T04C is dominated by the Rocky Flats TRU waste.

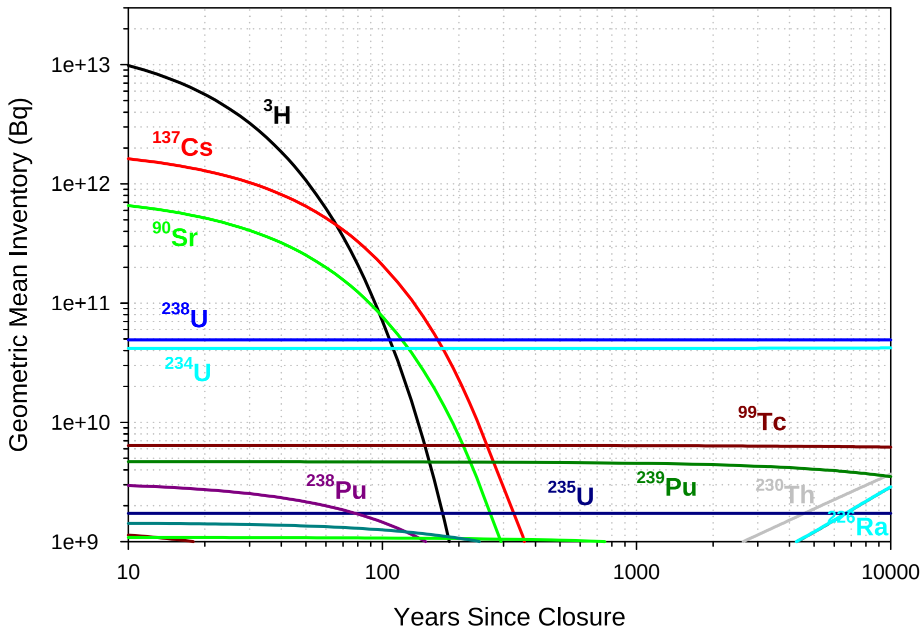


Figure 2.11 Estimated inventory of low-level waste disposed in T04C as a function of time.

2.4.2 Waste Forms and Containers

Waste forms and containers disposed in T04C are poorly known. However, the TRU waste in T04C was generated at Rocky Flats and Rocky Flats TRU waste disposed in GCD boreholes from 1985 to 1987 has been described (Chu and Bernard 1991). Rocky Flats TRU waste during this period was packaged in fiberboard drums, placed in a plastic bag, and overpacked in 55 gal steel drums. The waste forms consist of uranium and plutonium surface contaminated plastic and metal parts used in the manufacturing of nuclear weapons. Specific waste forms are graphite shapes used for casting weapon parts, tooling used to machine weapons components, plastic shapes used during shipment of weapon components, studs from uranium parts, and metal parts from retired weapons.

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3.0 Method of Analysis

The purpose of the SA model is to estimate the 40 CFR 191 regulated end points, which are the normalized cumulative release to the accessible environment and dose to the public. The modeling process follows a logical sequence of activities beginning with interpretation of regulatory requirements and proceeding through site characterization, conceptual model development, mathematical model development, performance assessment modeling, uncertainty analysis, sensitivity analysis, and finally an assessment of the likelihood of meeting regulatory requirements. If uncertainty analysis indicates that the likelihood of compliance is too low, sensitivity analysis can identify parameters for further uncertainty reduction through additional data collection. The SA model was developed from previous iterations of PA modeling completed for DOE-regulated and GCD TRU waste disposed at the Area 5 RWMS (Shott et al. 1998; BN 2001a; Cochran et al. 2001; BN 2006a).

3.1 Overview of Methods

The interpretation of the 40 CFR 191 regulatory requirements is summarized in Chapter 1. The two SA model endpoints are the normalized cumulative release as summarized by a complementary cumulative distribution function (CCDF) and the TEDE to a member of the public residing in the accessible environment.

The data collected to support PA modeling is summarized in the previous chapter and has been discussed in detail in the Area 5 RWMS and the GCD TRU PAs (Shott et al. 1998; BN 2001a, Cochran et al. 2001, BN 2006a). Site characterization data describe the properties and characteristics of environmental media in the model (i.e., waste, alluvium, air, water, biota) and rates of processes. Alluvium above and below the NLFB are assumed to have different water contents. Waste is assumed to have the same properties as alluvium below the NLFB. No new data were developed for the SA except for the description of the TRU waste inventory and data used to support model parameters for future climate regimes.

The conceptual model of site performance is unchanged from the model developed for the low-level waste PA (Shott et al. 1998; BN 2006a). Identifying features, events, and processes (FEPs) that affect long-term performance is an integral part of conceptual model development. The 40 CFR 191 compliance period (10,000 years) is substantially longer than the 1,000-year period used for LLW. The longer compliance period requires that the FEP list be reconsidered for processes that may be important over 10,000 years. Climate change was included as a base case FEP due to the increased length of the compliance period.

Previous PA analyses have indicated that the Area 5 RWMS is well suited for waste disposal and amenable to relatively simple models. An important simplifying feature is that a groundwater pathway is extremely unlikely. In addition, the site is located within laterally extensive alluvial deposits which are relatively homogenous in the horizontal plane. This allows 1-dimensional (1-D) model implementation in the vertical plane.

All radionuclide release and transport pathways are assumed to transport contaminants upward to the land surface and atmosphere. Important transport processes are assumed to be upward liquid advection, diffusion in the liquid and gas phase, plant uptake, and animal burrowing. Nuclides migrating in the liquid phase are assumed to instantaneously precipitate or adsorb on alluvium as predicted by thermodynamic equilibrium constants.

The model solves for the time-dependent radionuclide concentration in the accessible environment. The time-dependent media concentrations are integrated to calculate the cumulative release and multiplied by pathway dose conversion factors to calculate the dose to the member of the public in the accessible boundary. The dose is calculated for an on site residential exposure scenario without agriculture.

3.2 Conceptual Model Development

3.2.1 Important Assumptions

A simulation as complex as the SA makes numerous assumptions: some obvious and some more difficult to identify. Important assumptions are summarized in this section and elaborated upon in the following sections. Important modeling assumptions include:

- Radionuclides are immediately available for release and transport.
- Subsidence will occur, but will have negligible effects on site performance.
- All important radionuclide release and transport pathways are upward to the land surface.
- A groundwater pathway will not occur over the next 10,000 years.
- The upward transport processes can be modeled by a 1-D finite difference equation, with 15 nodes distributed over the approximately 9-m (29-ft) model domain.
- Upward liquid advection and liquid-phase diffusion are negligible above the NLFB.
- Future climate can be forecast from periodic variation in past climate. Biotic communities present under future climate regimes can be characterized from present-day analog sites with similar climate.
- Human-related FEPs are assumed to be limited to present-day conditions.
- The site will be closed with a 4-m (13-ft) monolayer-ET cover.
- The appropriate exposure scenario for representative members of a critical group is exposure of a resident living on the T04C disposal unit. The resident is a commuter that works at a distant site and does not produce any food at the residence.

3.2.2 Features, Events and Processes Affecting Site Performance

Part 191.13 states that the CRs shall be estimated for "*all significant process and events that may affect the disposal system*." Appendix C of Part 191 states that processes or events with less than one chance in 10,000 in 10,000 years or unlikely to significantly change cumulative releases need not be considered.

The Part 191.15 IPRs are different because doses are to be estimated for undisturbed performance through all potential pathways. Undisturbed performance is defined to exclude human intrusion and unlikely natural events.

The minor difference noted above requires that the CR and IPR analysis use a slightly different FEP list. The FEPs included in the SA model were developed from the results of previous PA model development cycles (Guzowski and Newman 1993; Shott et al. 1998; Cochran et al. 2001; BN 2006a). Human-induced FEPs such as land use and intrusion scenarios are based on elicitation of a panel of SMEs (Black et al. 2001). The probability of intrusion, as estimated from the opinions of SMEs, is within a range that would require inclusion of intrusion in calculation of the CRs. Intrusion is explicitly excluded from the IPRs, so FEP lists for the two endpoints are the same except that human intrusion is excluded from the IPR analysis.

Natural FEPs in the SA model that influence radionuclide release and transport are:

- Existence of a NLFB above which no liquid phase transport (i.e, advection and diffusion) occurs due to low water content
- Upward liquid advection below the NLFB
- Liquid-phase diffusion below the NLFB
- Precipitation/dissolution of solutes
- Adsorption on solid surfaces
- Gas-phase diffusion
- Animal burrow excavation and collapse
- Plant uptake, translocation, and senescence
- Radioactive decay and ingrowth
- Climate change
- Changing soil moisture contents in response to climate change
- Changing water potential gradients in response to climate change
- Changing primary productivity in response to climate change
- Changing flora and fauna composition and characteristics (i.e. root allometry, burrow excavation rates, and depth distributions) in response to climate change

Decay, collapse, and settlement of waste leading to subsidence is assumed to occur, but has no identified consequences for simulations with the monolayer-ET cover and is not explicitly included in the base case model.

Human-induced FEPs include:

- Establishment of a rural community of commuters within Frenchman Flat
- Drilling for groundwater

Irrigation, although possible, is considered too unlikely due to the cost of obtaining water from deep groundwater. Basement construction is eliminated based on the low frequency of basements in Southern Nevada, 1 per 100 residences, low probability of an on site residence, and the low consequences expected for a 4 m (13 ft) cover.

3.2.3 Waste Source Term

The Rocky Flats TRU waste is believed to be packaged in fiberboard drums, overpacked in 55 gal steel drums. The suspected waste forms are surface contaminated plastic, metal, and graphite.

Rather than explicitly account for the uncertainty in the performance of waste containers and forms, a conservative bounding assumption is made. All radionuclides are assumed to be immediately available for release and transport in a soil-like form for the CR and IPR analyses. One exception is ^{222}Rn which is assumed to be fractionally released to the air-filled pore space. The fraction released is described by the radon emanation coefficient, a stochastic model parameter selected to span a large range of waste forms.

The suspected waste components, fiberboard, plastic, metal, and graphite are insoluble and not expected to enhance transport. Given the dry oxic conditions in the vadose zone, these waste forms are not expected to generate significant degradation products that could enhance transport.

3.2.4 Subsidence

Subsidence of T04C is likely to occur over time as voids in waste containers and between waste containers fill in, as waste and waste containers decay, and as waste and soil backfill compacts. A previous analysis has estimated the extent, timing, and potential consequences of subsidence for the Area 5 RWMS (DOE/NV 1998b). The maximum subsidence predicted for classified materials trenches was 2.4 m (8 ft). By the end of the 100-year institutional control period, wooden boxes and steel drums are expected to be 75 percent or more degraded and steel boxes 20 percent degraded. The most significant consequences of subsidence are expected to be exposure of waste at the ground surface and enhanced infiltration in subsidence depressions.

Subsidence is not expected to have any consequences for radionuclide release and transport. Most subsidence is expected to occur during the period of active institutional control and will be repaired. In addition, the planned cover thickness, 4 m (13 ft), is expected to be sufficient to prevent waste exposure based on the conclusions of SMEs reviewing subsidence consequences (DOE/NV 1998b). The 4-m (13-ft) cover will also remain above grade after subsidence, preventing storm water run-on, and minimizing increases in infiltration.

3.2.5 Radionuclide Transport Pathways

Multiple natural FEPs operate to transport radionuclides upwards from the waste to the land surface and atmosphere. Radionuclides reaching the land surface or the atmosphere are assumed to be in the accessible environment and included in the calculation of the cumulative release. The surface soil and atmospheric concentrations are also used to calculate the dose for the member of public.

The conceptual model assumes that the following FEPs are operating to release and transport radionuclides:

- Existence of a boundary, the NLFB, above which no liquid phase transport occurs, due to the disconnected state of the soil pore water
- Upward liquid advection below the NLFB of soil pore water driven by the strongly negative matric potentials maintained at the surface by ET
- Liquid phase diffusion below the NLFB of dissolved solids, driven by the concentration gradient between waste and the surface
- Precipitation/dissolution of solutes, assumed to be in thermodynamic equilibrium with a solid phase as described by the solubility constant (K_{sp})
- Retardation of solute transport by adsorption on solid surface, as described by a distribution coefficient (K_d)
- Gas phase diffusion of volatile species, driven by the concentration gradient between the waste air-filled pore space and atmosphere
- Animal burrow excavation with deposition of spoils on the surface, with subsequent collapse and infilling with overlaying soil
- Plant radionuclide uptake, translocation to aboveground plant tissue, and deposition in surface soil after senescence and decay
- Radioactive decay and ingrowth
- Resuspension of radionuclides in soil to the atmosphere and advection off-site

This conceptual model of radionuclide transport has been successfully implemented in PA models for the Area 5 RWMS, the GCD boreholes, and the Area 3 RWMS. These models have been used to support DOE-approved PA/CAs for the Area 3 and Area 5 RWMS and for a 40 CFR 191 PA for the GCD boreholes (Shott et al. 1998, 2000; BN 2001a, 2006a; Cochran et al. 2001).

3.2.6 Climate Change

Three climate regimes are forecast for the next 10,000 years for the Area 5 RWMS. Present-day conditions are assumed to persist for 400 to 600 years. A monsoon period with increased summer precipitation and MAT is assumed to follow for 900 to 1,400 years. The remainder of the compliance period is assumed to be a glacial-transition period with colder temperatures and increased precipitation. These changes are assumed to occur instantaneously, but the timing is assumed to be uncertain (Figure 3.1).

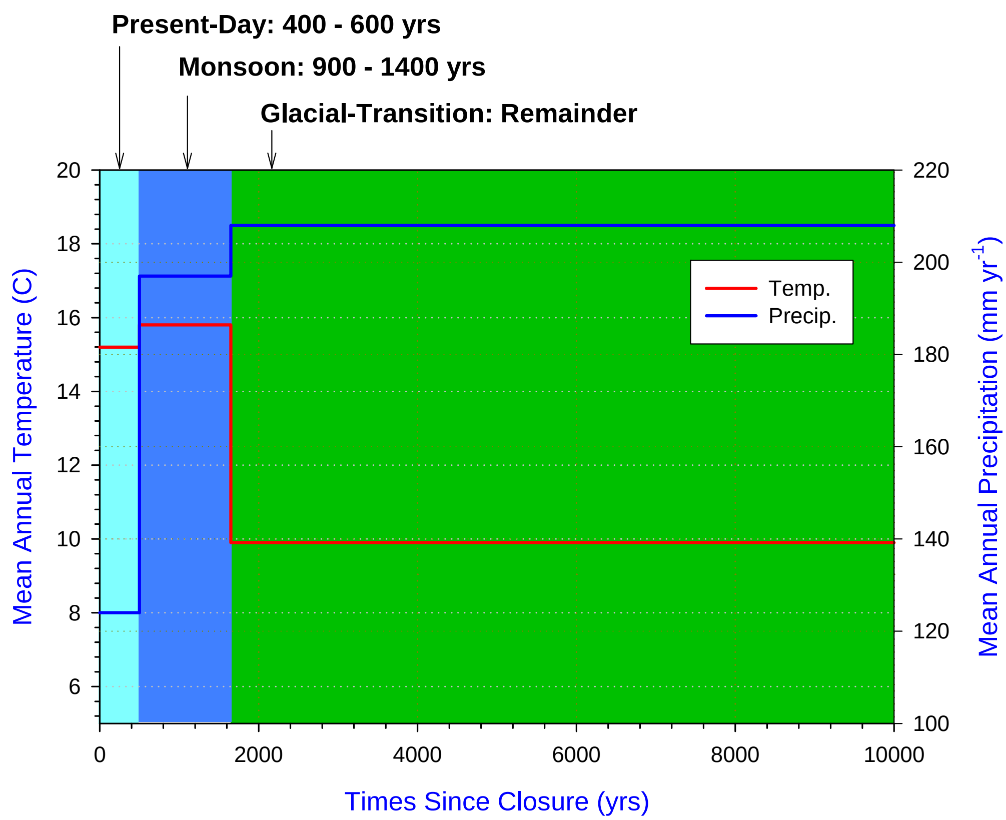

Figure 3.1 Conceptual model of future climate sequence.

Hydrologic Response to Climate Change

Current hydrologic conditions with negligible infiltration below the plant root zone are assumed to persist as long as the present-day climate continues. During the monsoon climate regime, precipitation will increase during the summer months. The increasing temperatures expected for the monsoon climate regime, high summer temperatures, and increased plant growth in response to increased precipitation are all assumed to work together to maintain high ET during the monsoon climate. Therefore, hydrologic conditions during the monsoon climate regime are assumed to be the same as present-day conditions.

With the onset of the glacial-transition period, colder temperatures and increased winter precipitation are expected to change site hydrology. Future hydrologic conditions were evaluated using the hydrologic process model, UNSAT-H v3.01 (Fayer 2000). Uncertainty in future hydrologic conditions was assessed by evaluating model cases for the mean and 99^{th} percentile MAP. Ninety-year simulations were run using daily precipitation and PET time series developed from NTS data. Mean glacial-transition precipitation was simulated from 46 years of daily precipitation records for 40-Mile Canyon station in NTS Area 30. The MAP for 40-Mile Canyon is 20.9 cm (8.3 in.) compared with 20.8 cm (8.2 in.) forecast for Frenchman Flat during the glacial-transition climate regime. The 99^{th} percentile glacial-transition precipitation was simulated from a 48-year daily precipitation record for NTS Area 12. The

Area 12 data were scaled by 0.907 to give a MAP of 28.3 cm (11.2 in.), equivalent to the 99th percentile expected for the glacial-transition climate regime. Daily PET time series were simulated using 13 years of meterological data recorded at the Area 5 RWMS. Daily air temperatures were reduced by 5.3 ºC to simulate glacial-transition conditions. The UNSAT-H results for the mean and 99th percentile MAP simulations were used to estimate the mean and 99th percentile future vadose zone conditions.

Based on the UNSAT-H simulations, alluvium moisture contents are assumed to increase during the glacial-transition climate regime. Infiltration below the plant root zone is also assumed to occur (Figure 3.2). The onset of infiltration below the plant root zone does not necessarily indicate recharge of the aquifer throughout the basin in 10,000 years. One argument against recharge is that the low water content and thickness of the vadose precludes transport to the water table in 10,000 years. In addition, the chloride accumulation at pilot wells 1 and 3 indicates that complete flushing of the vadose zone has not occurred over the last 95,000 to 110,000 years (Tyler et al. 1996). The historical record suggests that increased water availability does not necessarily lead to complete flushing of the soil column. Upward advection is assumed to end during the glacial-transition period, but a groundwater pathway is still assumed unlikely in 10,000 years.

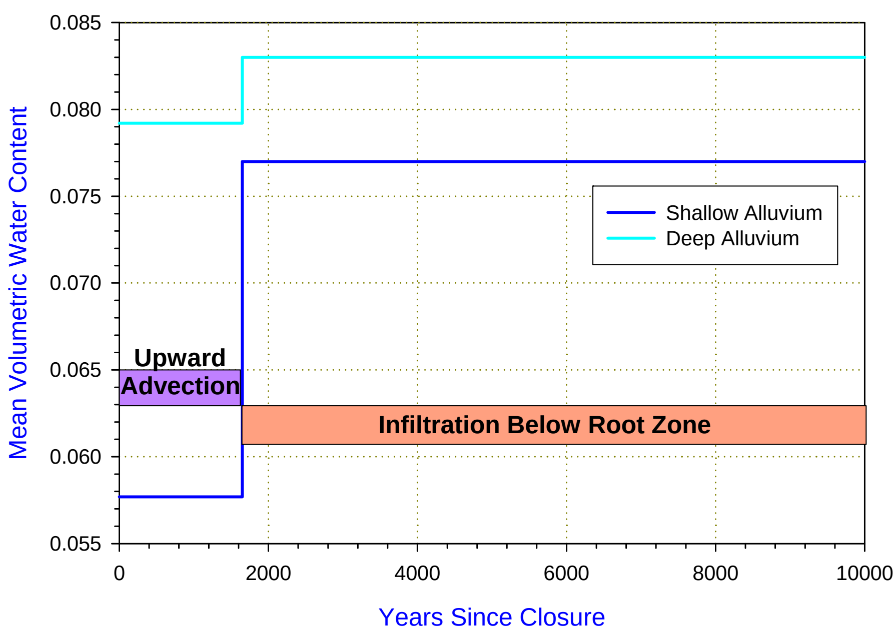

Figure 3.2 Conceptual model of site hydrology under climate change.

Ecological Response to Climate Change

Floral communities are assumed to change in response to climatic conditions. During the monsoon climate regime, the current plant community is assumed to persist, but increased precipitation causes increased primary productivity. An *Artemisia spp*. shrubland or grassland is assumed to be established during the glacial-transition climate regime. Primary productivity and its uncertainty are assumed to increase for future climate regimes (Figure 3.3).

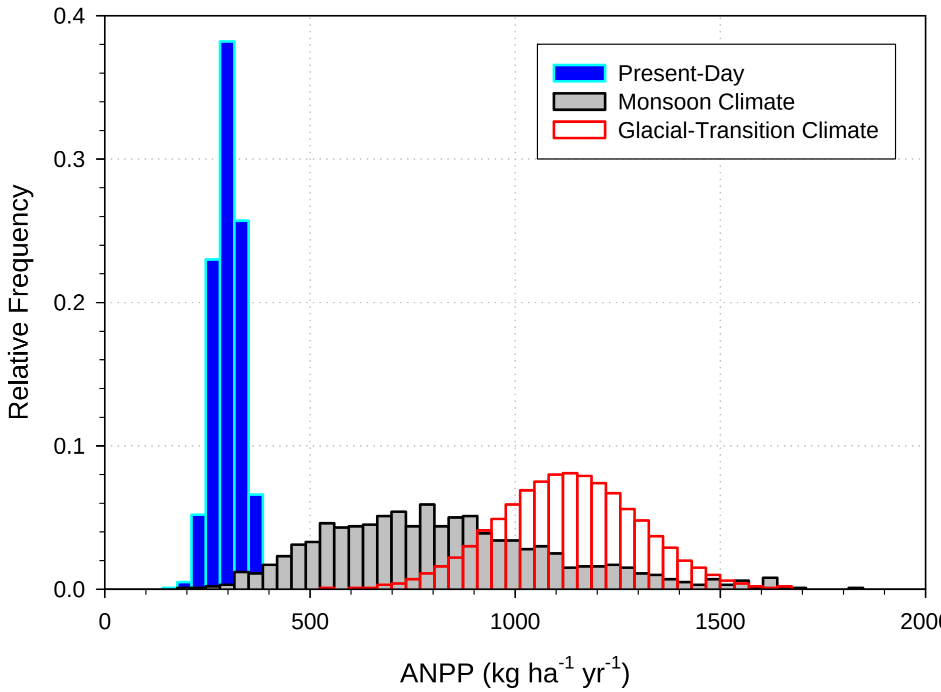

Figure 3.3 Comparison of simulated ANPP for present-day, monsoon, and glacial-transition climate regimes.

The response of the fauna to changing climatic conditions is inherently more difficult to understand. Increased primary productivity and water availability are assumed to increase population densities. Changing climate and floral communities are also expected to change species composition. Due to the increased uncertainty, the fauna are assumed to change with the onset of the monsoon climate regime. The fauna present, their population densities, and burrow characteristics are estimated for *Artemisia spp*. dominated analog sites in the Pacific Northwest. The most significant change is expected to be an increase in the population of large fossorial mammals such as badgers and rabbits. The assumed parameter values for future climate states leads to an increase in animal excavation rates and an increase in uncertainty (Figures 3.4 and 3.5).

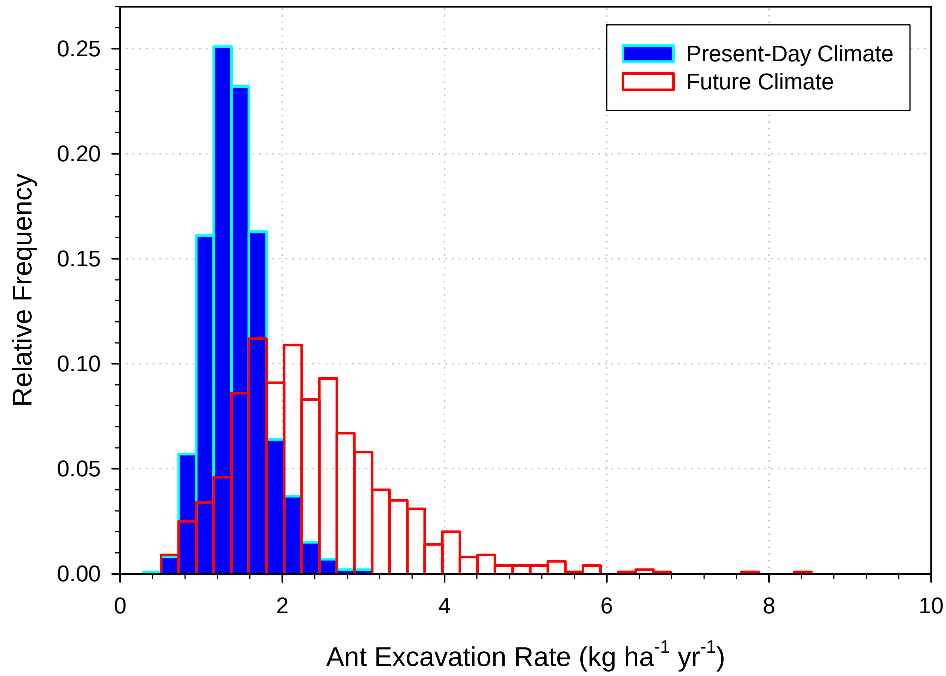

Figure 3.4 Comparison of simulated ant soil excavation rate under present-day and future climate regimes.

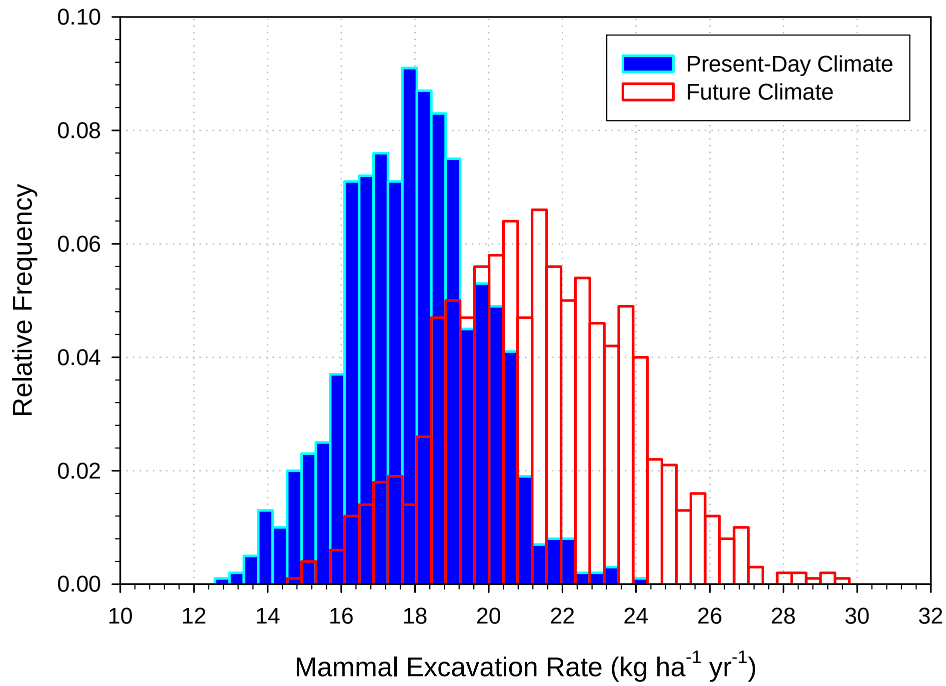

Figure 3.5 Comparison of simulated mammal soil excavation rate under present-day and future climate regimes.

3.2.7 Human Intrusion

The type and frequency of future intrusion at the Area 5 RWMS is uncertain due to lack of knowledge about future economic conditions, resource needs, and technology development. Quantifying and reducing these uncertainties by frequentist methods is not practical, because historical records of intrusion do not exist. One approach to addressing the likelihood of future intrusion scenarios is the informed opinions of SMEs.

A panel of SMEs was convened to develop quantitative models for human intrusion at the Area 5 RWMS (Black et al. 2001). The SMEs specifically considered community development scenarios that would lead to intrusion at the Area 5 RWMS. A major SME assumption was that future societal patterns would be the same as presently observed. SMEs identified four possible development scenarios for Frenchman Flat that could lead to members of the public living near the site. All of the scenarios require that individual or multiple water withdrawal wells be developed to supply drinking water to an individual homesteader or to a community water system. The number of replacement wells required by the community during its life time was also considered. SMEs were also queried about the effectiveness of markers and placards to deter intrusion. SME responses were used to estimate the probability of intrusion in 10,000 years, a probability mass function (pmf) for the number of wells to be developed under each scenario, and the effectiveness of institutional control over time.

The cumulative release from an intrusion event might also be enhanced by excavation of a basement during construction of a residence. Basements are uncommon in rural areas surrounding the NTS. A survey of tax assessment roles indicates that one percent of homes in rural southern Nevada have a basement (BN 2001c). The mean probability of an on site resident as estimated by the SME elicitation was approximately 0.03 in 10,000 years. The probability of an on site resident with a basement is then only about 3 chances in 10,000. The release caused by excavation of a basement is also unlikely to be important for a 4 m (13 ft) cover relative to a borehole drilled through the disposal unit, because a basement excavation will not contact waste directly. Appendix C of 40 CFR 191 allows exclusion of unlikely events with less than a 1 chance in 10,000 of occurrence or that are unlikely to affect the CCDF. The low probability of an on site resident with a basement combined with the small release expected for a 4 m cover, supports a conclusion that basement excavation not be included in the CR analysis.

3.2.8 Containment Scenarios

A single base case scenario is evaluated for the 40 CFR 191.13 CRs. The scenario includes the radionuclide release and transport FEPs listed in Section 3.2.4, climate change, and probabilistic human intrusion by water well drilling.

3.2.9 Assurance Requirements: Engineered Barriers

All radionuclide release processes at the Area 5 RWMS release radionuclides upward to the land surface. Features, events, and processes potentially transporting radionuclides to the land surface are gaseous diffusion, liquid diffusion, liquid advection, bioturbation, and human intrusion.

Climate change may initiate percolation of water below the root zone, but recharge of the water table is not expected to occur within 10,000 years.

Barriers that prevent or substantially delay upward releases were identified from past PAs and evaluated for their effectiveness. The barriers were ranked for cost-effectiveness using the analytic hierarchy process (AHP), a multicriteria decisional analysis (MCDA) method that decomposes complex decisions into a series of simple pair-wise comparisons (Saaty 1990).

The effectiveness of alternative engineered barriers is assessed through the following three steps.

Step 1) Identify Alternatives: Engineered barriers are identified that may prevent or reduce releases to the accessible environment. As the distance to the land surface and the atmosphere is much less than to any other part of the accessible environment, barrier options that limit releases to these points are emphasized. Model processes releasing radionuclides to the land surface and atmosphere include liquid advection/diffusion, gaseous diffusion, plant uptake, and animal burrowing. It is also appropriate to include barrier features that deter intrusion because 40 CFR 191.14 requires engineered barriers that increase confidence in compliance with the 40 CRF 191.13 CRs. The 40 CFR 191 CRs include releases caused by human intrusion.

Step 2) Develop a Model of Barrier Performance: Conceptual models of alternative barrier performance are developed and tested. Models are designed to be simple. Although the model is probabilistic, the changes implementing alternative barrier performance are deterministic. Uncertainty is accounted for by selecting deterministic parameters that will tend to overestimate the benefit of alternative barriers. This is conservative in the sense that it increases the likelihood that a barrier will be judged cost-effective.

Step 3) Score Performance of Alternative Barriers: The performance of barrier alternatives is evaluated using the 90^{th} and 99.9^{th} percentile of the normalized cumulative release, and the member of public TEDE at 10,000 years.

A total of 12 alternative barriers are evaluated (Table 3.1). The release and transport processes altered for each barrier are indicated. The SA model automatically accounts for the effects of increased cover thickness. All of the CR models also include excavation of a basement with a probability of occurrence of 0.01 per residence. Basement excavations are assumed to be 3-m (10-ft) deep and have a mean area of 94.5 m^2 based on data for southern Nevada (BN 2001c). The alternatives are compared with a 2.8-m (9.2-ft) monolayer-ET cover selected as the minimum cover that can meet the 40 CFR 191 IPRs.

Base Case: 2.8-m Evapotranspiration Cover

The base case is a vegetated 2.8-m (9 ft) thick monolayer evapotranspiration cover. A 2.8-m (9-ft) cover is selected as the base case because this was the minimum cover thickness that met the IPR dose limit. The base case barrier is simulated using a version of the 40 CFR 191 SA model modified to include probabilistic basement excavation as a process in the cumulative release analysis.

Table 3.1 Barrier alternatives evaluated

Alternative Number	Description	Cover Thickness (m)	Release Processes Modified by Barrier?	
			Biointrusion	Human Intrusion
Base Case	2.8 m ET Cover (Base Case)	2.8	No	No
1	Asphalt Layer	4.0	Yes	No
2	Capillary Break Layer	4.0	Yes	No
3	Rubber Tire Layer	12.5	No	Yes
4	Bailing Wire Layer	12.5	No	Yes
5	Reinforced Concrete Layer	5.0	Yes	Yes
6	Boulder Field on 2.8-m Cover	2.8	No	Yes
7	Boulder Wall on 2.8-m Cover	2.8	No	Yes
8	Boulder Mound on 2.8-m Cover	2.8	No	Yes
9	Thick (4 m) ET Cover	4.0	No	No
10	Boulder Field on 4.0-m Cover	4.0	No	Yes
11	Boulder Wall on 4.0-m Cover	4.0	No	Yes
12	Boulder Mound on 4.0-m Cover	4.0	No	Yes

Alternative 1: Asphalt Barrier Model

Asphalt barriers are resistive barriers employing an asphalt concrete layer overlain by a fluid-applied asphalt geotextile or geosynthetic clay liner. Asphalt barriers can be effective barriers to moisture movement and biointrusion while intact. Asphalt barriers are expected to be vulnerable to shear with differential subsidence.

The asphalt barrier model is based on a design for a proposed low-level waste disposal site in Texas (Scanlon et al. 1997). A 0.25-m (0.8-ft) asphaltic concrete layer is assumed to be installed directly on the 2.4-m (8-ft) operational cover. The asphalt layer is assumed to be covered with a geosynthetic clay layer. The barrier is overlain by 1.35 m (4.4 ft) of alluvium. The barrier is assumed to eliminate all biointrusion below 1.35 m (4.4 ft) for as long as it is intact. The barrier is assumed to remain intact until the end of the period of subsidence. The longevity of steel barrels and boxes has been estimated to be approximately 500 years or less at the Area 5 RWMS (DOE/NV 1998b). Therefore, the barrier is assumed to be effective for 500 years. The barrier is assumed to have no effect on hydrology because it is above the NLFB.

Alternative 2: Capillary-Break Barrier Model

Capillary-break barriers consist of a sequence of layers where the particle size increases with increasing depth in the cover. The overlaying fine layer must become almost saturated before water will flow into the coarser underlying layer. Capillary-break barriers were originally intended as barriers to moisture flow, but have also been shown to be effective barriers to plant roots and ant burrowing if the pores in the course material layer remain open and dry (Cline et al. 1980; Link et al. 1995). Over time fine particulates may filter into the open pores and greatly reduce the effectiveness of the barrier. The effectiveness of the barrier can be enhanced by placing a layer between the fine and coarse material that maintains a clean separation. Poor construction practices may also cause mixing of fine- and coarse-grained materials at certain spots or the pores of the coarse material will infill overtime. The barrier may also saturate and fail if the fine layer becomes saturated, for example, during snow melt.

The capillary-break barrier design features are based on the Idaho Completion Project (ICP) (ICP 2004) and Scanlon et al. (1997). The capillary-break barrier is assumed to be constructed directly on the existing 2.4-m (8-ft) operational cover. The barrier consists of a 0.3-m (1-ft) sand layer, 0.3-m gravel layer and a 0.3-m cobble layer. It is assumed that an additional 0.7 m (2.3 ft) of alluvium is placed over the capillary barrier, for a total cover thickness of 4 m (13 ft). The capillary-break barrier is assumed to completely stop biointrusion below 0.7 m (2.2 ft). No hydrologic effects are assumed because the barrier is above the NLFB. The capillary-break barrier is assumed to be somewhat resistive to subsidence because the layer can flow and heal breaches. The barrier is assumed to be effective for 1,000 years.

Alternative 3: Waste Rubber Tire Layer

Previous PA evaluations have proposed a subsurface intruder barrier consisting of a 9-m (30-ft) layer of waste rubber tires (Black et al. 2001; NSTec 2007). Subject matter experts believed that the discovery of this material by a driller might cause the driller to move to another location. The tire layer is assumed to be placed on the 2.4-m (8-ft) operational cover. An additional 1.1 m (3.6 ft) of alluvium is assumed to be placed above the tires to stabilize the tires and support revegetation. The entire cover is 12.5-m (41-ft) thick.

Voids in the tire layer are assumed to be filled with soil. Therefore, the tire layer is assumed to have no effect on biointrusion or cover alluvium properties. The barrier is assumed to deter intrusion only. SMEs believed the probability of deterring intrusion to be between 0.05 to 0.1 in 10,000 years.

Alternative 4: Bailing Wire Layer

This barrier consists of a 9-m (30-ft) layer of bailing wire. The SMEs believed that a bailing wire layer might cause a driller to relocate. The wire layer is assumed to be placed directly above the 2.4-m (8-ft) operational cover. An additional 1.1 m (3.6 ft) of alluvium is assumed to be placed above the wire to stabilize the wire layer and support revegetation. The entire cover is 12.5 m (41 ft) thick.

The wire layer is assumed to have no effect on biointrusion or cover properties. The barrier is assumed to deter intrusion. The subject matter experts believed the probability of deterring intrusion to be 0.1 in 10,000 years.

Alternative 5: Subsurface Reinforced Concrete Layer

This subsurface intruder barrier is a 1.5-m (5-ft) thick reinforced concrete slab. The slab is assumed to have 1-in. rebar spaced at 6-in. intervals. The SMEs believed this layer would destroy drill bits and, if sufficiently thick, a driller would consider relocation after destroying several bits.

The concrete layer is assumed to be installed directly on the existing 2.4-m (8-ft) operational cover. An additional 1.1 m (3.6 ft) of alluvium is assumed to be placed above the concrete layer to allow revegetation. The total cover thickness is 5.0 m (16 ft).

The concrete layer is assumed to stop all biointrusion for as long as it is intact. The barrier is assumed to be more robust than the asphaltic concrete layer and capillary-break barrier. The barrier is assumed to be effective for 3,000 years. Based on SME opinion, the barrier is assumed to reduce the probability of intrusion to 0.5 over 10,000 years.

Alternatives 6 and 10: Surface Boulders on a 2.8 or 4.0-m Cover

Alternatives 6 and 10 use evenly spaced boulders over the disposal unit to deter placement of a drill rig. The two alternatives consider different underlying cover thicknesses. The SMEs proposed 10-ton boulders at 3-m (10-ft) spacing. A spherical 10-ton boulder would have an approximate diameter of 2 m (6 ft). This barrier is estimated to have 0.1 probability of deterring intrusion over 10,000 years (Black et al. 2001). The barrier was evaluated for a 2.8- and 4.0-m (9-ft and 13 ft) cover.

Alternatives 7 and 11: Wall of Boulders on a 2.8- or 4.0-m Cover

This barrier is a 3-m (10-ft) high wall of boulders with a 2:1 slope. The wall surrounds the disposal unit. The boulder wall is estimated to have a 0.5 probability of deterring intrusion. The barrier is evaluated for a 2.8- and 4.0-m (9-ft and 13 ft) cover.

Alternatives 8 and 11: Mound of Boulders on 2.8- or 4.0-m Cover

This barrier is a 10-m (35-ft) high mound of boulders completely covering the disposal unit. This barrier is estimated to have a 0.95 probability of deterring intrusion in 10,000 years. The boulder mound is also assumed to make construction of a residence directly above the disposal unit impossible, and the member of public dose is evaluated at a distance of 100 m (330 ft) from T04C. The barrier is evaluated for a 2.8- and 4.0-m (9-ft and 13 ft) cover.

Alternative 9: 4.0-m Evapotranspiration Cover

This barrier consists of a vegetated 4-m (13-ft) thick monolayer of alluvium.

3.2.10 Member of Public Exposure Scenarios

A single base case scenario is evaluated for the 40 CFR 191.15 IPRs. A resident exposure scenario was selected to be consistent with PA guidance, which requires evaluation of dose to representative critical groups receiving the highest doses assuming average living habits and exposure conditions. The representative critical group receiving the highest dose is assumed to be a member of public residing at T04C. Members of the critical group are assumed to be residents at the disposal unit because a panel of SMEs considering intrusion identified three different development scenarios that could lead to a homesteader or community being established within Frenchman Flat. Agricultural production at the site is not included because it is not an average living habit or condition for southern Nevada locations without access to surface waste or shallow groundwater.

The scenario includes the radionuclide release and transport FEPs listed in Section 3.2.4, climate change, and exposure of an on site resident living on the T04C disposal unit. Direct intrusion into the waste is not included. The resident is assumed to be a commuter who is absent from the site 40 hours per week, because the SMEs believed that the most likely development scenarios for Frenchman Flat were individual homesteaders or a rural community with residents commuting to a more likely location for development such as Jackass Flats (Black et al. 2001).

The member of public is exposed to radionuclides released to surface soil and the atmosphere. Exposure pathways are assumed to include:

- External irradiation from radionuclides in soil
- External irradiation from particulate and volatile radionuclides in air
- Inhalation of particulate and volatile radionuclides in air, excluding ^{222}Rn and its short-lived progeny
- Dermal absorption of ^{3}H in air
- Inadvertent soil ingestion

Agricultural pathways are not included because they are not likely for a site in southern Nevada without surface water or shallow groundwater.

3.3 Model Implementation

All SA models are integrated in a single meta-model using the GoldSim probabilistic simulation platform (GTC 2007). GoldSim was developed specifically for probabilistic PA simulation.

3.3.1 GoldSim Overview

Goldsim is an object-orientated highly graphic simulation environment. Multiple object classes (e.g., stochastic and deterministic data sources, mathematical functions, radionuclide transport pathways, and result summaries) are programmed by the user through graphical user interfaces.

The model is graphically organized in a hierarchy of containers that logically compartmentalize related calculations. Graphical model documentation, element influences, and equations allow users to visualize model structure and function, allowing greater understanding of the model.

GoldSim was developed specifically for PA and offers multiple features that make it a logical choice for the SA modeling including:

- Built-in radioactive contaminant transport pathways which include diffusive and advective transport in porous media, adsorption, precipitation, and radioactive decay and ingrowth
- Simulation of random events
- A probabilistic dynamic simulation environment

- Graphic features (i.e., graphics, photos, and text), hot-links to external documents and internet content, and note panes designed to document model assumptions, structure, and data sources
- A versioning feature which documents and records changes during model development
- A robust, well documented platform that has been used in numerous environmental simulation applications

3.3.2 Uncertainty

Simulating the future performance of a waste disposal system is subject to considerable uncertainty. Understanding, defining, and introducing uncertainty into a simulation model is a complex process. Uncertainty can broadly be divided into aleatory uncertainty or natural variability in populations, space or time, and epistemic uncertainty or lack of knowledge. A hierarchy of epistemic uncertainty can exist in a simulation model including model (e.g., conceptual, mathematical) uncertainty and parameter uncertainty.

The SA primarily addresses epistemic parameter uncertainty by assigning probability density functions (pdfs) or pmfs to important input parameters and propagating this uncertainty through the model by Monte Carlo simulation. Variability is addressed by assigning pdfs that represent uncertainty in the average parameter value over the population, region, or duration of the model. The parameter pdfs express lack of knowledge about the mean parameter value averaged over the population, region, and/or time period simulated.

Although uncertainty analysis can be extended to include model uncertainty by randomly selecting alternative FEPs and models, this is seldom performed because of the additional model complexity and lack of knowledge of FEP and model probability. All SA FEPs are combined into a single base case because they have a reasonably high probability of occurrence and are not mutually exclusive. Human intrusion is simulated as a discrete event occurring randomly in time. Some simulations may include no intrusion events and other simulations many events. The exposure scenario is relevant to the IPRs only, which are not a probabilistic standard. The selected scenario represents the most probable scenario as selected by a panel of SMEs.

The uncertainty analysis begins by developing pdfs for input parameters. Input distributions are developed based on expert judgment, relevant literature, and site-specific characterization data. The pdfs are documented in external model documentation packages that can be accessed through model links. Again, the pdfs are selected to represent uncertainty or lack of knowledge about the population-average, long-term or spatially averaged value of the parameter.

Monte Carlo simulation begins by generating a random or stochastic value for each input parameter. The SA generates stochastic input vectors using the process of Latin hypercube sampling (LHS). GoldSim then solves the model equations as a function of time holding the input parameters constant. Discrete events such as intrusion may be generated randomly during the simulation. With climate change, different parameter values are used for each of the different climate regimes. The model outputs for the realization as a function of time are recorded. The process is repeated thousands of times, accumulating a vector of output results. The distribution of the model output represents uncertainty in the model result.

3.3.3 Model Development Process

The SA model is the result of multiple cycles of model development and testing. A model improvement cycle begins when the model development team agrees that a need for a change exists. The proposed changes are documented in an Engineering Analysis/Calculation package which is subject to technical review and management approval. A single copy of the current model version is maintained in a write-protected model repository. The proposed changes are made to a working copy of the model. If the model is found acceptable, the changes are implemented in the current model by the model custodian, and the changes are confirmed by a reviewer. The changes are automatically recorded by the GoldSim versioning feature and recorded by the model custodian in the model change log. The new version is run and the results recorded in the model output log which tracks how model output has changed over time with each version. The completed model is submitted to NNSA/NSO for acceptance testing. A more complete description of software quality assurance procedures can be found in Appendix A2.

The 40 CFR 191 SA model, version 1.002, originated from the Area 5 RWMS PA model, which has been subjected to external peer review. The most recent review was for the update of the Area 5 RWMS PA (BN 2006a) which was accepted without conditions (DOE 2007). The Area 5 RWMS PA model was initially modified to calculate the regulatory endpoints of 40 CFR 191. Starting with the Area 5 RWMS PA model v4.000, a process of simplification and modification was begun to create the final SA model. The steps involved were:

- Adding model elements to implement stochastic climate regime periods.
- Adding additional model parameters describing hydrologic conditions, plant uptake, and animal burrowing during future climate regimes.
- Deleting un-needed model components including cost-benefit optimization, composite analysis, and un-used disposal configurations (i.e., shallow land burial [SLB], Pit 6, Pit 13, Candidate 1, Candidate 2), and un-used waste inventories (i.e., post-1988 SLB, future waste inventory, thorium nitrate, Fernald thorium, pre-1988 GCD, post-1988 GCD, Fernald Silo wastes).
- Adding an on site residential exposure scenario without agriculture as the IPR scenario.

3.3.4 Radionuclide Release and Transport

Radionuclide release and transport are implemented as a series of connected mixing cells. Specifically for T04C, the model consists of a sink, an atmospheric mixing cell, four cover mixing cells above the NLFB, four cover mixing cells below the NLFB, and five waste mixing cells (Figure 3.6). The unsaturated porous medium is represented by three materials in each mixing cell: alluvium, air, and water.

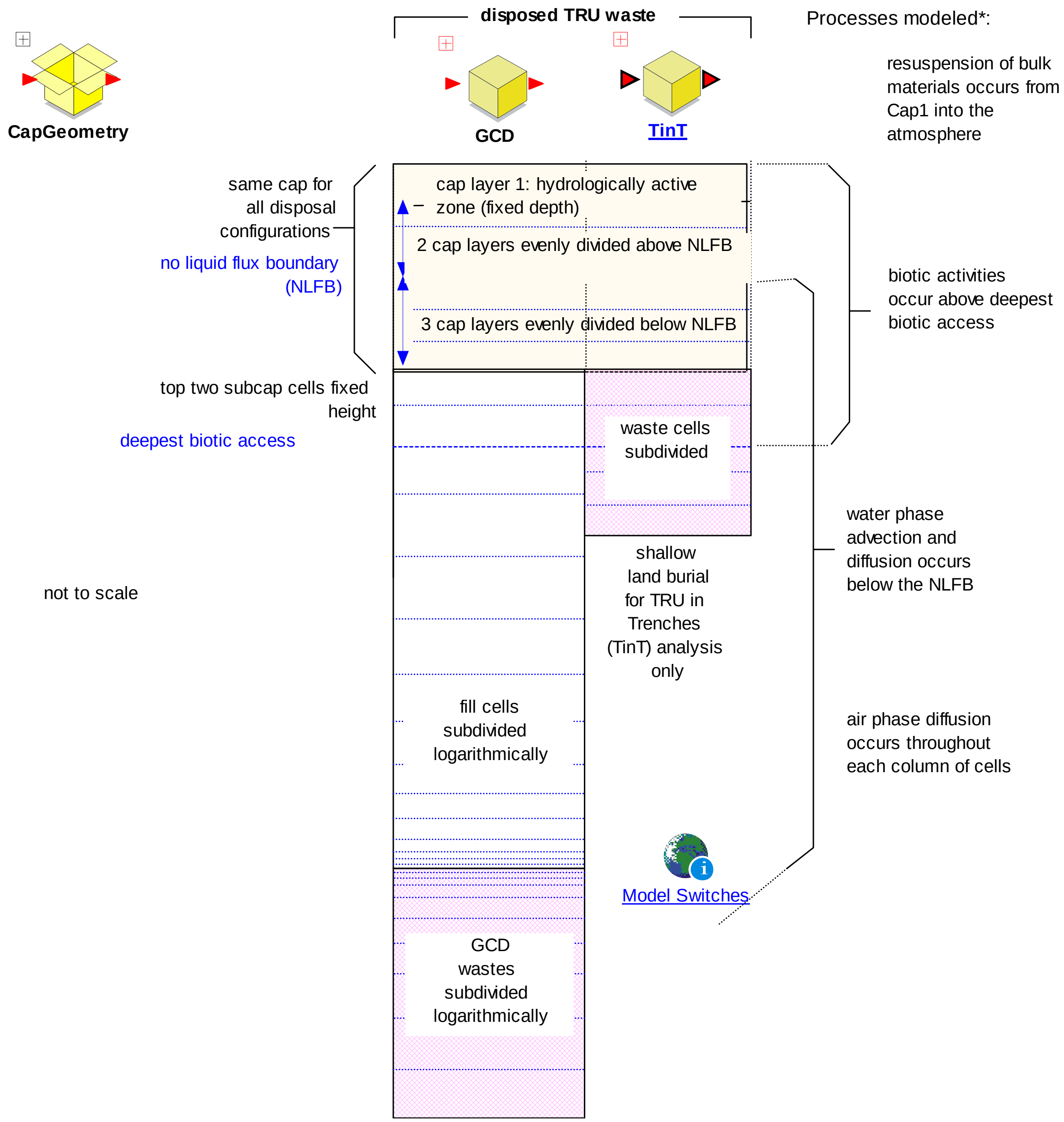

Figure 3.6 Diagram of waste and cover configurations for TRU waste units at the Area 5 RWMS (not to scale).

Built-in features of the GoldSim mixing cells implement the following features:

- Advection of water as an advective material flux; water advection links are included for cells below the NLFB only
- Retardation of dissolved solutes using constant radionuclide-specific soil-water distribution coefficients, K_d
- Instantaneous precipitation/dissolution of solutes based on the total aqueous concentration of an element and its equilibrium solubility constant, K_{sp}
- Liquid and air-phase diffusion implemented as diffusive fluxes
- Radioactive decay and ingrowth

- Plant uptake and animal burrowing are modeled using direct transfer rates between mixing cells

When modeling radioactive decay chains, the model assumes that short-lived progeny are in secular equilibrium and are transported with their long-lived parent. Explicitly modeled members of decay chains are listed in Appendix A1, Figure A1.1.

Plant and animal transfer rates between mixing cells are calculated externally to the mixing cells. The plant transfer rate is a function of the mixing cell concentration, plant-soil concentration ratio, primary productivity, and fraction of plant roots in the mixing cell. All contaminants transferred to aboveground plant tissue are assumed to be immediately transferred to the surface soil layer.

Animal burrowing transfer rates are the net rate calculated as the difference between removal from the mixing cell by excavation and input by collapse of the overlying layer required to maintain constant mass in the cell. The radionuclide-specific excavation rate is a function of the mixing cell concentration, soil excavation rate, and fraction of burrow volume in the mixing cell. The collapse rate is a function of the overlying mixing cell concentration and the burrow excavation rate in the underlying cell.

Radon diffusion calculations are adjusted to account for the coarse spatial and temporal discretization of the model relative to the short half-life of ^{222}Rn. A calibration factor, obtained from an analytical solution of the diffusion equation (NRC 1989), is applied to the radon diffusion coefficient to correct for the numerical error in the GoldSim result.

3.3.5 Climate Change

The climate regimes intervals are implemented as status elements in GoldSim (Figure 3.7). The climate status elements are controlled by timed event and event delay elements. Each interval length is a stochastic element with a uniform pdf. The triggering of the status elements can be turned off when the climate change process is turned off in the process switches dashboard. A switch element selects the appropriate parameter value based on the climate state. A separate switch is implemented for each parameter impacted by climate change.

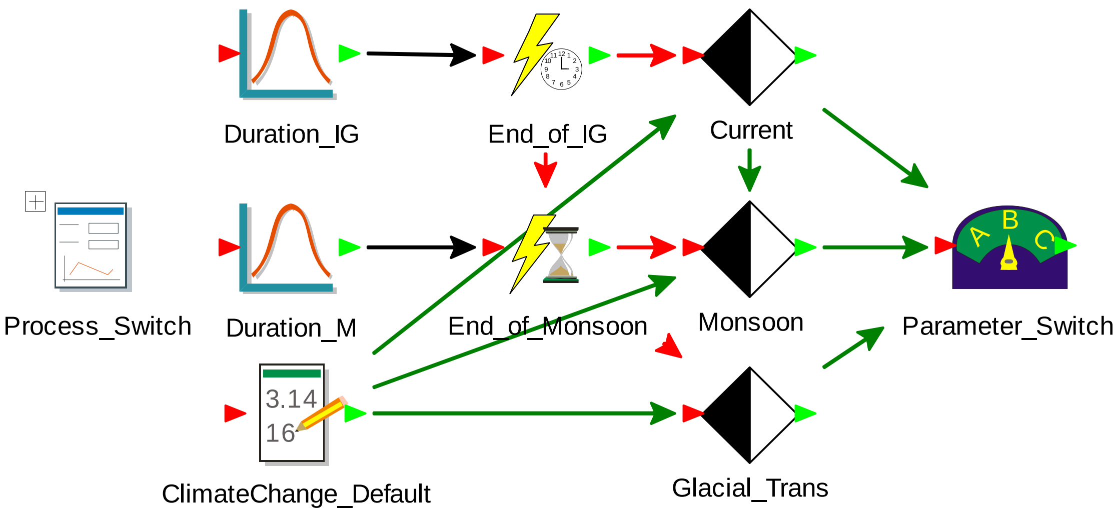

Figure 3.7 GoldSim model design for selecting alternative parameter distributions for future climate states.

3.3.6 Human Intrusion

The probability of intrusion is represented by a pdf describing the intrusion rate (probability per year). Random intrusion events are generated as a Poisson process by a timed event element. The intrusion rate is modified over time by a deterministic function that represents SME opinion about marker and placard effectiveness. This causes the probability of intrusion to increase over time as markers are judged to become less effective. Another stochastic element simulates the total number of wells developed for each intrusion event.

3.3.7 Cumulative Release

The cumulative release to the accessible environment is calculated as the cumulative release of volatile species to the atmosphere and of volatile and particulate radionuclides to the upper 15 cm (6 in.) of soil by plant uptake and animal burrowing. The transfer rates for these processes are continuously input to an integrator element, which does not perform radioactive decay. Therefore, the cumulative release does not include the radioactive decay and ingrowth of radionuclides that occurs between the time they reach the accessible environment and the end of the 10,000 year compliance period.

3.3.8 Assurance Requirements: Alternative Engineered Barrier Evaluation

The cost-effectiveness of alternative barriers is assessed by using AHP, a MCDA method (Saaty 1986, 1990). The AHP decomposes a complex decision into a series of simple pair-wise comparisons. The decision is defined by identifying the goal, decision criteria, and decision alternatives. The criteria or alternatives are then compared pair-wise with respect to each of the criteria at the next higher level. The result is a ranking of the decision alternatives that reflects the importance of the decision criteria and performance of the decision alternatives.

The AHP was implemented using the following five step process.

1) Define the Goal
The goal is to identify cost-effective engineered barriers that increase confidence in the containment of TRU waste disposed in T04C.

2) Define the Criteria that Measure Achievement of the Goal
Two categories of criteria are considered: benefits and costs.

Criteria that Measure Benefit

Reduction in the normalized cumulative release, R, at the 99.9th percentile.: This is defined as the reduction in the 99.9th percentile R relative to a 2.8-m (9-ft) cover without any intrusion barriers. This criterion is selected because it is the 40 CFR 191.13(a)(2) regulatory standard. The R reduction is obtained from results of a simple model modified to simulate the barrier alternatives as described in Section 3.2.9.

Reduction in the normalized cumulative release, R, at the 90th percentile. This is defined as the reduction in the 90th percentile R relative to a 2.8-m (9-ft) cover without intrusion barriers. This criterion is selected because it is the 40 CFR 191.13(a)(1) regulatory standard. The R reduction is obtained from results of simple model modified to simulate the barrier alternatives described in Section 3.2.9.

Reduction in the on site resident TEDE at 10,000 years. This is defined as the reduction in the mean on site resident TEDE at 10,000 years relative to results obtained for a 2.8-m (9-ft) cover without intrusion barriers. This is selected because it is the 40 CFR 191.15(a) regulatory standard.

Hydrologic Performance. Hydrologic performance describes the ability of the alternative cover to limit infiltration into waste relative to a 2.8-m (9-ft) vegetated ET cover.

Reliability. Reliability describes the expected ease or difficulty of constructing an alternative cover that functions as designed.

Criteria that Measure Cost

Cost of Construction**.** Costs associated with planning, design, supervision, labor, and equipment needed for barrier construction.

Cost of Materials**.** Costs associated with materials needed for barrier construction.

Cost of Maintenance**.** Costs associated with maintaining the barrier during active institutional control including: inspections, environmental monitoring, and repairs.

Worker Safety. Costs associated with risks to workers during barrier construction.

Compatibility. Compatibility describes design, planning, construction and materials costs needed to make the barrier compatible with the cover on surrounding disposal units. The surrounding final closure cover is assumed to be a vegetated 2.8-m (9-ft) ET cover.

Step 3) Identify Alternative Barrier Choices
Twelve alternative barriers are identified in Section 3.2.9 and evaluated.

Step 4) Make Pair-Wise Comparative Judgments
The decision is decomposed into two goals, each with five decision criteria, and 12 barrier alternatives (Figure 3.8). Pair-wise comparisons of criteria (or alternatives) with respect to a higher level criterion are made. The criteria are compared by asking two questions: 1) which is more important, with respect to the higher level criteria, and 2) how strongly using a scale from 1 to 9 (Table 3.2)? The decision criteria are compared relative to the decision goal. The decision alternatives (i.e., the 12 alternative covers) are compared relative to the decision criteria. The comparisons are only made one time. For example, if A is first ranked three times more important than B, the rank of B relative to A is assumed to be 1/3.

Table 3.2 Scale of relative importance for pair-wise comparison of decision criteria.

Importance	Definition
1	Equal importance for goal
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocal Values	Inverse of above relationships

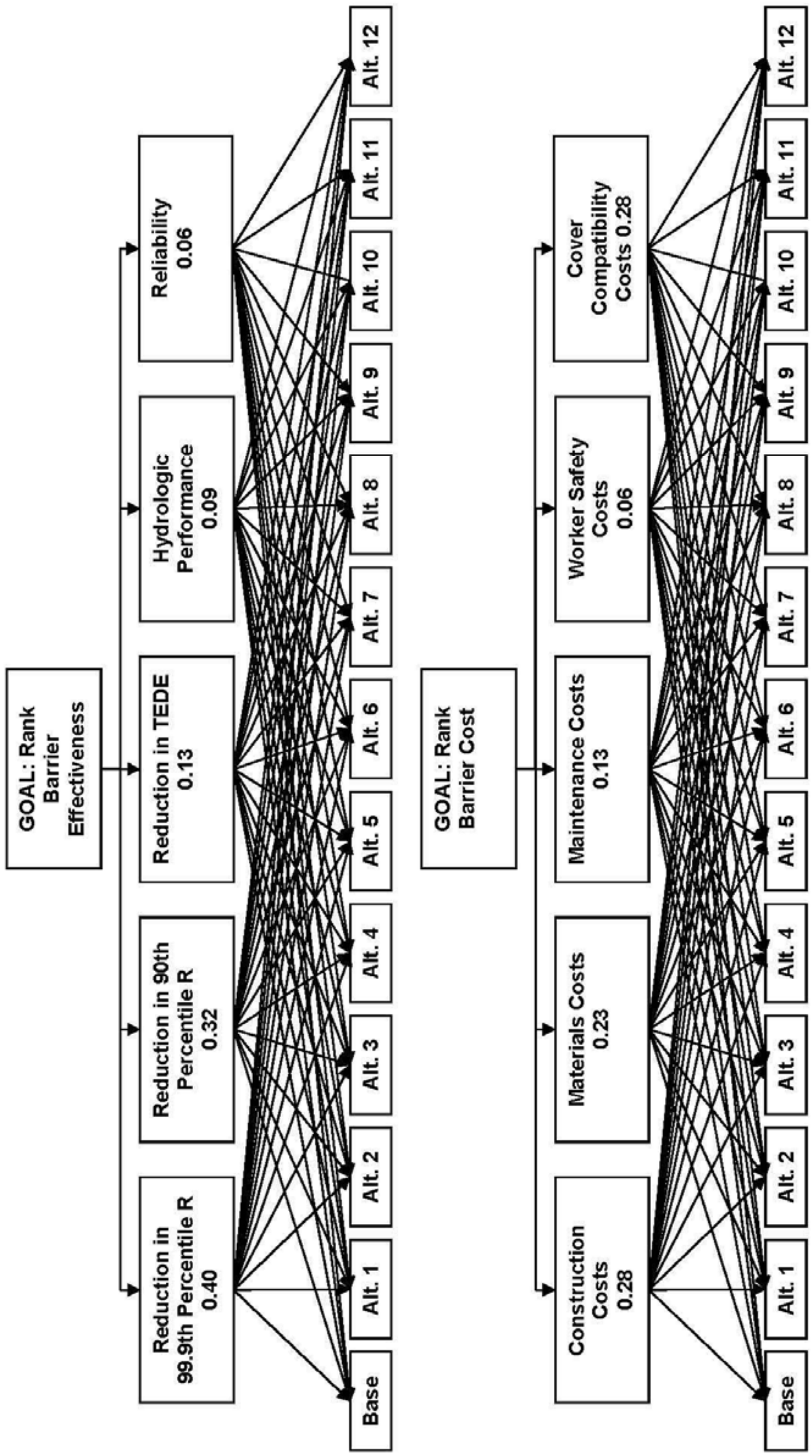

Figure 3.8. Analytic hierarchy process decomposition of the decision to select the most cost-effective barrier for isolation of buried TRU waste in T04C.

Step 5) Calculate Alternative Rankings
If the decision maker is totally consistent in the pair-wise comparison of the decision criteria (or alternatives), the weights of the criteria can be used to from a matrix, **A**, as:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{bmatrix}$$

where w_i is the weight (or local priority) of the i[th] criterion. Multiplying **A** by the vector of weights, **w**, of the criteria yields an equation of the form:

$$\begin{bmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{bmatrix} = \lambda \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{bmatrix}$$

where λ is a scalar. If the comparisons are totally consistent, λ is equal to n, the dimension of the matrix. Writing this expression in equation form:

$$\mathbf{A}\,\mathbf{w} = \lambda\,\mathbf{w}$$

it can be seen that λ is an eigenvalue of **A** and the vector of weights, **w,** is the eigenvector associated with λ.

Therefore, the weights of the decision criteria (or alternatives) can be obtained from a matrix of the pair-wise comparisons by solving for the dominant eigenvalue. The weights, **w**, are the eigenvector associated with the dominant eigenvalue.

For a consistent n x n matrix, the dominant eigenvalue is equal to n. In practice, the decision makers' pair-wise comparisons will not be totally consistent. Preparation of the matrixes requires redundant comparisons. For example if A is judged to be two times as important as B and B two times as important as C, then C and A need not be compared as these prior judgments imply C is four times as important as A. Nevertheless C is compared with A and it is inevitable that some redundant comparisons will not be consistent with earlier judgments. The eigenvalues can still be determined but will be slightly perturbed. The degree of perturbation is estimated by the consistency ratio which is the ratio of the matrix inconsistency divided by the average inconsistency of random matrixes. The matrix inconsistency, C_i, is calculated as:

$$C_i = \frac{\lambda - n}{n - 1}$$

Consistency ratios less than 0.1 are considered acceptable for matrixes 5 x 5 or larger (Saaty 1990).

The final rankings of the decision alternatives (or criteria priorities), r_j, are then obtained as the product of the matrix whose columns are the local priorities of the alternatives and the vector of the decision criteria priorities as:

$$\begin{bmatrix} w_{11} & w_{21} & w_{31} & \cdots & w_{n1} \\ w_{12} & w_{22} & w_{32} & \cdots & w_{n2} \\ w_{13} & w_{23} & w_{33} & \cdots & w_{n3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ w_{1n} & w_{2n} & w_{3n} & \cdots & w_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ \vdots \\ r_n \end{bmatrix}$$

where $w_{i,j}$ is the local priority of the j^{th} alternative with respect to the i^{th} decision criterion, w_i the priority of the i^{th} decision criterion, and r_j the rank (or global priority) of the j^{th} alternative. The rankings for effectiveness and cost are combined by taking the ratio of the effectiveness rank to the cost rank. The preferred alternative has the highest effectiveness/cost ratio.

The effectiveness of the alternative barriers is determined from modified versions of the SA model described in Section 3.2.8. The results from these models were post-processed by an Excel spreadsheet using a Visual Basic Application macro to calculate the eigenvalues and eigenvectors using the methods of Press et al. (1986).

3.3.9 Individual Protection Requirements

The transport portion of the model calculates the radionuclide concentration in air above the disposal unit and in surface soil. The on site resident TEDE is calculated as the product of the media concentrations and pathway dose conversion factors calculated for each radionuclide and each exposure pathway. The dose conversion factors for long-lived members of radionuclide decay chains include the contribution from short-lived progeny assumed to be in secular equilibrium. Long-lived members of radionuclide decay chains explicitly included in the model are listed in Appendix A1, Figure A1.1.

3.3.10 Sensitivity Analysis

Sensitivity analysis is the process of quantifying how uncertainty in model input contributes to model output uncertainty. Understanding this relationship can be useful for understanding and interpreting model behavior, comparing model behavior with the actual system, building model credibility, identifying model errors, and/or reducing output uncertainty.

The sensitivity analysis approach was to use multiple methods to confirm sensitivity ranking as recommended by Frey and Patil (2002). The methods used are the methods included in the GoldSim multivariate result element and Sobol' sensitivity indices calculated for a generalized boosted model (gbm) fit to GoldSim model inputs and outputs (R Project 2007; Ridgeway 2007; Sobol' 2001). Complete details of the sensitivity analysis methods and results can be found in Appendix A3.

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4.0 Results of Analysis

The SA model produces probabilistic results for the regulatory endpoints. This section summarizes the distributions of the results, the likelihood of meeting the requirements in light of uncertainty, and the sensitivity of the model to uncertainty in input parameters.

4.1 Containment Requirements

Ten thousand realizations of the cumulative normalized release, R, for a 4-m (13-ft) monolayer-ET cover over 10,000 years were generated using LHS. The containment requirements are given as a likelihood of R exceeding limits scaled to total inventory. The probability of R exceeding one must be less than 1 in 10 (i.e., Pr[R>1] < 0.1) and the probability of R exceeding 10 must be less than 1 in 1,000 (i.e., Pr[R>10] < 0.001).

The probability of R exceeding one for the present simulation was estimated to be 0.0093, an order of magnitude less than the 0.1 limit (Table 4.1). The largest value of R in 10,000 realizations was 4.9. Because there was no realization greater than 10, it is concluded that the Pr(R>10) is less than 0.0001. The performance assessment results provide a reasonable expectation of meeting the 40 CFR 191.13(a) CRs.

Table 4.1 Comparison of the 40 CFR 191.13 containment requirements with simulated cumulative normalized release, R, at 10,000 years.

Containment Requirement	Likelihood Limit	Simulated Likelihood
40 CFR 191.13(a)(1)	Pr(R>1) < 0.1	Pr(R>1) = 0.0093
40 CFR 191.13(a)(2)	Pr(R>10) < 0.001	Pr(R>10) < 0.0001[†]

[†] - Maximum normalized release, R, less than 1 in 10,000

4.1.1 Complementary Cumulative Distribution Function

Comparison of the disposal system performance with the containment requirements can also be visualized by the CCDF (Figure 4.1). The CCDF shows on the y-axis the probability of R exceeding the values on the x-axis. The red-hatched area shows the region that constitutes a violation of the CRs. The CCDF does not intersect the probabilistic release limits, indicating that the disposal system meets the containment requirements. The markedly different slopes of the CCDF indicate the pdf of R is at least bimodal. The lowest mode, which includes most of the probability, is composed of realizations where T04C is not disturbed by human intrusion. The realizations with the higher mode include intrusion events.

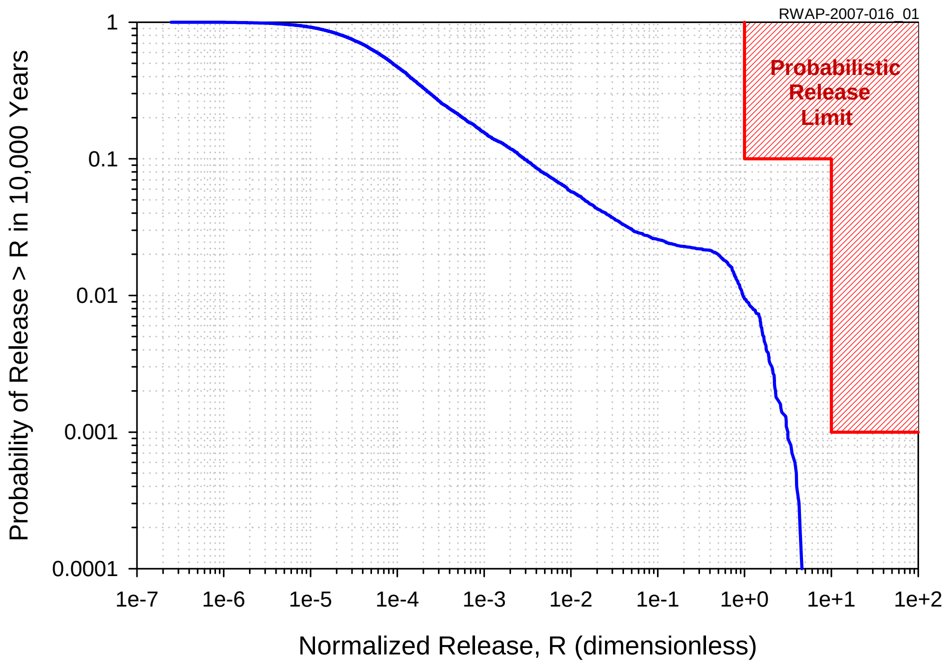

Figure 4.1 Complementary cumulative distribution function of the cumulative normalized release, R, over 10,000 years for the TRU waste buried in T04C.

4.1.2 Uncertainty Analysis

The CRs are probabilistic limits and the CCDF is an expression of uncertainty in the cumulative release. Two experiments were conducted to assess the adequacy of the sample size. The first experiment evaluates the precision of the 90th and 99.9th percentile cumulative normalized release as a function of sample size. The model was run repeatedly with increasing sample sizes and different seed numbers. The distribution of the 90th and 99.9th percentile cumulative release was estimated by resampling with replacement for each sample size. The 90th percentile normalized cumulative release appears to be stable by 3,500 realizations, but the 99.9th percentile continues to show significant variation with up to 10,000 realizations (Figure 4.2). A sample size of 10,000 is selected as a reasonable compromise between output stability and the availability of computer resources.

The second experiment evaluates the precision of the CCDF using 10,000 realizations by estimating the 95-percent centered confidence intervals about the CCDF. The confidence intervals were estimated using the percentile bootstrap confidence interval method (Hogg et al., 2005). The process proceeds by 1) drawing a random sample with replacement (n=10,000) from the normalized cumulative release, R, data, 2) assembling a new CCDF from the resampled data, 3) repeating the above steps 10,000 times, and 4) determining the 2.5th and 97.5th percentiles of the CCDF values from the 10,000 CCDFs. The confidence intervals indicate that the precision of the CCDF is sufficient to make a determination that the CRs are met (Figure 4.3).

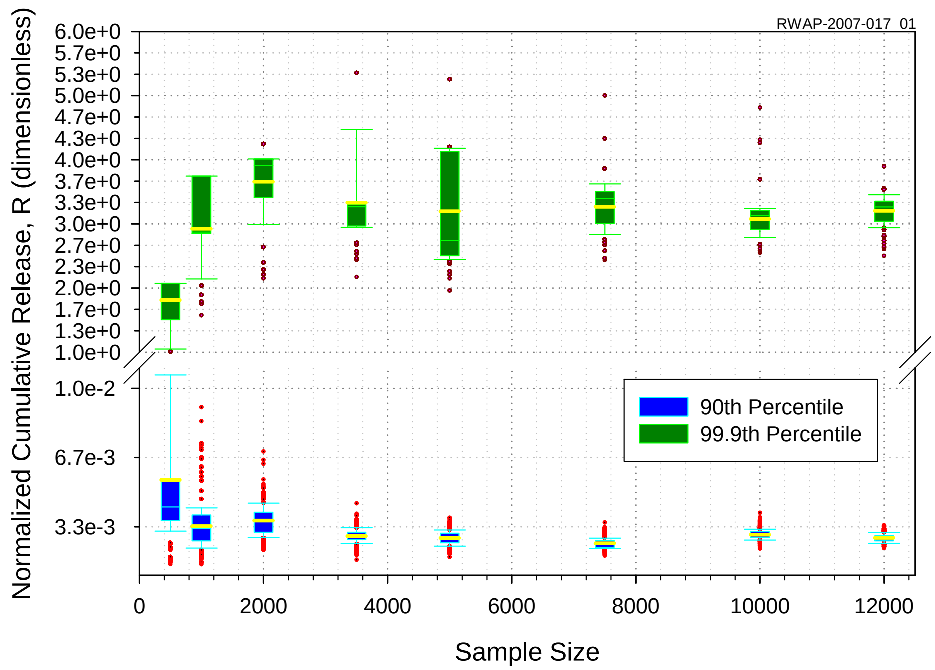

Figure 4.2 Boxplots of bootstrapped 90th and 99.9th percentile normalized cumulative release as a function of sample size. Boxplots show mean (yellow), median, 25th and 75th percentiles (box), 10th and 90th percentile (whiskers), and outliers (dots).

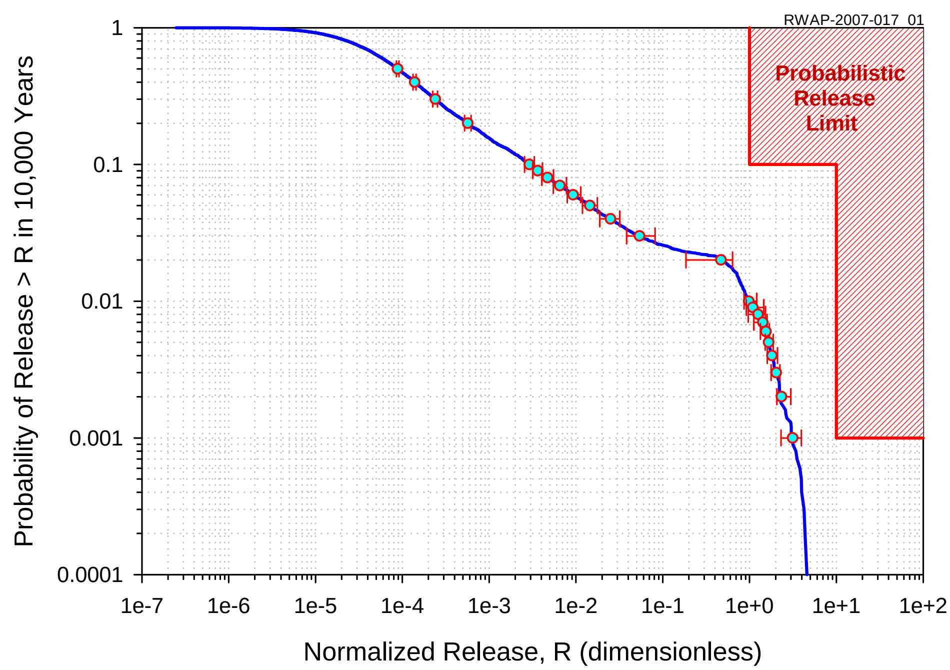

Figure 4.3 Complementary cumulative distribution function of the cumulative normalized release, R, over 10,000 years for the TRU waste buried in T04C with error bars. Error bars show the 95-percent central interval for 10,000 replicates generated by resampling with replacement.

Length of Compliance Period

The time-dependent behavior of the model may be subject to uncertainty. The model simulation duration was increased to assess the likelihood that uncertainty in the model's time response could impact the confidence in the conclusion that the requirements are met. The conceptual model and assumptions may become invalid as the model duration is increased. For example, infiltration below the root zone is expected to begin with the glacial-transition climate regime. If this infiltration is sufficient to reach the uppermost aquifer, a groundwater pathway may be present in the future. If the model duration were increased beyond this time, the model results would be misleading because the model does not include a groundwater pathway.

The model duration was increased to 20,000 years. An extension to 20,000 years was judged sufficient to investigate uncertainty in model response times, while not being so long that a groundwater pathway would be likely. Increasing the model duration to 20,000 years shifts the CCDF to the right, but not enough to violate the CRs (Figure 4.4). Uncertainty in the time response of the model does not appear to be sufficient to raise concerns about the model exceeding the CR limits.

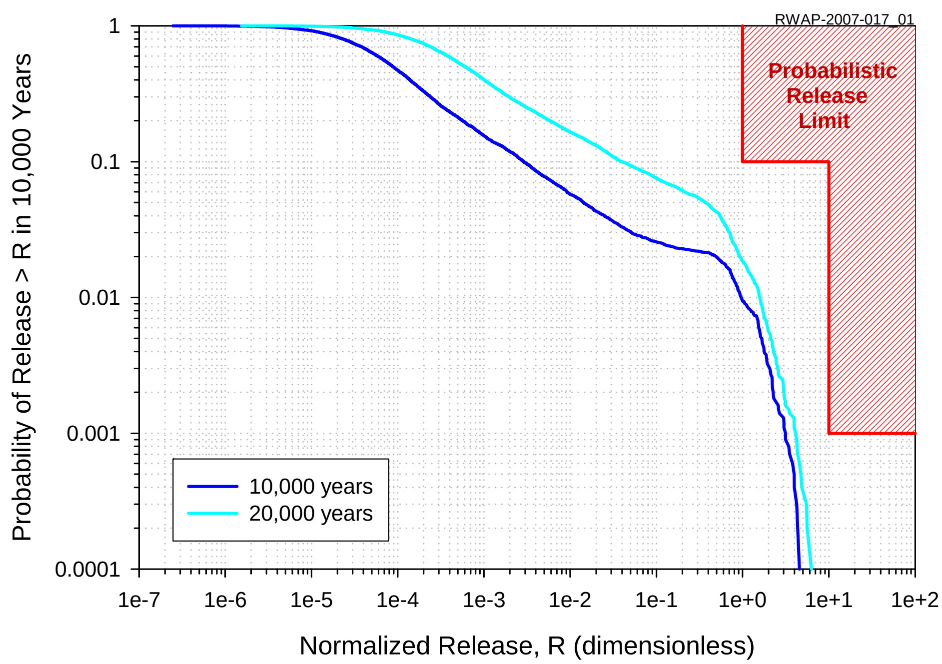

Figure 4.4 Complementary cumulative distribution function of the normalized cumulative release, R, at 10,000 and 20,000 years for the TRU waste buried in T04C.

Hydrogeologic Conceptual Model

The hydrogeologic conceptual model assumes that upward advection ceases during the glacial-transition climate regime. The effect of this assumption was evaluated by running an alternative model with upward advection continuing throughout the glacial-transition period. The upward advection pdf was the same as during the present-day period.

The CCDF with upward advection continuing through the glacial-transition period is nearly identical to the base case CCDF. The 50th percentile cumulative normalized release increases from 8.8E-5 to 9.1E-5 with continuing upward advection. Uncertainty concerning the status of upward advection during the glacial-transition period contributes negligibly to uncertainty in the cumulative release.

4.1.3 Sensitivity Analysis

The SA relies on regression techniques which adequately describe sensitivity to the extent that the regression model fits the data. The adjusted coefficient of determinations for the normal linear regression ($R^2 = 0.90$) and the gbm ($R^2 = 0.94$) indicate that the cumulative release regression models fit the data reasonably well and should provide accurate qualitative ranking of input parameter sensitivity. All of the sensitivity methods indicate that the normalized cumulative release is strongly sensitive to the total number of intruder boreholes. The Sobol' total effects sensitivity indices for the gbm indicate that there is moderate sensitivity to the number of boreholes per intrusion event and a slight sensitivity to the ^{239}Pu inventory. See Appendix A3 for complete details of the sensitivity analysis.

4.2 Assurance Requirements: Alternative Barrier Evaluation

The performance of the alternative engineered barriers was evaluated for the CRs using 10,000 LHS realizations and for the IPRs using 3,500 LHS realizations of the SA model. Each alternative barrier has a specific cover thickness. Performance is measured relative to a 2.8-m (9-ft) cover, the minimum cover thickness required to meet the CRs and IPRs.

4.2.1 Alternative Engineered Barrier Benefits

The benefit criteria were ranked based on their ability to increase confidence in meeting the requirements. Improved performance, as demonstrated by changes in the CR and IPR results of alternative engineered barrier models, was given the highest weight. Alternative barrier effectiveness with respect to hydrologic performance and reliability was ranked using professional judgment. The consistency of all matrixes was less than 0.1.

Cumulative Release

The normalized cumulative release results for the alternative barriers cluster about several points (Figure 4.5). At the 90th percentile, the alternatives fall into four groups that share common cover thicknesses. Alternatives 6, 7, 8, and the base case all have a 2.8-m (9-ft) cover. Alternatives 1, 2, 9, 10, 11, and 12 have a 4-m (13-ft) cover. Alternative 5 has a 5-m (16-ft) cover and alternatives 3 and 4 have a 12.5-m (41-ft) cover. Cover thickness appears to be the most important factor affecting cumulative release at the 90th percentile.

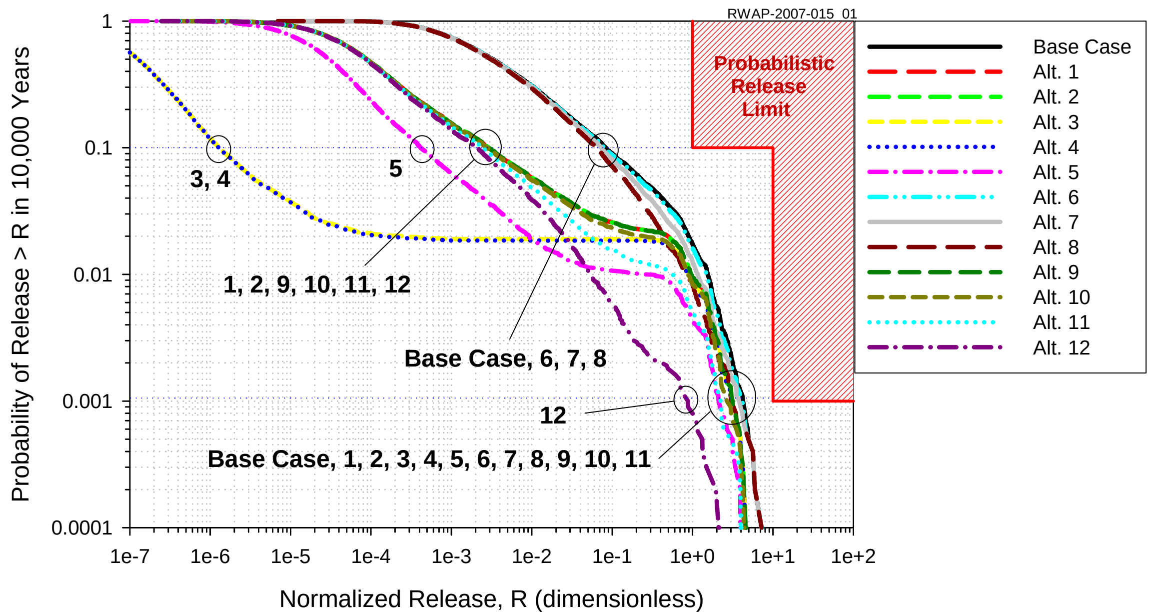

Figure 4.5 Effect of alternative engineered barriers on the CCDF.

The cumulative release at the 99.9th percentile falls into two groups, alternative 12 and all other alternatives. Alternative 12 has a thick 4-m (13-ft) cover and a highly effective intruder barrier. The remaining alternatives are clustered together, but appear to be ranked according to the effectiveness of their intruder barrier. At the 99.9th percentile, cover thickness does not appear to be important for the cumulative release, but effective intruder barriers seems to add benefit, especially if the cover is at least 4-m (13-ft) thick.

The highest weights were given to alternatives 3 and 4, the rubber tire and bailing wire subsurface intrusion barriers, at the 90th percentile (Figure 4.6). These two alternatives have the thickest cover. Alternative 12, the 4-m (13-ft) monolayer-ET cover with a boulder mound, had the highest score for the 99.9th percentile cumulative release. The 2.8-m (9-ft) monolayer-ET cover with surface intruder barriers performed no better than the base case.

The CCDF for alternative 9, the 4-m (13-ft) monolayer ET cover, also provides a check of the assumption that basement construction has negligible impact. The CCDF for alternative 9 includes basement construction. Comparison with the CCDF for the base case without basement construction, Figure 4.1, confirms that the two curves are nearly identical and basement excavation has negligible impact on the cumulative release for a 4-m (13-ft) cover.

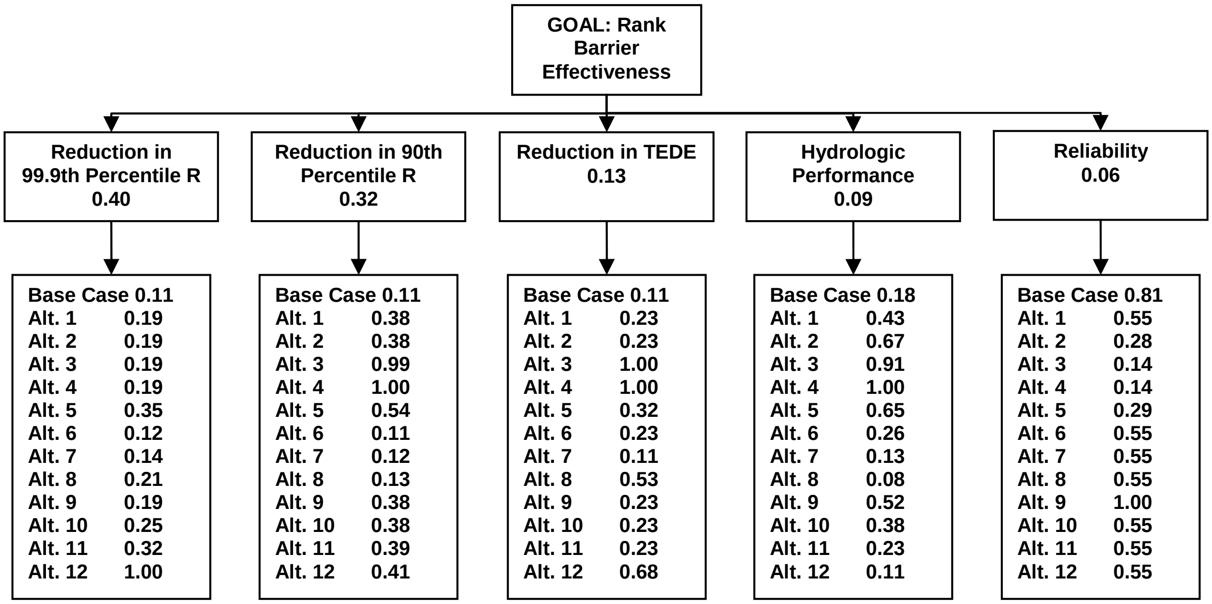

Figure 4.6 Summary of alternative engineered barrier effectiveness rankings.

Individual Protection Requirements

The IPR TEDE reduction data fall into six groups that share a common cover thickness (Figure 4.7). Increasing cover thickness reduces the member of public TEDE. The relative decrease for the different barriers is constant over time. The highest weight was assigned to alternatives 3 and 4, the alternatives with the thickest cover (Figure 4.7). Alternatives 8 and 12 include the boulder mound intruder barrier, which was assumed to preclude a residence directly above the trench. The remaining groups share common cover thicknesses of 5 m (16 ft) (alternative 5), 4.0 m (13 ft) (alternatives 1, 2, 9, 10, 11), and 2.8 m (9 ft) (base case, alternatives 6 and 7)

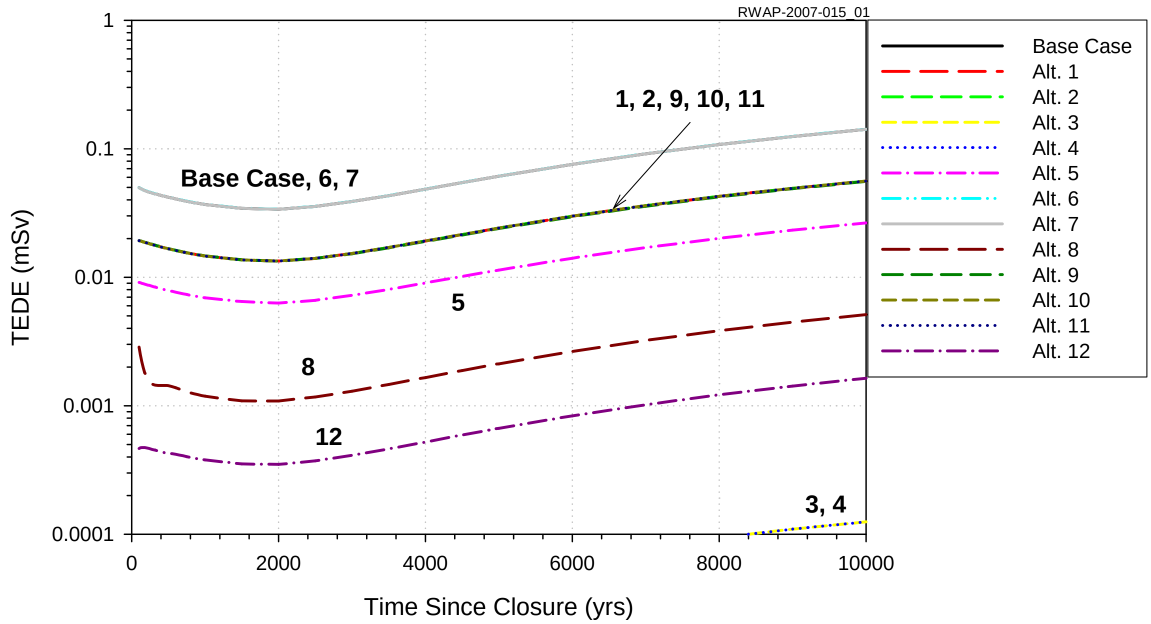

Figure 4.7 Effectiveness of alternative engineered barrier designs on the on site resident TEDE.

4.2.2 Alternative Engineered Barrier Costs

The base case and 12 alternative engineered barriers were ranked with respect to five cost criteria using professional judgment (Figure 4.8). Criteria that involved capital expenditures at closure were judged to have high and equal importance. The consistency ratio of all matrixes was less than 0.1. The 1.5-m (5-ft) reinforced concrete subsurface intruder barrier (alternative 5) was judged the most costly to construct and to have the highest material costs. The 9-m (30-ft) waste tire and bailing wire subsurface intruder barriers (alternatives 3 and 4) were judged most costly to maintain and integrate into the surrounding cover. The 4-m (13-ft) monolayer-ET covers with surface intruder barriers were judged most costly in terms of worker safety because they were judged to require the most labor hours with use of heavy equipment.

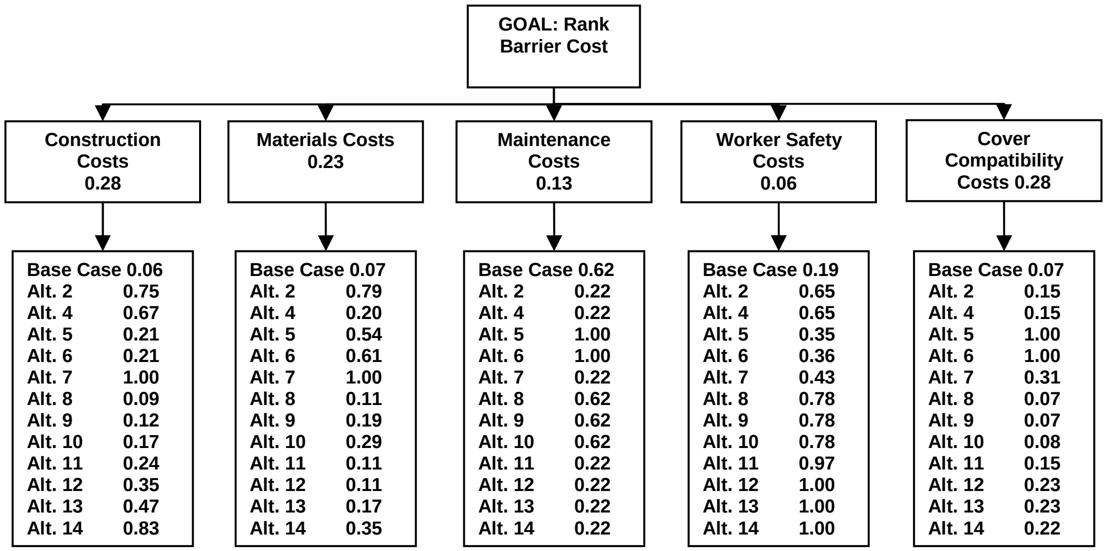

Figure 4.8 Summary of alternative engineered barrier cost rankings.

4.2.3 Cost-Effectiveness of Alternative Engineered Barriers

The benefit and cost weights for the various criteria are synthesized into a final score for each alternative (Table 4.2). The greatest benefits are expected for the 9-m (30-ft) waste rubber tire and bailing wire subsurface intruder barriers. Although these alternatives were conceived as intruder barriers, the benefit is achieved through the increased cover thickness and its effect on undisturbed performance.

The most costly alternative is the reinforced concrete subsurface intruder barrier, followed closely by the 9-m (30-ft) waste rubber tire and bailing wire subsurface intruder barriers.

Only three alternatives were judged to be more cost-effective than the base case option. The best benefit/cost ratio is obtained for the 4-m (13-ft) monolayer-ET cover. The second most cost-effective barrier is the 4-m (13-ft) monolayer-ET barrier combined with the boulder mound surface intruder barrier. The final alternative ranked above the base case was the 4-m (13-ft) monolayer-ET barrier combined with the boulder field surface intruder barrier.

Classified T04C is within the 92-ac LLWMU and will be closed when this entire unit is closed. The final closure plan for the LLWMU will be based on a formal cost-benefit analysis of closure cover options. The result of the MCDA of alternative engineered barriers for T04C is that a thicker monolayer-ET cover and a thicker monolayer-ET cover with a boulder mound surface intrusion barrier should be considered in the formal cost-benefit analysis for closure of T04C.

Table 4.2 Alternative engineered barrier benefit/cost ratios and ranks.

Alternative	Description	Benefit Rank	Cost Rank	Benefit/Cost Rank	Rank
Base	2.8 m ET Cover	0.160	0.147	1.085	4
Alt. 1	Asphalt Layer @ 1.35 m, 4-m Cover	0.301	0.510	0.589	13
Alt. 2	Capillary Break Layer @ 0.7 m, 4-m Cover	0.307	0.352	0.870	8
Alt. 3	9 m Rubber Tire Layer @ 1.1 m, 12.5-m Cover	0.619	0.626	0.988	6
Alt. 4	9 m Bailing Wire Layer @ 1.1 m, 12.5-m Cover	0.628	0.642	0.978	7
Alt. 5	1.5 m Reinforced Concrete Barrier @ 1.1 m, 5-m Cover	0.428	0.661	0.646	12
Alt. 6	Boulder Field, 2.8-m ET Cover	0.170	0.202	0.843	10
Alt. 7	Boulder Wall, 2.8-m ET Cover	0.154	0.231	0.666	11
Alt. 8	Boulder Mound, 2.8-m ET Cover	0.234	0.270	0.865	9
Alt. 9	Thick (4-m) ET Cover	0.337	0.227	1.481	1
Alt. 10	Boulder Field, 4.0-m ET Cover	0.318	0.284	1.121	3
Alt. 11	Boulder Wall, 4.0-m ET Cover	0.337	0.336	1.005	5
Alt. 12	Boulder Mound, 4.0-m ET Cover	0.659	0.475	1.388	2

4.3 Individual Protection Requirements

The 40 CFR 191.15 IPRs limit the member of public TEDE to less than 0.15 mSv in a year. The member of public TEDE was estimated for an on site resident living directly on T04C using 5,000 LHS realizations.

4.3.1 Dose Consequences

Environmental Media Radionuclide Concentrations

The TEDE received by a resident is a function of the radionuclide concentration in soil and air. The IPR analysis considers undisturbed performance only and does not include releases by intrusion. The concentration in soil of most radionuclides is increasing throughout the 10,000-year compliance period (Figure 4.9). The highest activity concentration radionuclides released to surface soil are not from the regulated TRU waste, but are from LLW disposed in T04C.

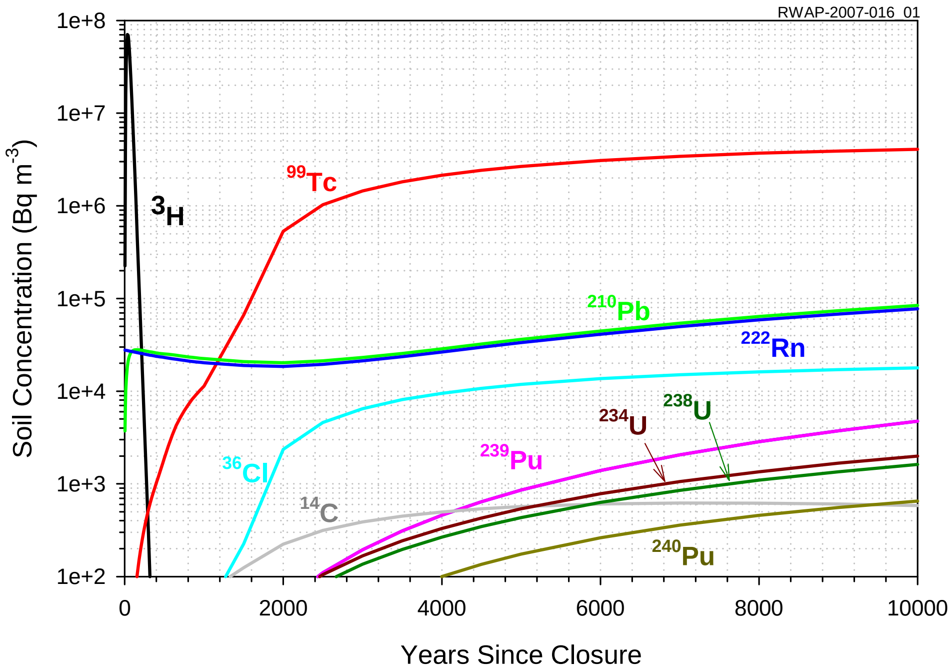

Figure 4.9 Mean radionuclide activity concentration in surface soil for undisturbed performance case.

Radionuclides transported by gaseous diffusion, ^{3}H, ^{222}Rn, and its progeny lead-210 (^{210}Pb), have the highest initial concentrations in surface soil. Tritium decays to negligible levels within a few hundred years. Radon-222 and ^{210}Pb concentrations change gradually reflecting the changing ^{222}Rn production rate in the waste. The remaining radionuclides show a gradual build-up of concentration over time as they are transported to the surface by liquid diffusion, liquid advection, and bioturbation. By 1,200 years, technetium-99 (^{99}Tc) becomes the highest concentration radionuclide. Technetium is preferentially released because its high solubility and poor adsorption on soil allows faster upward transport by liquid advection and diffusion. Once ^{99}Tc is released to cover soil below the NLFB where liquid diffusion and advection operate, plant uptake and animal burrowing transport it to surface soil.

The trends in air activity concentration closely follow that observed in soil. The activity concentration of gaseous species, ^{3}H and ^{222}Rn, are significantly enhanced relative to particulate radionuclides (Figure 4.10). Overall, air concentrations are many orders of magnitude less than soil concentrations.

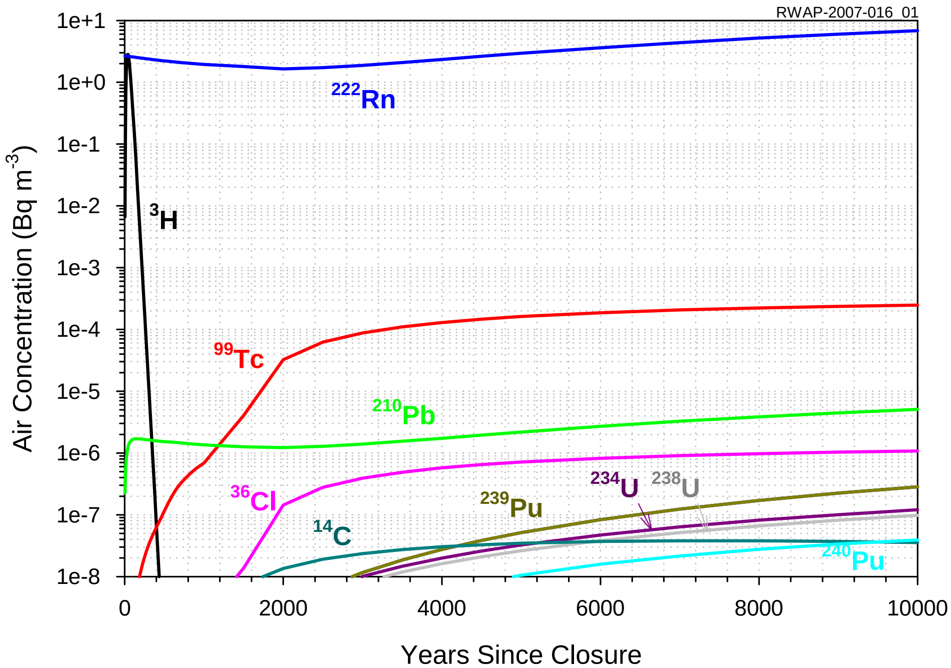

Figure 4.10 Mean radionuclide activity concentration in air above T04C.

On Site Resident Total Effective Dose Equivalent

The IPRs are assessed for an on site resident. Five thousand realizations of the TEDE were calculated for a period of 10,000 years after closure of the Area 5 RWMS. The mean TEDE reaches a maximum at 10,000 years (Figure 4.11). The mean, median, and 95th percentile TEDEs are less than the 0.15 mSv IPR throughout the 10,000-year compliance period (Table 4.3). The simulated on site resident TEDE results provide a reasonable expectation of meeting the 40 CFR 191.15 IPRs.

Table 4.3 Summary of TEDE results for the individual protection requirements on site resident scenario.

Scenario	Individual Protection Requirement (mSv)	Time of Maximum TEDE	Mean TEDE (mSv)	95th Percentile TEDE (mSv)
On Site Resident	0.15	10,000 yrs	0.055	0.15

The TEDE to an on site resident is mostly from radionuclides released from the LLW disposed in T04C (Figure 4.12). Ninety-seven percent of the TEDE at 10,000 years is from external irradiation from ^{214}Pb and bismuth-214 (^{214}Bi), short-lived progeny deposited in cover soil by ^{222}Rn diffusing in the gas phase. Another 2.5 percent is contributed by inadvertent ingestion of soil containing ^{210}Pb+P, another ^{222}Rn progeny. The TRU waste component in T04C contributes approximately 0.1 percent of the TEDE.

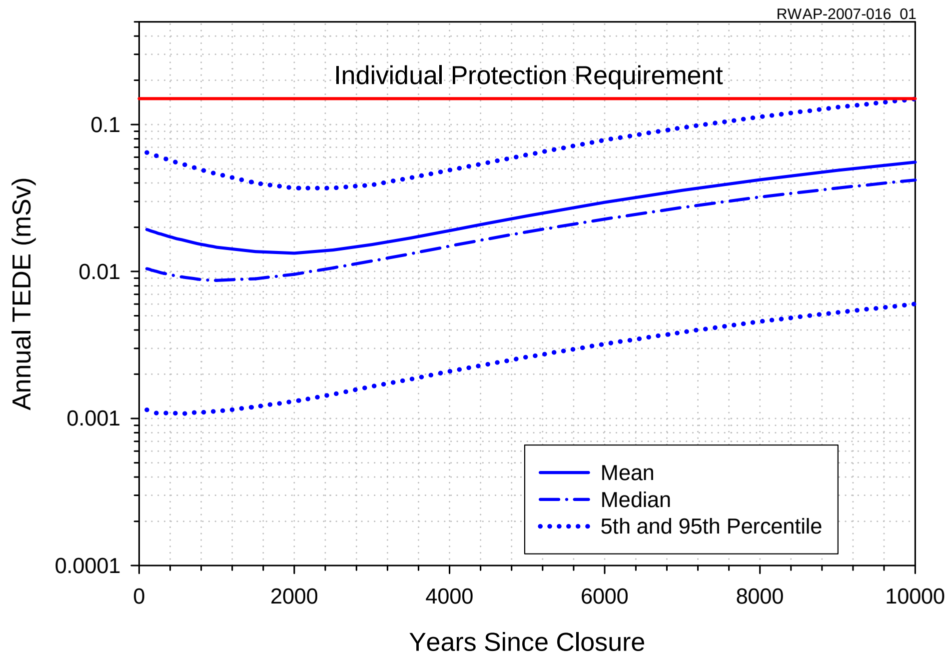

Figure 4.11 Total effective dose equivalent to an on site resident from waste disposed in T04C.

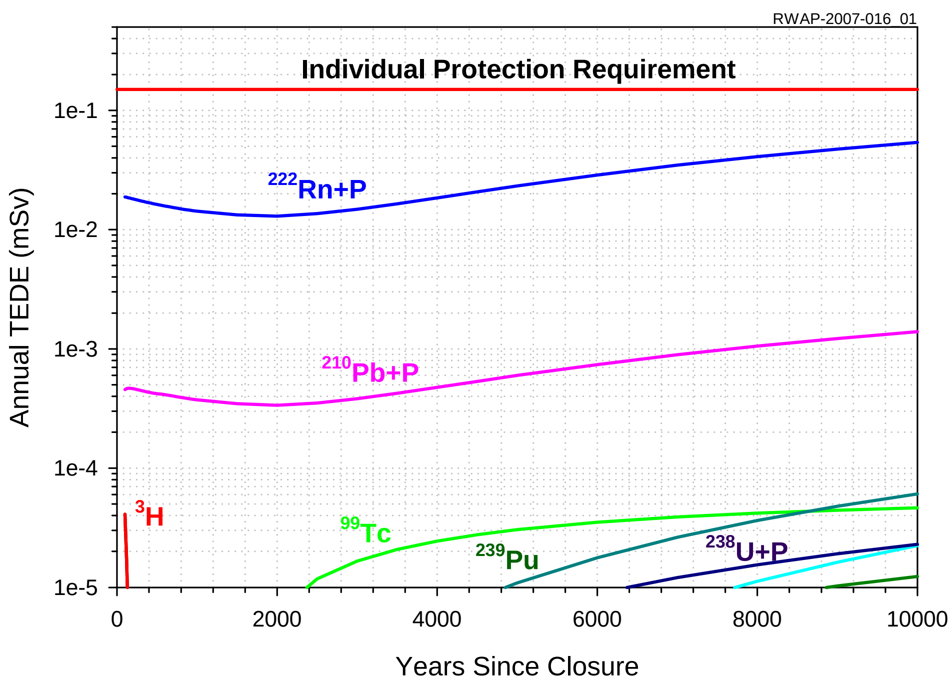

Figure 4.12 Total effective dose equivalent by radionuclide to an on site resident from waste disposed in T04C.

4.3.2 Uncertainty Analysis

Local maxima of the on site resident TEDE occur at 100 and 10,000 years after closure. The probability of exceeding the 0.15 mSv IPR was evaluated at these two times. A majority of the TEDE probability distribution at both times lies below the IPR (Figure 4.13). At 100 years, 99 percent of the cumulative probability is less than the 0.15 mSv limit. Ninety-five percent of the cumulative probability lies below the limit at 10,000 years. The probability distributions of the on site resident TEDE provide strong evidence that there is a very high probability of compliance with IPRs.

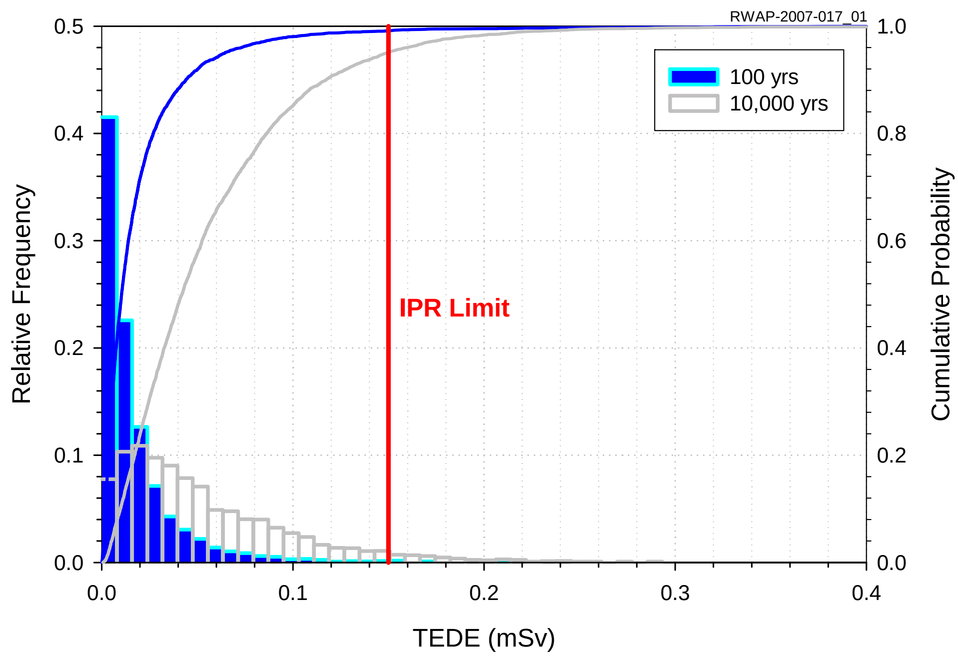

Figure 4.13 Relative frequency histogram and cumulative probabilities of on site resident exposure scenario TEDE at 100 and 10,000 years

The precision of the member of public TEDE as a function of sample size was investigated by estimating result statistics using resampling with replacement. Two thousand estimates of the mean and 95th percentile were generated from samples with different seed numbers ranging in size from 500 to 10,000 realizations. The mean and 95th percentile IPR results appear stable by approximately 5,000 realizations (Figure 4.14). A sample size of 5,000 was judged to provide acceptable precision.

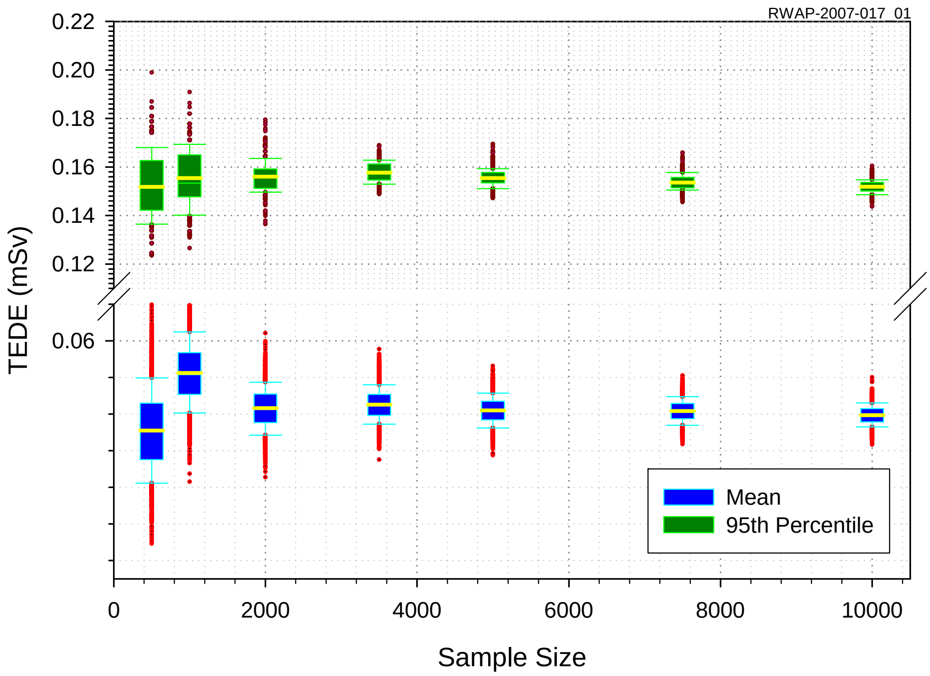

Figure 4.14 Boxplots of bootstrapped mean and 95th percentile on site resident TEDE at 10,000 years as a function of sample size. Boxplots show mean (yellow), median, 25th and 75th percentiles (box), 10th and 90th percentile (whiskers), and outliers (dots).

Length of Compliance Period

The model duration was increased to assess the likelihood that uncertainty in the model's time response could impact the confidence in the conclusion that the requirements are met. The model duration was increased to 20,000 years.

From 10,000 to 20,000 years the resident TEDE continues to increase (Figure 4.15). The on site resident TEDE is expected to approximately double from 10,000 to 20,000 years (Table 4.4). The increases are still not sufficient for the mean to exceed the IPR limit. The 95th percentile, however, exceeds the IPR limit after approximately 10,000 years.

Table 4.4 Summary of TEDE results for the IPR on site resident scenario.

Scenario	Individual Protection Requirement (mSv)	Time of Maximum TEDE	Mean TEDE (mSv)	95th Percentile TEDE (mSv)
On Site Resident	0.15	10,000 yrs	0.055	0.15
On Site Resident	0.15	20,000 yrs	0.12	0.33

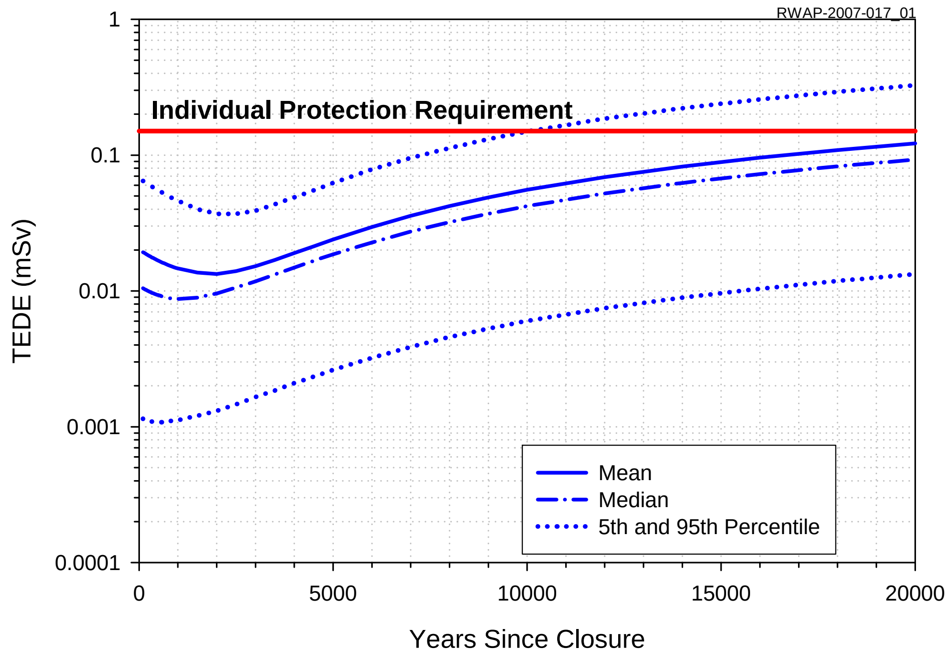

Figure 4.15 On site resident exposure scenario TEDE over 20,000 years.

Alternative Exposure Scenarios

Exposure of the public may occur under a range of exposure scenarios with different probabilities of occurrence. Alternative exposure scenarios were evaluated to assess uncertainty contributed by exposure scenario selection. Four alternative scenarios previously used for Area 5 RMWS PAs were evaluated.

The transient visitor scenario assumes that a person is directly over the site for 40 hours per week. The resident farmer scenario is identical to the resident scenario except that the resident farmer produces agricultural products (i.e., beef, chicken, milk, eggs, fruits, and vegetables) at the site and resides at the 100-m (330-ft) site boundary. The open rangeland scenario assumes that a ranch has been established at a remote site and free-range cattle can graze at the site. The ranch residents are exposed primarily through milk and beef from cattle grazing at the site. The open rangeland scenario was evaluated with a ranch located at Cane Spring (14.3 km [8.8 mi] west) and at the nearest NTS boundary.

The mean TEDEs for the alternative scenarios remain below the 0.15 mSv limit except for the resident farmer scenario (Table 4.5). The 95^{th} percentile equals or exceeds the limit for all scenarios except the transient visitor.

Table 4.5 Summary of TEDE results for the IPR using alternative exposure scenarios.

Scenario	Time of Maximum	Mean TEDE (mSv)	95th Percentile TEDE (mSv)
Transient Visitor	10,000 yrs	0.033	0.087
Resident Farmer	10,000 yrs	0.21	0.45
Open Rangeland: Cane Springs	100 yrs	0.036	0.15
Open Rangeland: NTS Boundary	100 yrs	0.037	0.15

The transient visitor TEDE is contributed mostly by external irradiation from ^{214}Pb and ^{214}Bi deposited in soil by diffusing ^{222}Rn. The transient visitor TEDE displays a similar time-dependence as the on site resident scenario and remains less than the IPR limit throughout the 10,000 year compliance period (Figure 4.16).

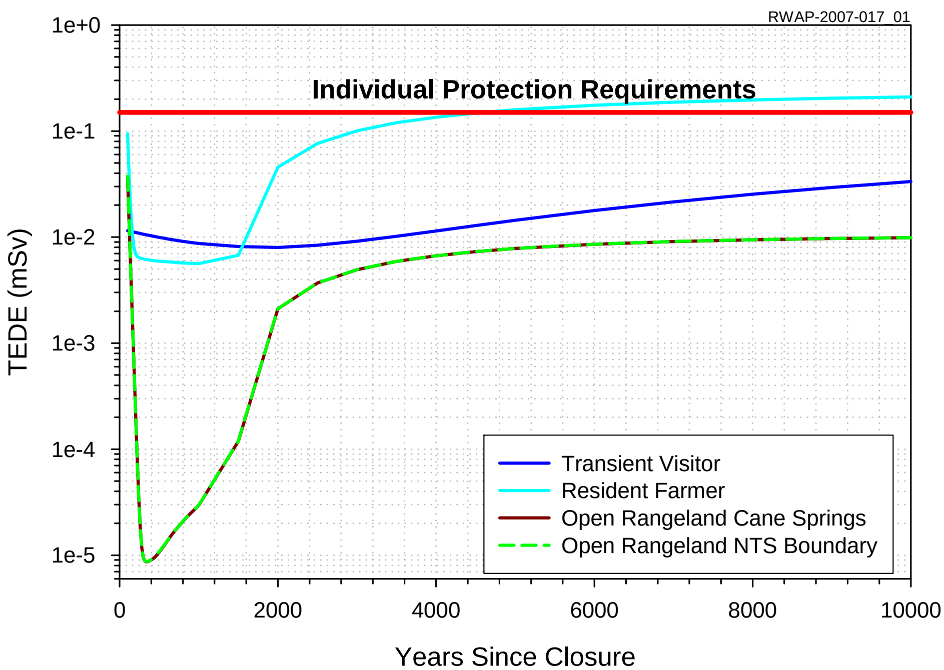

Figure 4.16 Alternative exposure scenarios mean TEDE over time.

The resident farmer and open rangeland scenarios display a similar time-dependence with early and late maxima. The early maxima for both scenarios are due to ^{3}H. The resident farmer maximum at 10,000 years is contributed mostly by ingestion of ^{210}Pb+P in vegetables grown on site. The open rangeland maxima at 10,000 years are due to ingestion of ^{210}Pb+P in beef from cattle grazing on site. The resident farmer TEDE exceeds the IPRs by approximately 4,500 years.

The alternative exposure scenario results should be considered in light of their likelihood and relation to the regulated TRU waste disposed in T04C. The doses that exceed the IPR in the resident farmer scenario are caused by radionuclides from the LLW co-located in T04C. That is to say that all disposal units at the Area 5 RWMS would likely fail this analysis due to the more restrictive 40 CFR 191 IPR limit. More restrictive requirements include evaluation of a 10,000-

year compliance period and a lower dose limit. These results would comply with the DOE M 435.1-1 performance objectives.

The likelihood of these scenarios is also low. The resident farmer scenario assumes non-commercial agricultural production, a rare event at sites throughout southern Nevada without surface water or shallow groundwater. The transient visitor scenario assumes that a transient is on site 40 hours per week (2,000 hours per year), an extremely unlikely event unless the transient were employed at the site. The foot print of the TRU waste could range from approximately 4 to 10 m^2 (43 - 107 ft^2) making it highly unlikely that a transient would be confined to this small area for such a long period. A much more likely scenario is transient visitation of the site for some short-term recreational activity.

While these results indicate the exposure scenario is an important source of uncertainty in the estimation of the dose to the member of public, the low probability of the scenario that exceeds the IPR argues that there is still a reasonable expectation of meeting the IPR.

Hydrogeologic Conceptual Model

The effect of assuming upward advection ceases during the glacial-transition climate regime was evaluated by running an alternative model with upward advection continuing throughout the glacial-transition period. The upward advection pdf was the same as during the present-day period.

The resident TEDE with upward advection continuing through the glacial-transition is nearly identical to the base case TEDE. The mean TEDE at 10,000 years increases from 0.055 to 0.056 mSv with continuing upward advection. Uncertainty concerning the status of upward advection during the glacial-transition period contributes negligibly to uncertainty in the resident TEDE.

4.3.3 Sensitivity Analysis

The sensitivity of the on site resident TEDE was evaluated at 100, 1,000 and 10,000 years. The coefficients of determination were significantly better for the gbm than the normal linear models and the gbm results are considered more accurate. The adjusted coefficients of determination for the on site resident TEDE gbm at 100, 1,000, and 10,000 years was 0.94, 0.95, and 0.99, respectively.

The sensitivity of the on site resident TEDE at 100 and 1,000 years was similar. The gbm predicted on site resident TEDE was strongly sensitive to the co-located low-level waste radium-226 (^{226}Ra) inventory and moderately sensitive to the radon emanation coefficient at both times. Slight sensitivity to the residence gamma radiation transmission factor and time spent in sedentary activities was also observed.

At 10,000 years, the gbm predicted on site resident TEDE is strongly and approximately equally sensitive to the co-located low-level ^{234}U waste inventory and the radon emanation coefficient.

Again, slight sensitivity to the residence gamma radiation transmission factor and time spent in sedentary activities was observed.

The onsite resident TEDE is predominately from external irradiation from short-lived ^{222}Rn progeny in soil. The sensitive model parameters are all related to this exposure pathway. The most sensitive parameters are related to the production and release of ^{222}Rn from the low-level co-located waste. The residence gamma radiation transmission factor and time spent in sedentary activities are also related to external irradiation. Time spent in sedentary activities is negatively related to the on site resident TEDE, because these activities are assumed to occur indoors where the residence provides partial shielding from gamma emitting ^{214}Pb and ^{214}Bi in soil.

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5.0 Performance Evaluation

The purpose of the SA is to evaluate the impacts of inadvertent disposal of small quantities of TRU waste in T04C at the Area 5 RWMS. Review of the composite analysis results and the DAS confirms that the Area 5 RWMS with the TRU waste in T04C is compliant with all DOE O 435.1-1 requirements.

Although not required, supplemental 40 CFR 191 analyses were performed. Quantitative modeling was performed to simulate releases and doses for comparison with the 40 CFR 191.13 CRs, and the 40 CFR 191.15 IPRs. The modeling was performed using the 40 CFR 191 SA v1.002 GoldSim model developed from the LLW PA model. Additional modeling was also performed to rank the cost-effectiveness of alternative engineered barriers required under 40 CFR 191.14 to increase confidence in the long-term compliance with the CRs.

The CRs limit the probability of the normalized cumulative release, R, exceeding one times the release limit to less than 1 chance in 10 (Pr[R>1] < 0.1) and the Pr(R>10) to less than 1 chance in 1,000. The SA simulated Pr(R>1) was 0.009 and Pr(R>10) was less than 1 in 10,000. Uncertainty analysis indicates that there is a very high likelihood that the CRs will be met. Uncertainty in the cumulative release is contributed predominately by uncertainty in the number of intruder boreholes.

The intent of the assurance requirements is to increase confidence in long-term compliance by requiring institutional controls (i.e., active and passive institutional controls, and monitoring) and protective site features (i.e., multiple natural and engineered barriers, lack of attractive resources, and capability to retrieve waste). Review of closure plans and DOE policies indicates that the required controls will be implemented and that the site possesses the desired features. An MCDA of alternative engineered barriers indicates that the most cost-effective engineered barriers are a thicker monolayer-ET cover and a boulder mound intruder surface barrier on a thicker monolayer-ET cover. Final closure planning will include a formal quantitative cost-benefit analysis of these two alternatives.

The IPRs limit the dose to the public to less than 0.15 mSv in a year during the 10,000 year compliance period. The SA calculated a maximum 0.055 mSv mean TEDE for an on site resident at 10,000 years. Uncertainty analysis indicates that there is a high likelihood of meeting the IPRs. Uncertainty in the on site resident TEDE is contributed predominately by the ^{222}Rn source term. The exposure scenario is another potentially significant source of uncertainty.

The Subpart C groundwater protection requirements stipulate that there must be a reasonable expectation of meeting the requirements of the *National Primary Drinking Water Regulations*, 40 CFR 141. Past performance assessment modeling has shown that there is a negligible probability of a groundwater pathway under present-day conditions. The SA results indicate that this conclusion is likely valid for 10,000 years even with changing climate. Therefore, the SA concludes that there will be no groundwater pathway for 10,000 years and there is a reasonable expectation of meeting the groundwater protection standards.

The conclusion of the SA is that there is a reasonable expectation that the TRU waste disposed in T04C with implementation of the planned institutional controls meets the requirements of DOE M 435.1-1. The approved composite analysis and DAS issued after review of the composite analysis confirm that the requirements of DOE 435.1-1 have been met. Evidence of meeting the 40 CFR 191.13 CRs is provided by the CCDF which indicates the cumulative releases are substantially below the limits. Consistency with the 40 CFR 191.14 assurance requirements is confirmed by closure plans which include all required features. Reasonable expectation of meeting the 40 CFR 191.15 IPRs is provided by the distribution of TEDEs calculated for a future resident which indicate a high level of confidence of meeting the 0.15 mSv dose limit.

6.0 References

Beatley, J.C. 1976. *Vascular plants of the Nevada Test Site and Central-Southern Nevada: Ecologic and geographic distributions*. Springfield, VA: U.S. Department of Commerce.

______. 1974. Effects of rainfall and temperature of the distribution of Larrea tridentata (Creosote Bush) in the Mojave Desert of Nevada. *Ecology* 55: 245-261.

______. 1969. Biomass of desert winter annual plant populations in southern Nevada. *Oikos* 20: 261-273.

Bechtel SAIC (Science Applications International Corporation). 2004a. *Future climate analysis*. Las Vegas, NV: Bechtel SAIC, ANL-NBS-GS-000008 Rev. 1, September 2004.

______. 2004b. *Technical basis document No. 1: Climate and infiltration*. Las Vegas, NV: Bechtel SAIC, Rev. 1, May 2004.

BN (Bechtel Nevada). 2006a. *Addendum 2 to the performance assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada: Update of performance assessment methods and results*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718—176ADD2.

______. 2006b. *A hydrostratigraphic model and alternatives for the groundwater flow and contaminant transport model of corrective action unit 97: Yucca Flat-Climax Mine, Lincoln and Nye Counties, Nevada*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718—1119.

______. 2005a. *Integrated closure and monitoring plan for the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718--449-REV2; 2005a.

———. 2005b. *A hydrostratigraphic model and alternatives for the groundwater flow and contaminant transport model of Corrective Action Unit 98: Frenchman Flat, Clark, Lincoln, and Nye Counties, Nevada*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718—1064.

———. 2005c. *Annual summary report for the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Bechtel Nevada.

———. 2005b. *Data report: Groundwater monitoring program Area 5 Radioactive Waste Management Site*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718--1015.

———. 2001a. *Composite analysis for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Bechtel Nevada, DOE/NV—594.

______. 2001b. *Ecology of the Nevada Test Site: An annotated bibliography*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718—594.

______. 2001c. *Addendum 1: Performance assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718—176-ADD1, November 2001.

Biondini, M.E., C.D. Bonham, and E.F. Redente. 1985. Secondary successional patterns in a sagebrush (*Artemisia tridentata*) community as they relate to soil disturbance and soil biological activity. *Plant Ecology* 60: 25-36.

Black, P., K. Black, L. Stahl, M. Hooten, T. Stockton, and D. Neptune. 2001. *Assessing the probability of inadvertent human intrusion at the Nevada Test Site Radioactive Waste Management Sites, Vols I and II*. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office, DOE/NV—593-Vol. I, II.

Blout, D.O., W.S. Birchfiel, D.P. Hammermeister, K.A. Zukosky, and K.D. Donnelson. 1995. *Site characterization data from the Area 5 science boreholes, Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Reynolds Electrical and Engineering Co. Inc., DOE/NV11432—170, February 1995.

Canadell, J., R.B. Jackson, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D. Schulze. 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia* 108: 583-595.

Carr W.J. 1983. *Regional structural setting of Yucca Mountain, Southwestern Nevada, and late Cenozoic rates of tectonic activity in parts of the Southwestern Great Basin, Nevada and California*. Washington, DC: U.S. Geological Survey Open-File Report 84-854.

Carr, W.J., G.D. Bath, D.L. Healey, and R.M. Hazelwood. 1975. *Geology of Northern Frenchman Flat, Nevada Test Site*. Washington, DC: U.S. Geological Survey, USGS Report 474-216.

Case, C., J. Davis, R. French, and S. Raker. 1984. *Site Characterization in Connection with the Low Level Defense Waste Management Site in Area 5 of the Nevada Test Site, Nye County, Nevada, Final Report*. Las Vegas, NV: Desert Research Institute, Publication No. 45034.

Castor, S.B., S.C. Feldman, and J.V. Tingley. 1990. *Mineral Evaluation of the Yucca Mountain Addition, Nye County, Nevada*. Reno, NV: Nevada Bureau of Mines and Geology, Open File Report 90-4.

Chapman J.B. 1994. *Classification of groundwater at the Nevada Test Site*. Las Vegas, NV: Desert Research Institute, DOE/10384--28.

Chu M.S.Y., and E.A. Bernard. 1991. *Waste inventory and preliminary source term model for the Greater Confinement Disposal site at the Nevada Test Site*. Albuquerque, NM: Sandia National Laboratories, SAND91—0170.

Cline J.F., K.A. Gano, and L.E. Rogers. 1980. Loose rock as biobarriers in shallow land burial. *Health Physics* 39: 497-504.

Cochran, J.R., W.E. Beyeler, D.A. Brosseau, L.H. Brush, T.J. Brown, B. Crowe, S.H. Conrad, P.A. Davis, T. Ehrhorn, T. Feeney, B. Fogleman, D.P. Gallegos, R. Haaker, E. Kalinina, L.L Price, D.P. Thomas, and S. Wirth. 2001. *Compliance assessment document for the transuranic wastes in the Greater Confinement Disposal Boreholes at the Nevada Test Site*. Albuquerque, NM: Sandia National Laboratories, SAND2001-2977, September 2001.

Connor, C.B., J.A. Stamatakos, D.A. Ferrill, B.E. Hill, G.I. Ofoegbu, F.M. Conway, B. Sagar, and J. Trapp. 2000. Geologic factors controlling patterns of small-volume basaltic volcanism: Application to a volcanic hazards assessment at Yucca Mountain, Nevada. *J. of Geophysical Research* 105: 417-432.

Crowe, B.M., P. Wallmann, and L.M. Bowker. 1998. Probabilistic modeling of volcanism data: Final volcanic hazard studies for the Yucca Mountain site. In *Volcanism studies: Final Report for the Yucca Mountain Project,* ed. F.V. Perry, B.M. Crowe, G.A. Valentine, and L.M. Bowker. Los Alamos, NM: Los Alamos National Laboratory Report LA-13478.

Crowe, B.M. 2006. *Remediation options for accidentally disposed transuranic materials in trench T04C at the Area 5 Radioactive Waste Management Complex, Nevada Test Site*. Las Vegas, NV: Apogen Technologies, DOE/NV--1267.

______. 1990. Basaltic volcanic episodes of the Yucca Mountain region. In *Proceedings of the International Meeting on High-Level Radioactive Waste Management*. 65-73. Las Vegas, Nevada: American Nuclear Society.

DOE (U.S. Department of Energy). 2007. Memorandum from Frank Marcinowski to Gerald L. Talbot, Manager Nevada Site Office. "Addendum 2 of the performance assessment for the Department of Energy, Nevada Operations Office, Nevada Test Site, Area 5 Radioactive Waste Management Site." 30 April 2007.

______. 2003a. *Environmental protection program*. Washington, D.C.: U.S. Department of Energy, DOE Order 450.1, 15 January 2003.

______. 2003b. *Use of risk-based end states*. Washington, D.C.: U.S. Department of Energy, DOE Policy P 455.1, 15 July 2003.

______. 2002. Memorandum from EM-30 to Carl Gertz, Assistant Manager of Environmental Management, Nevada Operations Office. “Compliance assessment for the transuranic wastes in the Greater Confinement Boreholes at the Nevada Test Site.” 5 February 2002.

———. 2001a. *Radioactive waste management*. Washington, D.C.: U.S. Department of Energy, DOE Order 435.1 Chg 1.

———. 2001b. *Radioactive waste management manual*. Washington, D.C.: U.S. Department of Energy, DOE M 435.1-1 Chg 1.

______. 2000. Memorandum from EM-35 to Kathleen Carlson, Manager, Nevada Operations Office. “Disposal authorization for the Nevada Test Site Area 5 Low-Level Waste Disposal Facility.” 5 December 2000.

______. 1999a. Memorandum from EM-412 to Carl Gertz, Assistant Manager of Environmental Management, Nevada Operations Office. “Performance assessment for the Greater Confinement Boreholes at the Nevada Test Site.” 6 August 1999a.

______. 1999b. *From cleanup to stewardship, a companion report to accelerating cleanup: Paths to closure*. Washington, DC: U.S. Department of Energy, DOE/EM-0466, October 1999.

______. 1998. *Accelerating cleanup: Paths to closure*. Washington, D.C.: U.S. Department of Energy, Office of Environmental Management, DOE/EM-0362, June 1998.

———. 1997. *Final waste management programmatic environmental impact statement for managing, treatment, storage, and disposal of radioactive and hazardous waste, Vols. I-V.* Washington, D.C.: U.S. Department of Energy, DOE/EIS-0200-F.

______. 1996. *Land and facility use planning*. Washington, D.C.: U.S. Department of Energy, DOE P 430.1, 9 July 1996.

______. 1990. *Radiation protection of the public and the environment*. Washington, D.C.: U.S. Department of Energy, Office of Environment, Safety and Health, DOE Order 5400.5, 8 February 1990.

______. 1984. *Radioactive waste management*. Washington, D.C.: U.S. Department of Energy, DOE Order 5820.2, 6 February 1984.

DOE/NV (U.S. Department of Energy, Nevada Operations Office). 2000. *FY 2000 long-term stewardship report, Nevada Test Site*. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office.

______. 1998a. *Nevada Test Site resource management plan*. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office, DOE/NV-518, December 1998.

______. 1998b. *Consequences of subsidence for the Area 3 and Area 5 Radioactive Waste Management Sites, Nevada Test Site*. Las Vegas, NV: U.S. Department of Energy Nevada Operations Office, DOE/NV—502.

______. 1998c. *Accelerating cleanup: Paths to closure*. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office, June 1998.

______. 1997. *Regional groundwater flow and tritium transport modeling and risk assessment of the underground test area, Nevada Test Site, Nevada*. Las Vegas, NV: U.S. Department of Energy, Nevada Site Office, DOE/NV—477.

______. 1996. *Final environmental impact statement for the Nevada Test Site and off-site locations in the state of Nevada*. Las Vegas, NV: U.S. Department of Energy, Nevada Operations Office, DOE/EIS 0243, August 1996.

Doorenbos, J., and W.O. Pruit. 1977. *Guidelines for predicting crop water requirements*. Rome: Food and Agriculture Organization of the United Nations, FAO Irrigation and Drainage Paper 24.

Eckerman, K.F., A.B. Wolbarst, and A.C.B. Richardson. 1998. *Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion*. Washington, D.C.: U.S. Environmental Protection Agency, Federal Guidance Report 11.

Eckerman, K.F., and J.C. Ryman. 1993. *External exposure to radionuclides in air, water, and soil*. Washington, D.C.: U.S. Environmental Protection Agency, Federal Guidance Report 12.

Ehrlinger, J.R., S.L. Philips, W.S.F. Schuster, and D.R. Sandquist. 1991. Differential utilization of summer rains by desert plants. *Oecologia* 88: 430-434.

EPA (U.S. Environmental Protection Agency). 1995. *Criteria for the certification and determination of the Waste Isolation Pilot Plant's compliance with environmental standards for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes; proposed rule*. Washington D.C.: Federal Register (Volume 60, Number 19), Proposed Rules, Pages 5765-5791, 30 January 1995.

______. 1993. *Environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes*. Washington, D.C.: U.S. Environmental Protection Agency, 40 CFR Part 191.

Fayer, M.J. 2000. *UNSAT-H version 3.0: Unsaturated soil water and heat flow model*. Richland, WA: Pacific Northwest National Laboratory, PNNL--13249.

Fehner, R., and F.G. Gosling. 2000. *Origins of the Nevada Test Site*. Washington, D.C.: U.S. Department of Energy, DOE/MA-0518, December 2000.

Fleck, R.J., B.D. Turrin, D.A. Sawyer, R.G. Warren, D.E. Champion, M.R. Hudson, and S.A. Minor. 1996. Age and character of basaltic rocks of the Yucca Mountain region. *J. of Geophysical Research* 101: 8205-8227.

Forester, R.M., J.P. Bradbury, C. Carter, A.B. Elvidge-Tuma, M.L. Hemphill, S.C. Lundstrom, B.D. Mahan, L.A. Neymark, J.B. Paces, S.E. Sharpe, J.F. Whelan, and P.E. Wigland. 1999. *The climatic and hydrologic history of Southern Nevada during the late Quaternary*. Denver, CO: U.S. Geological Survey Open-File Report 98--635.

Frey, H.C., and S.R. Patil. 2002. Identification and review of sensitivity analysis methods. *Risk Analysis* 22(3): 553-578.

Garside, L.J., R.H. Hess, K.L. Fleming, and B.S. Weimer. 1988. *Oil and gas developments in Nevada*. Reno, NV: Nevada Bureau of Mines and Geology, Bulletin 104.

Gholz, H.L. 1982. Environmental limits on aboveground net primary production, leaf area, and biomass in vegetation zones of the Pacific Northwest. *Ecology* 63(2): 469-481.

GTG (GoldSim Technology Group). 2007. *User's guide, GoldSim probabilistic simulation environment, version 9.60*. Issaquah, WA: GoldSim Technology Group LLC.

Gustafson, D.L., S.E. Rawlinson, and J.J. Miller. 2007. *Summary of natural resources that potentially influence human intrusion at the Area 5 Radioactive Waste Management Site DOE/Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: National Security Technologies, LLC, DOE/NV/25946--198.

Guzowski, R.V., and G. Newman. 1993. *Preliminary identification of potentially disruptive scenarios at the Greater Confinement Disposal Facility*. Albuquerque, NM: Sandia National Laboratory, SAND93--7100.

Hadley, N.F., and S.R. Szarek. 1981. Productivity of desert ecosystems. *Bioscience* 31: 747-753.

Hampton, N.L. 2006. *Biological data to support Operable Unit 7-13/14 modeling of plant and animal intrusion at buried waste sites*. Idaho Falls, ID: CH2M-WG Idaho, LLC, INEEL/EXT-01-00273.

Hansen, A.J., J.J. Rotella, M.P.V. Kraska, and D. Brown. 2000. Spatial patterns of primary productivity in the Greater Yellowstone Ecosystem. *Landscape Ecology* 15: 505-522.

Hansen, D.J., and W.K. Ostler. 2003. *Rooting characteristics of vegetation near Areas 3 and 5 Radioactive Waste Management Sites at the Nevada Test Site*. Las Vegas, NV: Bechtel Nevada, DOE/NV1171--595.

Heizler, M.T., F.V. Perry, B.M. Crowe, L. Peters, and R. Appelt. 1999. The age of the Lathrop Wells volcanic center: An $^{40}Ar/^{39}Ar$ dating investigation. *J. of Geophysical Research* 104: 767-804.

Hogg, R.V., J.W. McKean, and A.T. Craig. 2005. *Introduction to mathematical statistics*. 6th ed. Upper Saddle River, NJ: Pearson Prentice Hall.

Hooten, M.M., J.T. Markwiese, T.G. Myles, P. Black, and R. Ryti. 2004. *A literature review of biotic components, processes, and characteristics central to biotic transport modeling of soils at the Nevada Test Site*. Los Alamos, NM: Neptune and Company, Inc, Unpublished manuscript.

ICP (Idaho Completion Project). 2004. *Preliminary design for an engineered surface barrier at the Subsurface Disposal Area*. Idaho Falls, ID: Idaho Completion Project, ICP/EXT-04-00216, September 2004.

Imbrie, J., A.C. Mix, and D.G. Martinson. 1993. Milankovitch theory viewed from Devils Hole. *Nature* 363: 531-533.

Istok, J.D., D.O. Blout, L. Barker, K.R. Johnejack, and D.P. Hammermeister.1994. Spatial variability in alluvium properties at a low-level nuclear waste site. *Soil Science Society of America J.* 58: 1040-1051.

Jackson, R.B., J. Canadell, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D. Schulze. 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia* 108: 389-411.

Kemnitz, M. 1999. *Seismic evaluation of the U3ax/bl landfill in the Area 3 RWMS, Nevada Test Site, Nevada*. Las Vegas, NV: University of Nevada, Las Vegas, Unpublished master's thesis.

Knapp, A.K., and M.D. Smith. 2001. Variation among biomes in temporal dynamics of aboveground primary productivity. *Science* 291: 481-484.

Knapp, P.A. 1996. Cheatgrass (*Bromus tectorum*) dominance in the Great Basin Desert. *Global Environmental Change* 6: 37-52.

Law, B.E., and R.H. Waring. 1994. Combining remote sensing and climatic data to estimate net primary production across Oregon. *Ecological Applications* 4(4): 717-728.

Laczniak, R.J., J.C. Cole, D.A. Sawyer, and D.A. Trudeau. 1996. *Summary of hydrogeologic controls on groundwater flow at the Nevada Test Site, Nye County, Nevada*. Denver, CO: U.S. Geological Survey, Water-Resources Investigation Report 96-4109.

Lin, G., S.L. Philips, and J.R. Ehleringer. 1996. Monsoonal precipitation responses of shrubs in a cold desert community on the Colorado Plateau. *Oecologia* 106: 8-17.

Link, S.O., L.L. Cadwell, K.L. Petersen, M.O. Sackschewsky, and D.S. Landeen. 1995. *The role of plants and animals in isolation barriers at Hanford, Washington*. Richland, WA: Pacific Northwest Laboratory, PNL-10788. September 1995.

Mann, F.M., R.J. Puigh, S.H. Finfrock, R. Khaleel, and M.I. Wood. 2003. *Integrated disposal facility risk assessment*. Richland, WA: CH2M Hill Hanford Group, Inc, RPP-15834.

NAS (National Academy of Sciences). 2005. *Risk and decisions about disposition of transuranic and high-level radioactive waste*. Washington, D.C.: National Academy Press.

NNSA/NSO (National Nuclear Safety Administration/Nevada Site Office). 2007a. Individual Protection Requirements Dose Evaluation for Transuranic (TRU) Materials in Trench T04C. Memorandum from E.F. DiSanza to J.A. Ciucci, 21 December 2007.

______. 2007b. *Plan for retrieval of radioactive classified waste packages from trenches and greater confinement disposal boreholes at the Nevada Test Site, Area 5 Radioactive Waste Management Site*. Las Vegas, NV: National Nuclear Security Administration Nevada Site Office, DOE/NV--1190-REV1.

______. 2006. *Nevada Test Site Environmental Management end state vision*. Las Vegas, NV: National Nuclear Security Administration Nevada Site Office, DOE/NV--958, January 2006.

______. 2003. *Nevada Test Site waste acceptance criteria*. Las Vegas, NV: National Nuclear Security Administration Nevada Site Office, DOE/NV--325-Rev. 5.

______. 2002. *Performance management plan*. Las Vegas, NV: National Nuclear Security Administration Nevada Operations Office, August 2002.

NRC (U.S. Nuclear Regulatory Commission). 1989. *Calculation of radon flux attenuation by earthen uranium mill tailings covers*. Washington, D.C.: U.S. Nuclear Regulatory Commission, Regulatory Guide 3.64.

NSTec (National Security Technologies). 2007. *Passive barriers to inadvertent human intrusion for use at the Nevada Test Site*. Las Vegas, NV: National Security Technologies, LLC, DOE/NV/2594--206.

Ostler, K.W., D.J. Hansen, D.C. Anderson, and D.B. Hall. 2000. *Classification of vegetation of the Nevada Test Site*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718--477.

Pearson, L.C. 1965. Primary production in grazed and ungrazed desert communities of Eastern Idaho. *Ecology* 46(3): 278-285.

Press, W.H., B.P. Flannery, S.A. Teukolsky, and W.T. Vetterling. 1986. *Numerical recipes*. Cambridge: Cambridge University Press.

REECo (Reynolds Electrical and Engineering Co. Inc.). 1993. *Hydrogeologic data for science trench boreholes at the Area 5 Radioactive Waste Management Site, Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Reynolds Electrical and Engineering Co. Inc, DE-AC08-NV11432, December 1993.

______. 1994. *Site characterization and monitoring data from Area 5 pilot wells, Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Reynolds Electrical and Engineering Co. Inc, DOE/NV/11432-74, February 1994.

Richard-Haggard, K. 1983. *Economic potential of alternative land and natural resources uses at the Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Desert Research Institute, Publication No. 45030.

Ridgeway, G. 2007. Generalized boosted models: A guide to the gbm package [on line]. Available at: http://i-pensieri.com/gregr/papers/gbm-vignette.pdf. Accessed 18 July 2007.

R Project. 2007. The R-project for statistical computing [on line]. Available at: http://www.r-project.org. Accessed 18 July 2007.

RSN (Raytheon Services Nevada). 1994. *Summary of volcanic activity at the Area 5 Radioactive Waste Management Site, Department of Energy, Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Raytheon Services Nevada, Letter Report.

Rundel, P.W., and A.C. Gibson. 1996. *Ecological communities and processes in a Mojave Desert ecosystem: Rock Valley, Nevada*. 1st ed. New York, NY: Cambridge University Press.

Saaty, T.L. 1990. How to make a decision: The analytic hierarchy process. *European J. of Operational Research* 48: 9-26.

______. 1986. Axiomatic foundation of the analytic hierarchy process. *Management Science* 32(7): 841-855.

Sawyer, D.A., R.J. Fleck, M.A. Lanphere, R.G. Warren, D.E. Broxton, and M.R. Hudson. 1994. Episodic caldera volcanism in the Miocene Southwestern Nevada Volcanic Field: Revised stratigraphic framework, $^{40}Ar/^{39}Ar$ geochronology, and implications for magmatism and extension. *Geological Society of America Bull*.: 1304-1318.

Scanlon, B.R., R.P. Langford, and R.S. Goldsmith. 1999. Relationship between geomorphic settings and unsaturated flow in an arid setting. *Water Resources Research* 35: 983-999.

Scanlon, B.R., W.F. Mullican , R.C. Reedy, and E.S. Angle. 1997. Prototype engineered barrier designs for low-level radioactive waste disposal in Texas. In *Landfill capping in the semi-arid West: Problems and solutions* ed. T.D. Reynolds, and R.C Morris, Idaho Falls, ID: Environmental Science and Research Foundation.

Schenk, J.H., and R.B. Jackson. 2002. Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. *J. of Ecology* 90: 480-494.

Shott, G.J., V. Yucel, M.J. Sully, L.E. Barker, S.E. Rawlinson, and B.S. Moore BS. 2000. *Performance assessment/composite analysis for the Area 3 RWMS at the NTS, Nye County, Nevada, Revision 2.1*. Las Vegas, NV: Bechtel Nevada, DOE/NV--491-REV 2.1, October 2000.

Shott, G.J., L.E. Barker, S.E. Rawlinson, M.J. Sully, and B.A. Moore. 1998. *Performance assessment for the Area 5 Radioactive Waste Management Site, Nye County, Nevada*. Las Vegas, NV: Bechtel Nevada, DOE/NV/11718--176.

Sims, P.L., and J.S. Singh. 1978a. The structure and function of ten western North American grasslands, III. Net Primary production, turnover, and efficiencies of energy capture and water use. *J. of Ecology* 66: 573-597.

Sims, P.L., J.S. Singh, and W.K. Lauenroth. 1978b. The structure and function of ten western North American grasslands, I Abiotic and vegetational characteristics. *J. of Ecology* 66: 251-285.

SND (State of Nevada Demographer). 2007. 2006 estimates by county [online]. Available at: http://www.nsbdc.org/what/data_statistics/demographer/pubs/pop_increase/. Accessed 30 August 2007.

SNL (Sandia National Laboratories). 1992. Memorandum to Natalie Olague from Laura Price. Inventory of TRU waste in the trenches. 29 April 1992.

Sobol', I.M. 2001. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. *Mathematics and Computers in Simulation* 55: 217-280.

State of Nevada, U.S. Department of Energy, and U.S. Department of Defense. 2007. Federal facility agreement and consent order (FFACO). May 10, 1996. January 2007 revision [online]. Available at: http://empcs.nv.doe.gov/emis2/fa/pg/FFACO.pdf. Accessed 2 April 2007.

Stoller-Navarro. 2006. *Phase II groundwater flow model of corrective action unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada*. Las Vegas, NV: Stoller-Navarro, S-N/99205--074, May 2006.

TRW (Thompson Ramo Wooldridge, Inc). 1996. *The vegetation of Yucca Mountain: Description and ecology*. Las Vegas, NV: TRW Environmental Safety Systems, DOE/RW/00134--281-96.

Tyler, S.W., J.B. Chapman , S.H. Conrad, D.P. Hammermeister, D.O. Blout, J.J. Miller, M.J. Sully, and J.M. Ginanni. 1996. Soil-water flux in the southern Great Basin, United States: Temporal and spatial variation over the last 120,000 years. *Water Resources Research* 32(6): 1481-1499.

USDA (U.S. Department of Agriculture). 2007. Forest service fire effects information system\Larrea tridentata [online]. Available at: http://www.fs.fed.us/database/feis/plants/shrub/lartri/all.html. Accessed 28 March 2007.

Virta, R.L. 2006. *2005 Minerals yearbook, zeolites*. Washington, D.C.: U.S. Geological Survey, June 2006.

Walvoord, M.A., F.M. Phillips, S.W. Tyler, and P.C. Hartsough. 2002. Deep arid system hydrodynamics, 2. Application to paleohydrologic reconstruction using vadose zone profiles from the northern Mojave Desert. *Water Resources Research* 38(12): 271-276.

Webb, W., S. Szarek, W.K. Lauenroth, and M. Smith. 1978. Primary productivity and water use in native forest, grassland, and desert ecosystems. *Ecology* 59(6): 1239-1247.

Whittaker, R.H., and W.A. Niering. 1975. Vegetation of the Santa Catalina Mountains, Arizona. V. Biomass, production, and diversity along the elevation gradient. *Ecology* 56: 771-790.

Winograd, I.J., and W. Thordarson. 1975. *Hydrologic and hydrochemical framework, South-Central Great Basin, Nevada-California, with special reference to the Nevada Test Site*. Washington, DC: U.S. Geological Survey, Professional Paper 712-C.

Wolfsberg, A., and P. Stauffer. 2003. *Vadose zone fluid and solute flux: Advection and diffusion at the Area 5 Radioactive Waste Management Site*. Los Alamos, NM: Los Alamos National Laboratory, LA-UR-03-4819.

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7.0 Appendices

A1 Waste Inventory

The inventory of T04C was estimated using the Area 5 Inventory Model, version 2.021. The model is implemented in the probabilistic GoldSim modeling platform, allowing estimation of inventory uncertainty by Monte Carlo simulation. Inventory radioactive decay and ingrowth during the operational period is also handled by native GoldSim routines for solution of the Bateman equations. Model input data, data sources, assumptions, and methods are documented in notes, comments, hyperlinks, and graphics included within the model.

The model algorithm follows the following sequence:

1) Get individual nuclide annual disposal rates (Bq yr^{-1}) and volume disposal rate (m^3 yr^{-1}) summed over all generators by fiscal year from inventory records.
2) Estimate future disposal rates based on generator projections of future waste volume and past annual mean waste activity concentrations.
3) Estimate scaling factors for nuclides not recorded on past inventory records. Estimate the volume of waste not included in inventory queries.
4) Correct past disposal rates for radionuclides and waste volume not included in inventory records. Integrate corrected disposal rates over time, including effects of radioactive decay and ingrowth.

Important model inputs are probability density functions (pdfs) representing uncertainty. Input pdfs are repeatedly sampled and propagated through the model to produce a distribution of model results. The model output distributions are well represented by lognormal distributions and are input into the 40 CFR 191 SA model as lognormal distributions with the geometric mean and standard deviation of the inventory model outputs.

A1.2 Data Sources

Inventory records for the Area 5 RWMS are maintained in three major sources: the waste management logbook, the waste management database (WMD), and the low-level waste information system (LWIS). In addition to the database records, unclassified records accompanying the shipment, on site survey records, and receipt records are maintained in an electronic imaging system.

Three data sources were used to estimate the inventory in T04C. The TRU waste inventory is estimated from an unclassified memorandum (Sandia 1992). The co-located low-level waste inventory data sources are the waste management logbook, in use from 1961 to 1978, and the WMD, an electronic database in use from approximately 1978 to 1993.

The records described above have numerous limitations that have been noted in the past (Shott et al. 1998; 2000). Known problems include:

- Waste characterization before 1994 is not complete. Important radionuclides may not be reported. In early records, no radionuclides may be identified and disposals are simply recorded as "Curies." Some records indicate mixtures of radionuclides, such as mixed fission products, depleted uranium, enriched uranium, plutonium, or plutonium scrap codes (e.g., PU51, PU52, or PU57).
- Inventory records are not complete. Not all disposals were entered into waste management records. During some periods, classified disposals were not recorded in the databases. The disposals in T04C apparently occurred during this period, and very few of the disposals in T04C are recorded in the WMD.
- The pre-1993 relational database (i.e., the WMD) tables are not completely populated with data. Consequently, some records in different database tables cannot be linked and retrieved in queries.
- The pre-1993 database nuclide quantity data is recorded by shipment rather than by container. If containers within a shipment were sent to different disposal units, the total shipment inventory will be recorded as disposed in each unit. This may cause multiple counting of some inventories.

The T04C TRU waste inventory is reported in an unclassified memorandum which summarizes the waste inventory (SNL 1992). The data in the memorandum were extracted from the original shipping records, which remain classified.
Because specific disposal records are not available for T04C, the co-located low-level waste inventory is estimated as the mean waste activity concentration of waste disposed before 26 September 1988.

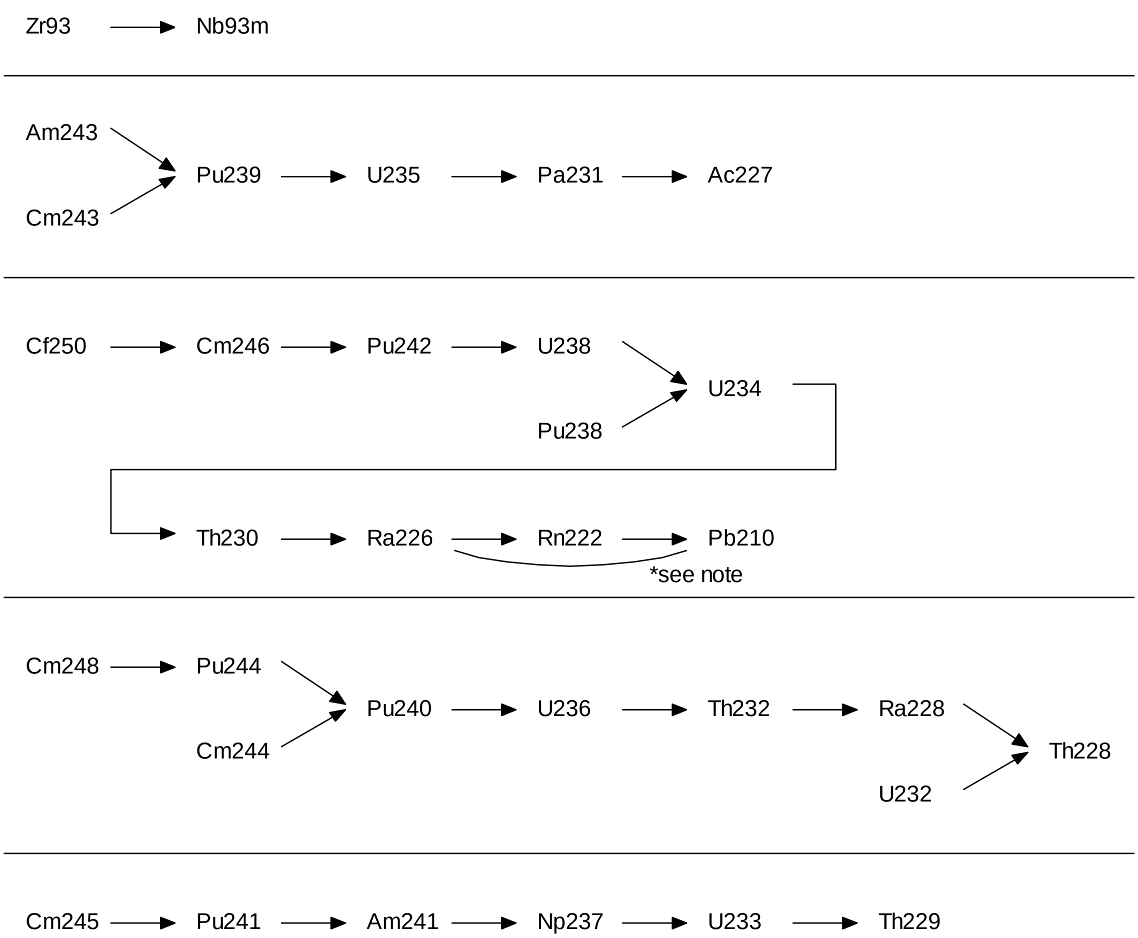
A1.3 Important Model Assumptions

Model methods and assumptions are documented within the model itself. Important model assumptions include:

- Radionuclides included in the inventory are limited to those with a half-life greater than five years or those that decay to a progeny with a half-life greater than 5 years. Short-lived progeny are assumed to be in secular equilibrium with a long-lived parent. Radionuclides not appearing in Figure A1.1 are those assumed to be in equilibrium.
- Uncertainty in disposed waste inventories is poorly known. Therefore, waste uncertainty is represented by what is believed to be a conservative distribution. The annual sums of radionuclide activity disposed before 1 October 1988, are assumed to be the median of a loguniform distribution.
- Waste disposed before fiscal year (FY) 1994 is assumed to be incompletely characterized. Radionuclide disposal rates before FY 1994 are corrected for unreported radionuclides. Activity disposed as gross activity or mixed fission product activity is scaled to estimate individual radionuclide activity assuming that the mixture has the same radionuclide composition as the Nevada Test Site underground testing areas (Bowen et al. 2001). The reported gross activity or fission product

activity is assumed to be the activity of ^{137}Cs and all other fission product and activation product activity is scaled from ^{137}Cs. The activity of ^{238}U and ^{235}U disposed before FY 1994 is assumed to be the activity of depleted and enriched uranium, respectively. Scaling factors for other uranium isotopes are based on a published relationship between specific activity and enrichment of uranium for the gaseous diffusion process (DOE 2001). Scaling factors for minor contaminants in uranium are estimated from data provided by generators. Plutonium disposed as PU51, PU52, and PU57 are assigned individual radionuclide activities based on isotopic composition of standard plutonium scrap codes (ANSI 1987) and typical values expected for weapons-grade plutonium.

- Waste management databases do not include data for all disposed wastes. Some waste shipments were not recorded in the databases. Some database tables are not fully populated and waste inventories cannot be retrieved by queries. The potential missing waste has been estimated by subtracting the volume of disposed waste retrieved from the databases from the physical volume of filled waste disposal units. The missing volume has been added to the inventory assuming it has the mean concentration of disposed waste. This correction is applied to pre-1988 waste only.



*the radon emanation factor for all materials is incorporated by branching from Ra226 to Rn222 and Pb210

Figure A1.1 Long-lived radionuclides included in model decay chains.

A1.4 Waste Inventory

A1.4.1 TRU Waste Inventory

The inventory of waste in the 102 TRU waste containers from Rocky Flats is summarized in Table A1.1. The inventory has been revised to account for other radionuclides likely present in weapons-grade plutonium and highly enriched uranium, but not reported in the disposal records. The inventory is also decayed to the assumed date of final site closure in 2028 (Table A1.1). The data are reported as the geometric mean and standard deviation of a lognormal distribution.

Table A1.1 Inventory of TRU waste buried in T04C on 1 October 2028

Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation	Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation
^{210}Pb	1.3E+02	2.68	^{235}U	5.3E+06	2.77
^{226}Ra	4.1E+02	2.65	^{236}U	1.3E+06	2.28
^{228}Ra	1.2E-03	2.10	^{238}U	4.4E+03	2.85
^{227}Ac	2.1E+03	2.85	^{237}Np	1.3E+07	2.35
^{228}Th	1.1E-03	2.09	^{238}Pu	9.3E+10	2.89
^{229}Th	1.5E+00	2.44	^{239}Pu	3.1E+12	2.93
^{230}Th	4.6E+04	2.58	^{240}Pu	7.5E+11	2.85
^{232}Th	1.7E-03	2.13	^{241}Pu	8.3E+11	2.89
^{231}Pa	4.6E+03	2.83	^{242}Pu	4.5E+07	2.81
^{233}U	1.1E+03	2.40	^{241}Am	1.0E+12	2.27
^{234}U	1.3E+08	2.45	Total	5.7E+12	

A1.4.2 Co-Located LLW Inventory

The dose assessment for the IPRs includes the dose from LLW disposed in T04C. This waste is referred to as the co-located low-level waste. Because there are no database records identifying this waste, the inventory is estimated as the product of the T04C trench volume, corrected for the TRU volume, and the mean activity concentration of pre-1988 LLW. The LLW inventory is summarized in Table A1.2 as the geometric mean and standard deviation of a lognormal distribution. The waste inventory has been corrected for radionuclides likely present in LLW, but not recorded in disposal records. The inventory is decayed to the expected closure date, 1 October 2028.

Table A1.2 Estimated inventory of low-level waste disposed in T04C on 1 October 2028.

Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation	Nuclide	Geometric Mean Activity (Bq)	Geometric Standard Deviation
^{3}H	7.0E+14	1.57	^{210}Pb	2.4E+10	2.52
^{14}C	5.7E+09	1.56	^{226}Ra	3.1E+10	2.53
^{26}Al	1.8E+05	1.70	^{228}Ra	9.2E+08	2.09
^{36}Cl	1.0E+09	1.65	^{227}Ac	2.5E+08	1.61
^{39}Ar	4.5E+09	1.67	^{228}Th	1.2E+09	1.78
^{40}K	2.6E+08	1.61	^{229}Th	3.5E+06	1.83
^{41}Ca	7.4E+09	1.66	^{230}Th	8.7E+08	1.59
^{60}Co	4.6E+10	2.27	^{232}Th	9.3E+08	2.09
^{59}Ni	1.9E+08	1.65	^{231}Pa	1.6E+08	1.62
^{63}Ni	1.4E+10	1.66	^{232}U	2.4E+08	1.67
^{85}Kr	9.0E+09	2.25	^{233}U	7.6E+08	1.90
^{90}Sr	3.4E+13	3.56	^{234}U	1.7E+12	1.73
^{93}Zr	2.5E+07	1.61	^{235}U	7.0E+10	1.75
^{93m}Nb	2.4E+09	1.67	^{236}U	2.3E+10	2.36
^{94}Nb	6.2E+09	1.65	^{238}U	2.0E+12	1.90
^{99}Tc	2.6E+11	2.38	^{237}Np	4.8E+09	1.74
^{107}Pd	1.1E+06	1.61	^{238}Pu	1.3E+11	1.69
^{113m}Cd	2.0E+09	1.67	^{239}Pu	1.9E+11	1.49
^{121m}Sn	5.4E+10	1.65	^{240}Pu	4.4E+10	1.47
^{126}Sn	1.1E+07	1.61	^{241}Pu	5.1E+10	1.49
^{129}I	7.9E+05	1.56	^{242}Pu	1.3E+07	1.52
^{133}Ba	4.0E+06	2.54	^{244}Pu	1.1E+08	3.92
^{135}Cs	1.9E+07	1.61	^{241}Am	5.8E+10	1.44
^{137}Cs	8.3E+13	2.84	^{243}Am	1.1E+07	2.14
^{151}Sm	2.2E+10	1.61	^{243}Cm	1.3E+08	2.16
^{150}Eu	7.9E+09	1.76	^{244}Cm	1.6E+09	2.65
^{152}Eu	5.6E+10	2.05	^{245}Cm	3.1E+03	2.89
^{154}Eu	6.6E+09	1.94	^{246}Cm	1.8E+03	2.50
^{152}Gd	3.4E-02	2.11	^{248}Cm	1.5E+03	2.95
^{166m}Ho	2.4E+08	1.64	^{250}Cf	5.7E+03	2.13
^{207}Bi	1.3E+04	3.03	Total	8.2E+14	

A1.5 Quality Assurance

The Area 5 Inventory GoldSim model is subject to the same Software Quality Assurance Plan as described for the 40 CFR 191 SA GoldSim model in Appendix A2.

A1.6 References

ANSI (American National Standards Institute). 1987. *American national standard for nuclear materials - Unirradiated plutonium scrap - Classification*. New York: American National Standards Institute, ANSI N 15.10-1987.

Bowen, S.M , D. L. Finnegan, J. L. Thompson, C. M. Miller, P. L. Baca, L. F. Olivas, G. C. Geoffrion, D. K. Smith, W. Goishi, B. E. Esser, J. W. Meadows, N. Namboodiri, and J. F. Wild. 2001. *Nevada Test Site radionuclide inventory, 1951 - 1992*. Livermore, CA: Lawrence Livermore National Laboratory, LA-13859-MS.

DOE (U.S. Department of Energy). 2001. *Health physics manual for good practices for uranium facilities*. Washington, DC: U.S. Department of Energy.

Shott, G. J., V. Yucel, M. J. Sully, L. E. Barker, S. E. Rawlinson, and B. A. Moore. 2000. *Performance assessment for the Area 3 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada (Rev. 2.1)*. Las Vegas, NV: Bechtel Nevada, DOE/NV--176-REV 2.1.

Shott, G. J., L. E. Barker, S. E. Rawlinson, M. J. Sully, and B. A. Moore. 1998. *Performance assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada (Rev. 2.1).* Las Vegas, NV: Bechtel Nevada, DOE/NV/11718--176, UC-721.

SNL (Sandia National Laboratories). Memorandum to Natalie Olague from Laura Price. Inventory of TRU waste in the trenches. 29 April 1992.

A2 Software Quality Assurance

The 40 CFR 191 SA, v 1.002, GoldSim model was developed and controlled under the National Security Technologies (NSTec) Software Quality Assurance Plan (SQAP), *Software Quality Assurance Plan for the GoldSim Models Supporting the Area 3 and Area 5 Radioactive Waste Management Site Performance Assessment Program* (NSTec 2007). The SQAP implements quality requirements described in the NSTec Company Directive CD-3500.009, *Software Quality Assurance*; and Requirements Document RD-3200.001, *Quality Assurance Requirements Document*. These NSTec documents implement the requirements of DOE Order 414.1C, *Quality Assurance* (DOE 2002). The following sections briefly summarize important features of the SQAP.

A2.1 Model Development

The Area 3 and Area 5 GoldSim Performance Assessment models are subject to a continuous process of improvement as summarized in Figure A2.1. The 40 CFR 191 SA v1.002 model was developed from the A5 RWMS v4.000 performance assessment model. Development of the 40 CFR 191 SA model required the addition of new model components (i.e. the cumulative release calculations and climate change effects) and removal of unnecessary model components. These changes were controlled and documented under the SQAP.

Model Custody

The current version of each GoldSim model is maintained throughout the development process in a network model repository in a single file. Write privileges for the model repository are granted to a single person designated as the model custodian. A custody log is maintained that records the custodian's identity and the version number of the current version over time. When a new version is created, a copy is saved in an archive folder in the model repository.

Periodically after completing acceptance testing, the current model version is issued as a baseline model for routine application. Approved baseline models are maintained in a separate write protected repository file. Baseline models are also issued to project members on a compact disk for archival purposes. Analysts performing calculations for the SA, obtain a copy of the baseline model from the repository and document their calculation in an Engineering Analysis/Calculation package which includes a copy of all models saved with results.

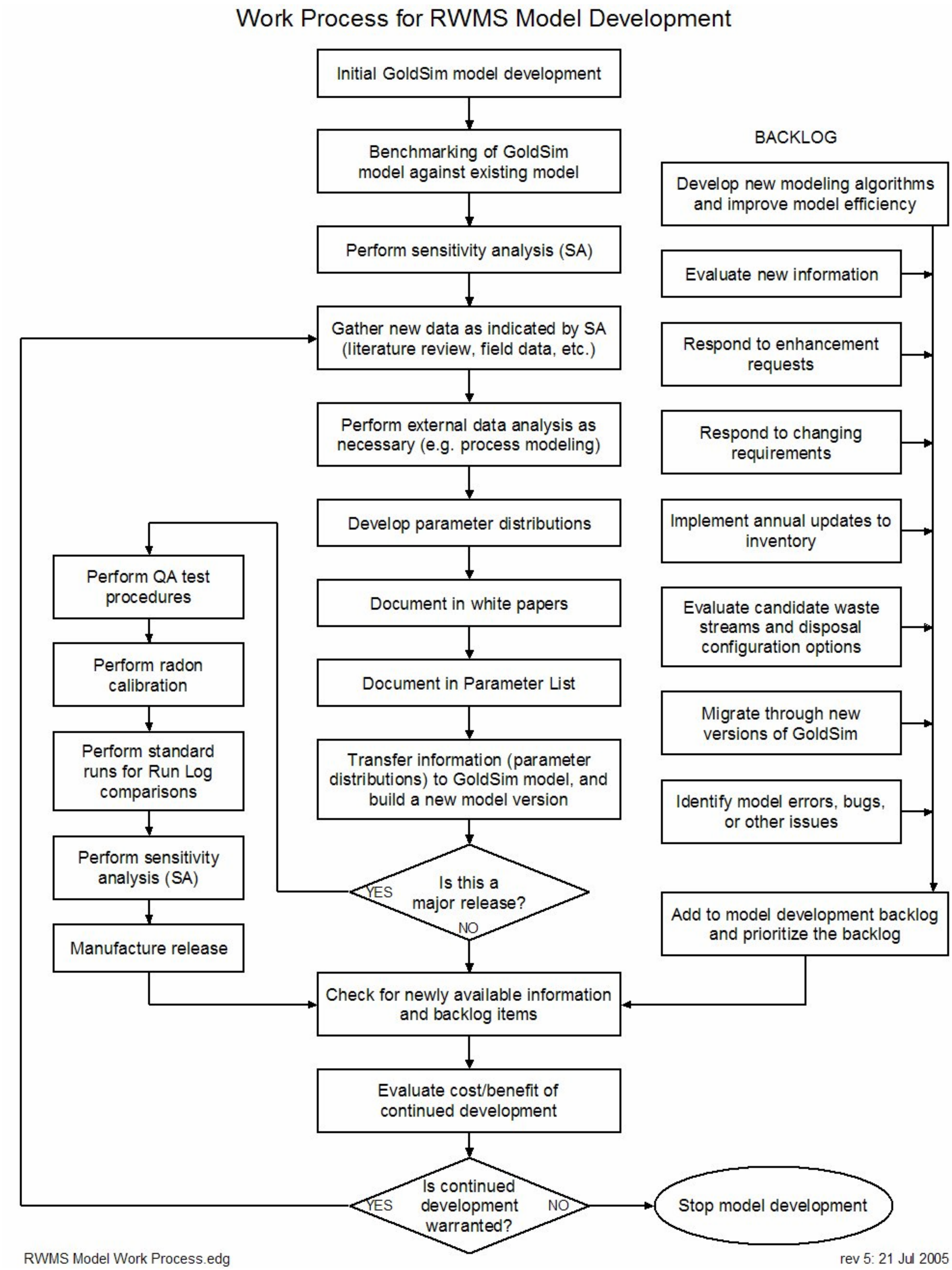


Figure A2.1 GoldSim model development process.

Documentation and Records

Multiple records are maintained to document the model development process. The GoldSim software includes a versioning feature that automatically records model changes. Periodically during the model development process, the model custodian will create a new model version and save a copy in the model repository archive. Each archived version represents a snapshot of the model at a particular time in the development process. The GoldSim software can generate a report listing changes between any two model versions and can highlight changed elements in the model browser window.

In addition to GoldSim's automatic change tracking, model developers maintain several important records within and external to the model. Whenever an element is changed, a version change note pane is available where the analyst, date, and nature of changes are recorded. Version change notes are included in the GoldSim version report described above. A higher level, chronological history of changes is recorded in a note pane associated with the \Documentation container. A brief summary of the most significant changes for each version is maintained in the \Whats_New container. An external model run log is also maintained in an Excel spreadsheet that records the result of important model end points (e.g., scenario dose, surface soil concentrations) for each model version. The model run log allows review of how model results have changed over time in response to model changes and improvements.

Additional notes can be recorded in the note pane associated with each model element. These notes are used to explain the function or performance of an element, the data source for data or stochastic input elements, and record quality assurance checks made by reviewers. Complex model components or data inputs may be supported by external documentation or Engineering Analysis/Calculation packages maintained in the model reference folder. External documents are hot-linked to the model by icons located throughout the model.

A2.2 Model Review and Acceptability Testing

Throughout the model development process, model changes are checked by a reviewer for correctness and completeness and approved by the PA/CA task leader. Model versions prepared as baseline models for release are submitted to the National Nuclear Security Administration Nevada Site Office for acceptability testing. Acceptability testing produces a report summarizing the model's performance and describing appropriate application and limitations on use of the model.

A2.3 Model Application

Each calculation supporting the SA is a model application documented by an Engineering Analysis/Calculation package. The analyst prepares the calculation documenting the software version used, assumptions, input data, calculations, and results. Each Engineering Analysis/Calculation package is checked by a subject matter expert and approved for use by the responsible manager.

A2.4 References

NSTec (National Security Technologies). 2007. *Software quality assurance plan for GoldSim models supporting the Area 3 and Area 5 Radioactive waste management site performance assessment program*. Las Vegas, NV: National Security Technologies.

DOE (U.S. Department of Energy). 2005. *DOE Order 414.1C, Quality Assurance*. Washington, DC: U.S. Department of Energy, DOE O 414.1C, June 17, 2005.

A3 Sensitivity Analysis

Sensitivity analysis is the process of quantifying how uncertainty in model input contributes to model output uncertainty. Understanding this relationship can be useful for understanding and interpreting model behavior, comparing model behavior with real system behavior, building model credibility, identifying model errors, and/or reducing output uncertainty.

Preferred sensitivity analysis methods should be global, quantitative, and model independent (Saltelli et al. 1999). A global sensitivity analysis investigates the model output response throughout the input sample space. Local sensitivity methods investigate the model response with respect to one input parameter while all other inputs are conditioned at a single value, typically the mean or median. A quantitative sensitivity analysis determines the quantitative fraction of the output variance that can be attributed to each input parameter. Model independent methods require no assumptions regarding the relationship between inputs and outputs. Model dependent methods typically assume that a linear or monotonic relationship exists between the input variable and output. If the model dependent assumptions are correct, then model dependent sensitivity indices may be nearly quantitative.

The 40 CFR 191 SA v1.002 model presents several challenges for sensitivity analysis. The model is non-linear, has non-monotonic relationships, is highly dimensional, and has limited built-in sensitivity analysis capabilities. The selected sensitivity analysis approach is to use multiple methods to confirm sensitivity ranking as recommended by Frey and Patil (2002). The methods used are the methods included in the GoldSim multivariate result element and Sobol' sensitivity indices (SIs) calculated for a generalized boosted model (gbm), a type of non-parametric regression model, fit to GoldSim model inputs and outputs (R Project 2007; Ridgeway 2007; Sobol' 2001). Sensitivity is evaluated for four model end points: the normalized cumulative release at 10,000 years and the on site resident total effective dose equivalent (TEDE) at 100, 1,000, and 10,000 years.

The GoldSim multivariate result element calculates the correlation coefficient, standardized regression coefficient (SRC), partial correlation coefficient (PCC), and the variance-based importance measure. The correlation coefficient, SRC, and PCC are model dependent methods that are reliable when the relationship between input and output is linear. The importance measure is a model independent method, but is itself a random variable and may be very uncertain if the sample size is too small (Shott et al. 2007).

The gbm package fits a non-parametric regression model to the data using the methods of Freidman (2001, 2002). The package returns a plot of the residual sum of squares versus iteration, the relative influence, and the marginal dependence of the explanatory parameters. The relative influence is a sensitivity index calculated as the Type III sum of squares error normalized to 100. The Type III sum of squares error measures the reduction in the residual sum of squares due to adding the parameter to the model with all other parameters included. The marginal dependence graphically represents the relationship between a single model input and the model prediction. The marginal dependence indicates the range over which a parameter is sensitive and indicates where thresholds may occur. Main effect and total effect Sobol' SIs were calculated for the gbm. The Sobol' SI is a global, model independent SI. However, the Sobol' SIs are not strictly quantitative for the GoldSim model because they are calculated for the gbm. The main effect SI quantifies the fraction of the model prediction variance that is attributable to variance in the input factor. The total effect SI indicates the fraction of the model variance that is attributable to the model input and all of its higher order interactions with other parameters. If the main effect and total effect SI are significantly different, this indicates that higher order interactions are present.

A3.1 Sensitivity Analysis of Cumulative Release

The SA relies on regression techniques which adequately describe sensitivity to the extent that the regression model fits the data. The adjusted coefficient of determination indicates that the cumulative release regression models fit the data reasonably well and should provide accurate qualitative ranking of input parameter sensitivity (Table A3.1). The gbm provided the best fit of the data (Figure A3.1)

Table A3.1 Sensitivity analysis regression model adjusted coefficient of determination for the normalized cumulative release.

Model Output	Normal Linear Regression	Generalized Boosted Regression
Normalized Cumulative Release	0.90	0.95

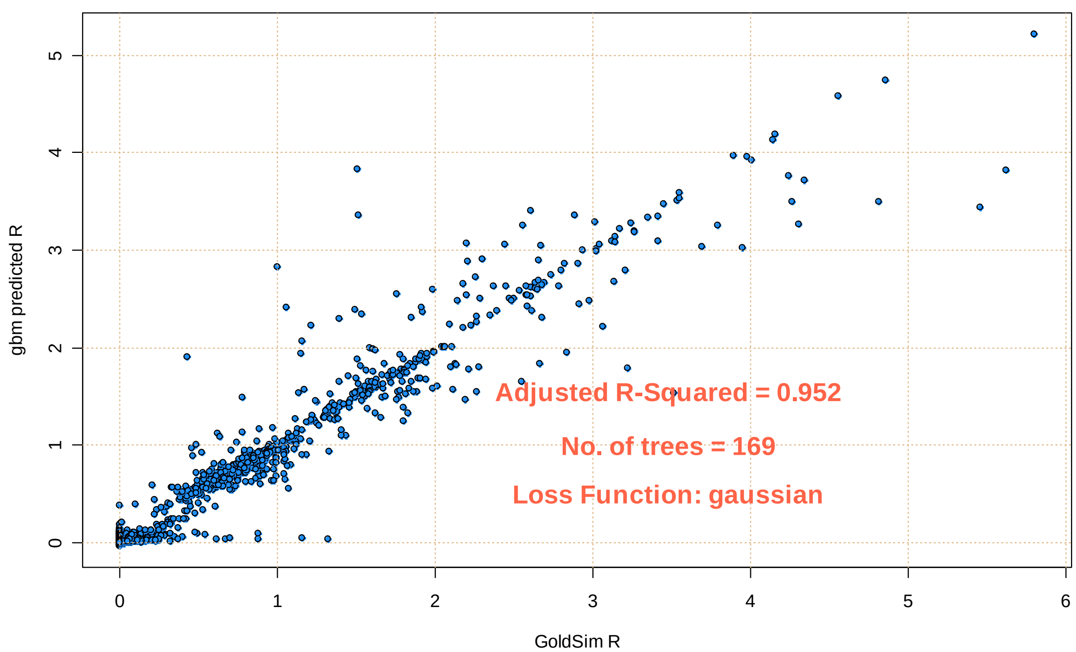


Figure A3.1 Gbm predicted normalized cumulative release, R, versus GoldSim results.

All of the GoldSim sensitivity analysis methods indicate that the normalized cumulative release is strongly sensitive to the total number of intruder boreholes, except the GoldSim importance

(Table A3.2). The cause of the poor performance of the GoldSim importance to detect the sensitivity of the total number of boreholes is unknown.

Table A3.2 Summary of GoldSim sensitivity analysis results for the normalized cumulative release

Parameter	Correlation Coefficient	SRC	PCC	GoldSim Importance
Number of Boreholes	0.948	0.947	0.948	0

The gbm predicted cumulative release was also strongly sensitive to the number of intruder boreholes with 78 percent of the model variance explained by this parameter (Table A3.3). The total effect of the number of intruder boreholes accounted for 100 percent of the model variance. Moderate total effects sensitivity to the number of boreholes per intrusion event and slight sensitivity to the ^{239}Pu inventory was observed. These parameters influence model variance through interactions with other model parameters.

Table A3.3 Main and total effects Sobol' SIs for the normalized cumulative release.

Parameter Description	Main Effects SI	Total Effect SI
Total Number of Intruder Boreholes	0.78	1.00
Number of Wells per Intrusion	N.D.	0.15
^{239}Pu TRU Inventory	N.D.	0.03
Total	0.78	1.18

N.D. – sensitivity not detected

The gbm model marginal dependencies indicate that the cumulative release is an approximately linearly increasing step function of the total number of intruder boreholes and the number of boreholes per intrusion event (Figure A3.2). The ^{239}Pu TRU inventory shows a non-linear rapidly increasing relationship with the cumulative release. The decreasing relationship between cumulative release and ^{241}Am inventory appears to be a spurious relationship in the gbm.

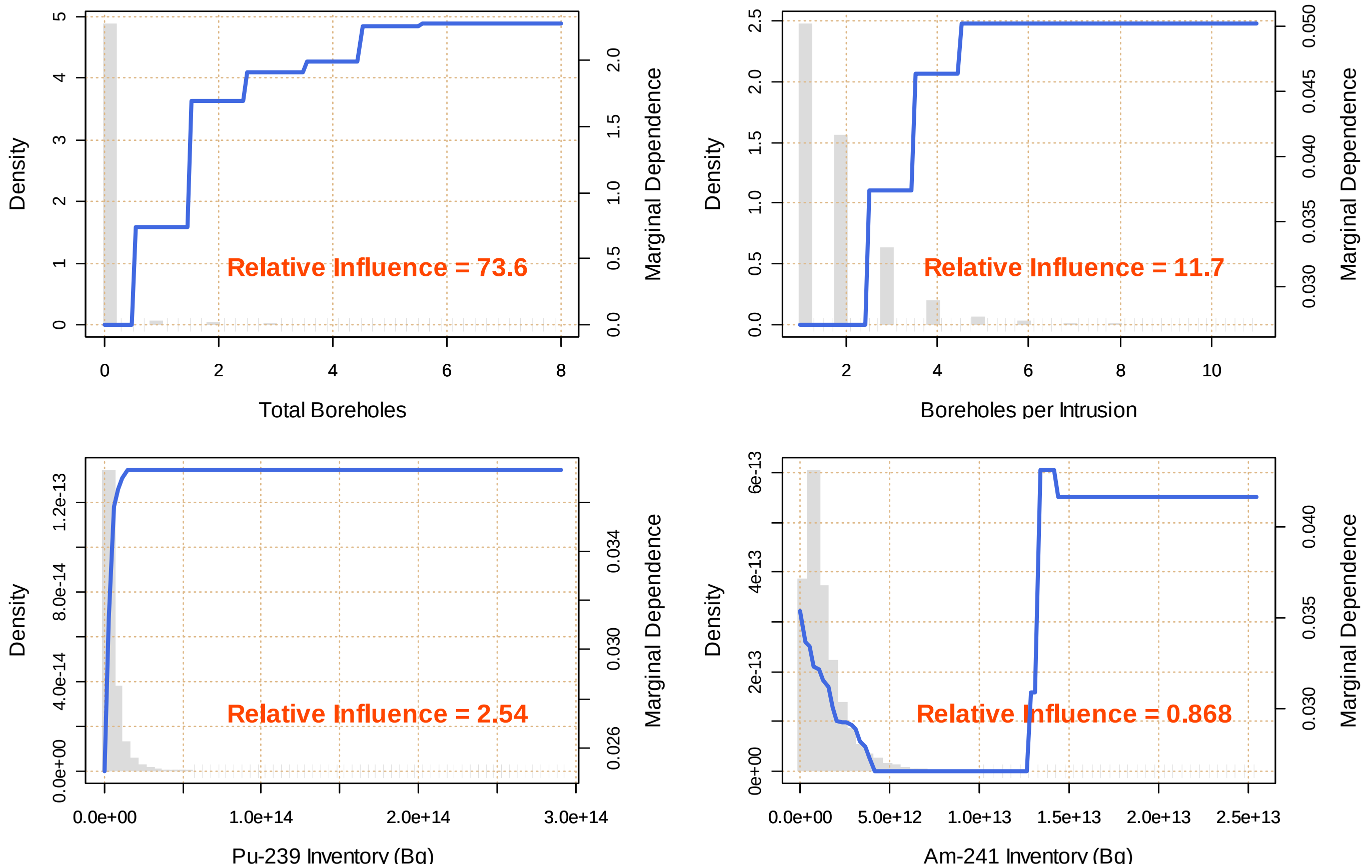


Figure A3.2 Histogram (gray) and marginal dependence (blue) of most sensitive input parameters for the cumulative release as measured by the gbm relative influence.

The scatterplot matrix shows a strong relationship between the cumulative release and two input parameters: the total number of boreholes and the number of wells per intrusion event (Figure A3.3). The total number of boreholes is not a stochastic input parameter, but rather an intermediate value calculated as the product of the number of intrusion events and number of wells per intrusion event. Before this calculated value was included in the sensitivity analysis, the gbm fit of the data was poor. The poor fit was likely caused by the nonmonotonic relationship that can be seen in the scatterplot of the cumulative release and the number of wells per intrusion event (row 1, column 3). The nonmonotonic relationship occurs, because the wells per intrusion event probability mass function is sampled every realization, but most realizations do not include an intrusion event. Therefore, for each discrete value of the number of wells per intrusion event there are two possible outcomes: an increase in cumulative release if intrusion occurs and no increase if intrusion does not occur. The scatterplots are generally consistent with the relative influences and marginal dependencies from the gbm model.

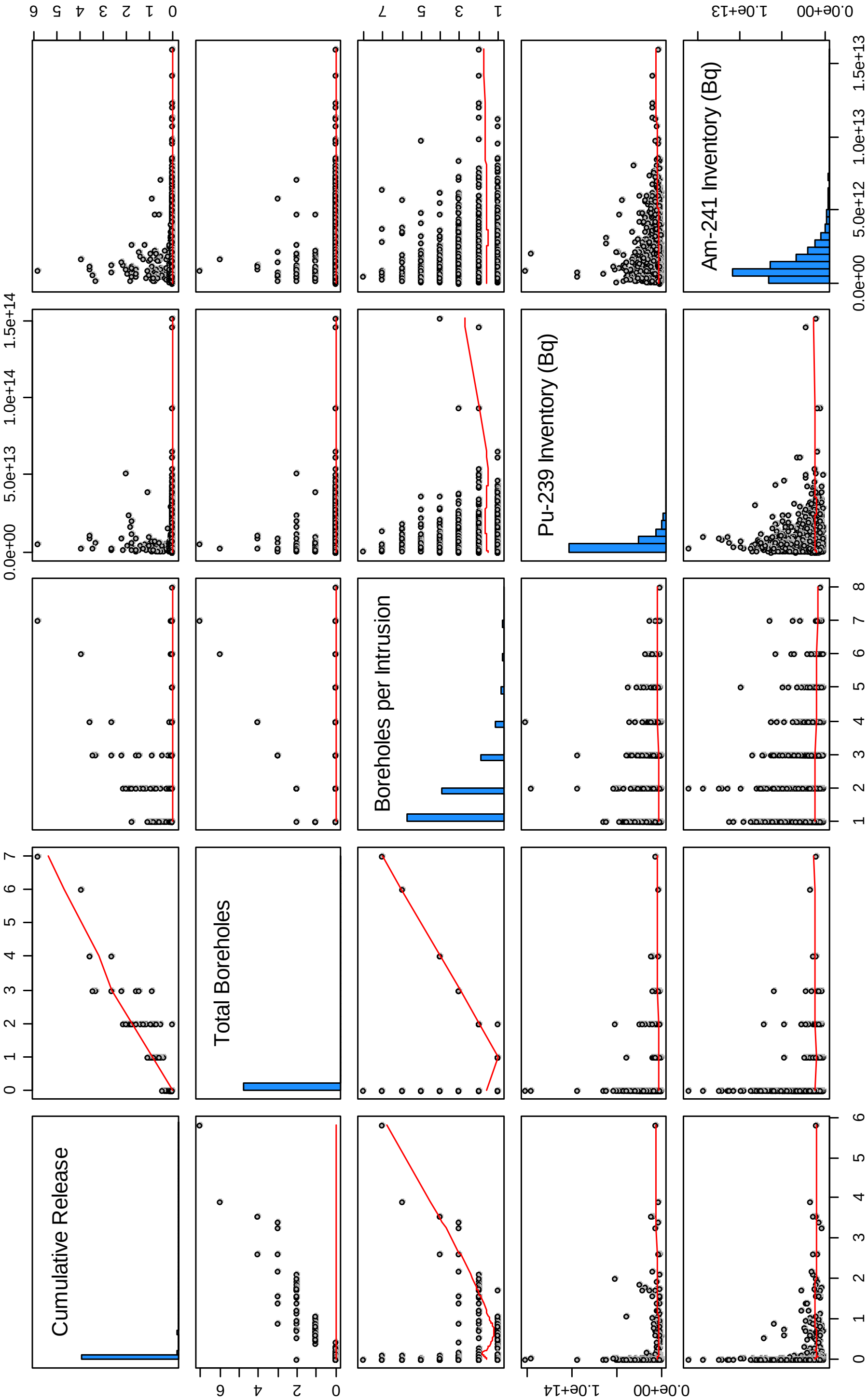


Figure A3.3 Scatterplot matrix for the cumulative release and most sensitive input parameters as measured by the gbm relative influence. Histogram of the underlying parameter distributions appears on the leading diagonal. Off-diagonal elements are pair-wise scatterplots of variables. Red line shows a smoothed (LOESS - locally weighted polynomial regression) fit of the data

A3.2 Sensitivity Analysis of On Site Resident TEDE at 100 Years

The sensitivity of the on site resident TEDE was evaluated at 100, 1,000, and 10,000 years. The adjusted coefficient of determination for the regressions was significantly better for the gbm than the normal linear model (Table A3.4). Therefore, the gbm model results are considered more reliable. The fit for the data at 10,000 years was slightly better than at 100 and 1,000 years due to a single outlier (Figures A3.4 and A3.5).

Table A3.4 On site resident TEDE regression models coefficient of determination.

Model Output	Normal Linear Regression	Generalized Boosted Regression
On Site Resident TEDE at 100 years	0.74	0.94
On Site Resident TEDE at 1,000 years	0.78	0.95
On Site Resident TEDE at 10,000 years	0.85	0.99

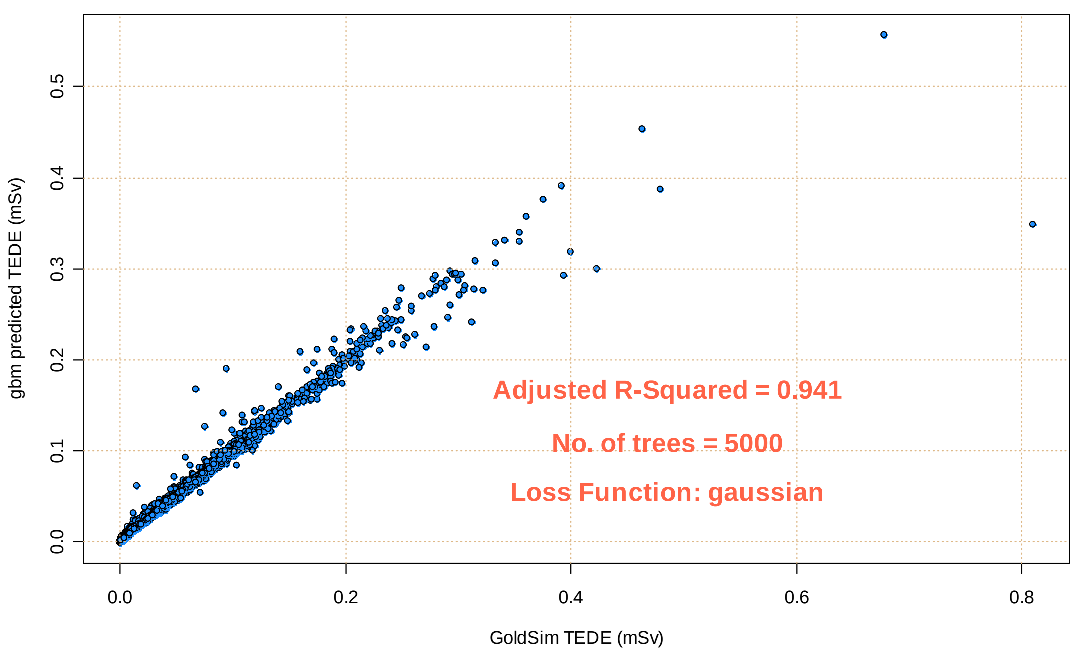


Figure A3.4 Gbm predicted TEDE at 100 years versus GoldSim model results.

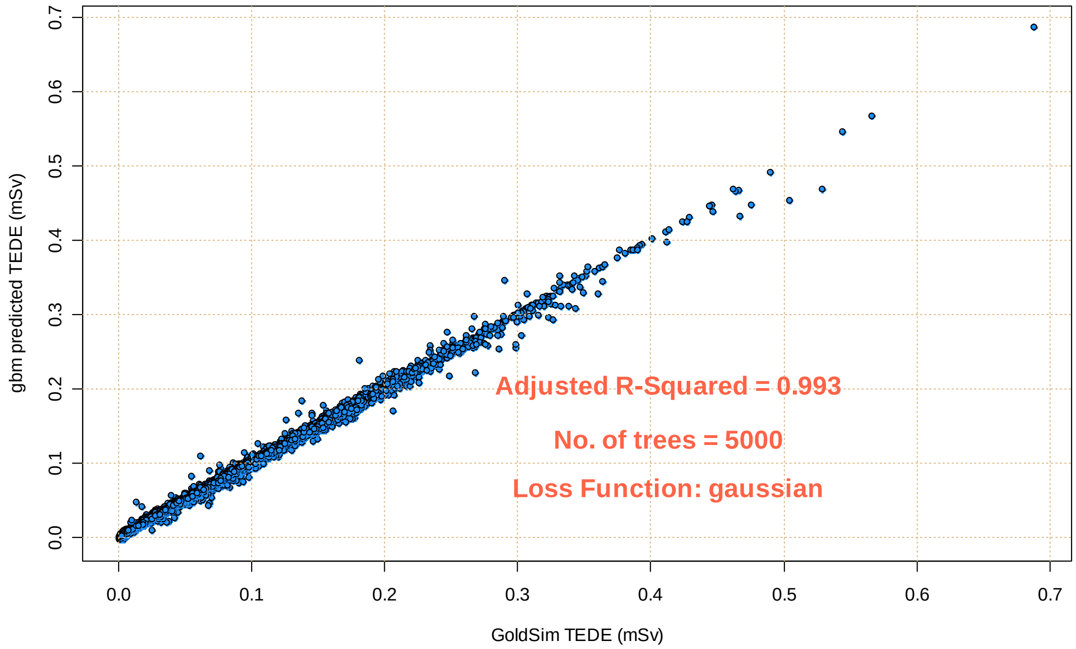


Figure A3.5 Gbm predicted TEDE versus GoldSim results at 10,000 years.

The GoldSim SIs all indicate that the on site resident TEDE at 100 years is strongly sensitive to the co-located low-level waste ^{226}Ra inventory, although there is significant variation among the different methods (Table A3.5). The radon emanation coefficient is identified as the second most sensitive parameter, followed by a slight to moderate sensitivity to the residence gamma radiation transmission factor.

Table A3.5 Summary of GoldSim sensitivity analysis sorted by SRC for the resident TEDE at 100 years.

Variable	Correlation Coefficient	SRC	PCC	GoldSim Importance
Co-Located Ra-226 Inventory	0.767	0.767	0.843	0.454
Radon Emanation Coefficient	0.375	0.379	0.610	0.149
Residence Gamma Transmission	0.123	0.124	0.245	0.025

The gbm marginal dependence shows a strong positively increasing relationship between the TEDE and the ^{226}Ra inventory, radon emanation coefficient, and the residence gamma radiation transmission factor (Figure A3.6). The relationships are linear except for the relationship with ^{226}Ra inventory which exhibits a threshold and irregular behavior at high inventories. These irregularities may reflect the low frequency of model realizations with high ^{226}Ra inventory. A linearly decreasing relationship is observed for the time spent in sedentary activity. Increasing time spent in sedentary activity increases the time indoors where external gamma irradiation is attenuated by the residence.

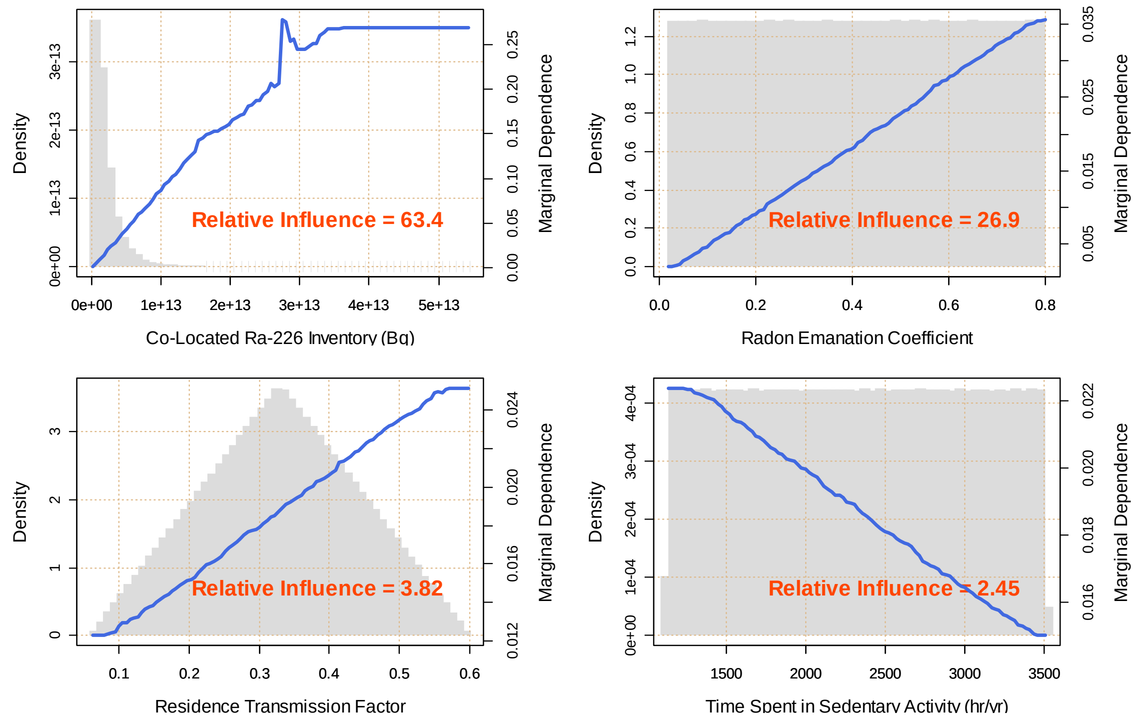


Figure A3.6 Histogram (gray) and marginal dependence (blue) of most sensitive input parameters for resident TEDE at 100 years as measured by the relative influence.

The Sobol' SIs indicate the resident TEDE at 100 years is strongly sensitive to the co-located ^{226}Ra inventory, moderately sensitive to the radon emanation coefficient, and slightly sensitive to the residence gamma transmission factor and time spent in sedentary activity (Table A3.6). First order effects account for approximately 75 percent of the model variance. The total effects SIs are significantly increased relative to the main effect for the ^{226}Ra inventory and radon emanation coefficient, indicating that interactions with other factors are occurring. It is suspected that this interaction is between these two parameters themselves, as the difference between the main and total effects SIs are approximately equal for both parameters.

Table A3.6 Main and total effects Sobol' SIs for the on site resident TEDE at 100 years. .

Parameter Description	Main Effects SI	Total Effect SI
^{226}Ra Co-Located Waste Inventory	0.58	0.83
Radon Emanation Coefficient	0.15	0.37
Residence Gamma Transmission Factor	0.01	0.03
Time Spent in Sedentary Activity	0.008	0.02
Total	0.75	1.25

A3.3 Sensitivity Analysis of On Site Resident TEDE at 1,000 Years

The sensitivity of the on site resident TEDE at 1,000 years is similar to the results for 100 years. A slight decrease in the sensitivity of the ^{226}Ra inventory and increase in the sensitivity of the emanation coefficient and residence gamma transmission factor is noted (Table A3.7).

Table A3.7 Summary of GoldSim sensitivity analyses sorted by SRC for the resident TEDE at 1,000 years.

Variable	Correlation Coefficient	SRC	PCC	GoldSim Importance
Co-Located ^{226}Ra Inventory	0.75	0.751	0.842	0.434
Radon Emanation Coefficient	0.41	0.413	0.65	0.176
Residence Gamma Transmission	0.132	0.134	0.268	0.027

The gbm marginal dependence shows a strong positively increasing relationship between the TEDE and the ^{226}Ra inventory, radon emanation coefficient, and the residence gamma radiation transmission factor (Figure A3.7). The relationships are linear except for the relationship with ^{226}Ra inventory which exhibits a threshold and irregular behavior at high inventories. These irregularities may reflect the low frequency of model realizations with high ^{226}Ra inventory. A linearly decreasing relationship is observed for the time spent in sedentary activity. Increasing time spent in sedentary activity increases the time indoors where external gamma irradiation is attenuated by the residence.

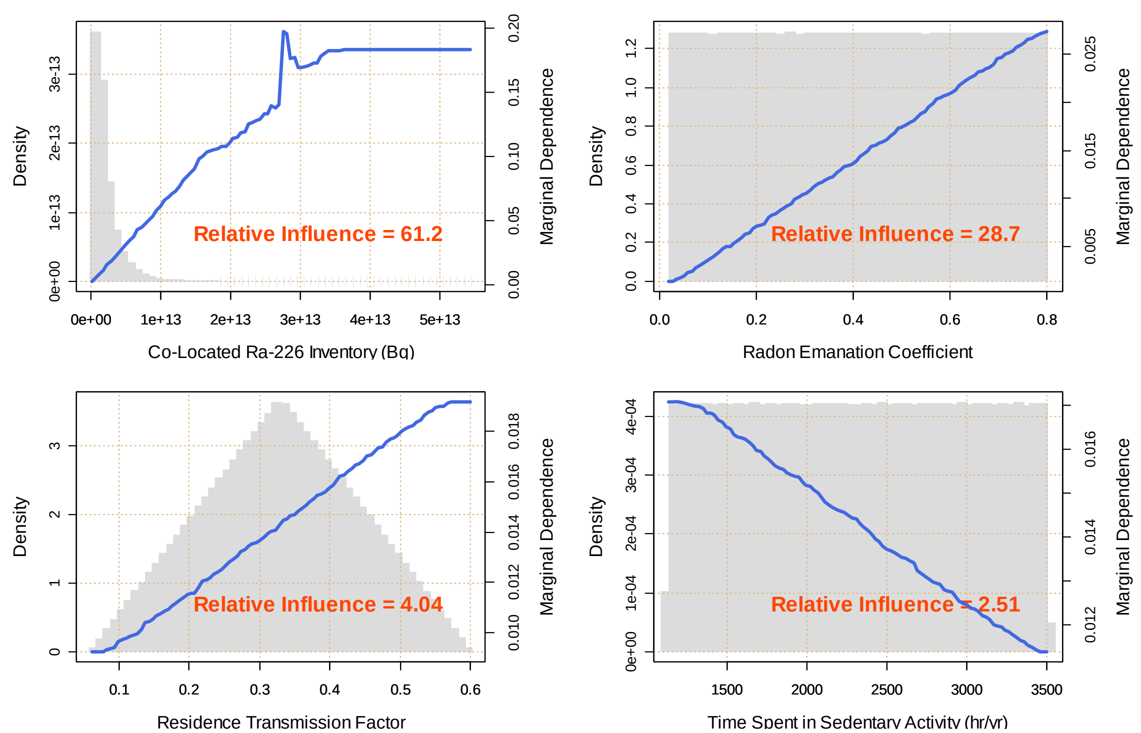


Figure A3.7 Histogram (gray) and marginal dependence (blue) of most sensitive input parameters for resident TEDE at 1,000 years as measured by the relative influence. .

The same trends observed for the GoldSim SIs are seen in the Sobol' SIs (Table A3.8). A very slight sensitivity to the ^{234}U co-located waste inventory appears at 1,000 years. Important interactions appear to exist for the ^{226}Ra inventory and emanation coefficient.

Table A3.8 Main and total effects Sobol' SIs for the on site resident TEDE at 1,000 years.

Parameter Description	Main Effects SI	Total Effect SI
^{226}Ra Co-Located Waste Inventory	0.55	0.79
^{234}U Co-Located Waste Inventory	N.D.	0.004
Radon Emanation Coefficient	0.18	0.40
Residence Gamma Transmission Factor	0.01	0.04
Time Spent in Sedentary Activity	0.008	0.02
Total	0.75	1.25

N.D. – sensitivity not detected

A3.4 Sensitivity Analysis of On Site Resident TEDE at 10,000 Years

The sensitivity of the on site resident TEDE at 10,000 years is similar to the result at 100 years except that the sensitivity to ^{226}Ra inventory is replaced by the co-located low-level waste ^{234}U inventory (Table A3.9). By 10,000 years, most ^{222}Rn released from the site will be produced by the decay of ^{234}U. The radon emanation coefficient has approximately equal sensitivity to the ^{234}U inventory at 10,000 years. The GoldSim SIs identify moderate to slight sensitivity to the time spent in sedentary activity for the first time.

Table A3.9 Summary of GoldSim sensitivity anlayses sorted by SRC for the resident TEDE at 10,000 years.

Variable	Correlation Coefficient	SRC	PCC	GoldSim Importance
Radon Emanation Coefficient	0.614	0.61	0.833	0.384
Co-Located ^{234}U Inventory	0.638	0.638	0.845	0.318
Residence Gamma Transmission	0.167	0.185	0.416	0.03
Time Spent in Sedentary Activity (hr/yr)	-0.153	-0.155	-0.36	0.03

The gbm indicates linearly increasing relationships between the on site resident TEDE at 10,000 years and the sensitive parameters (Figure A3.8).

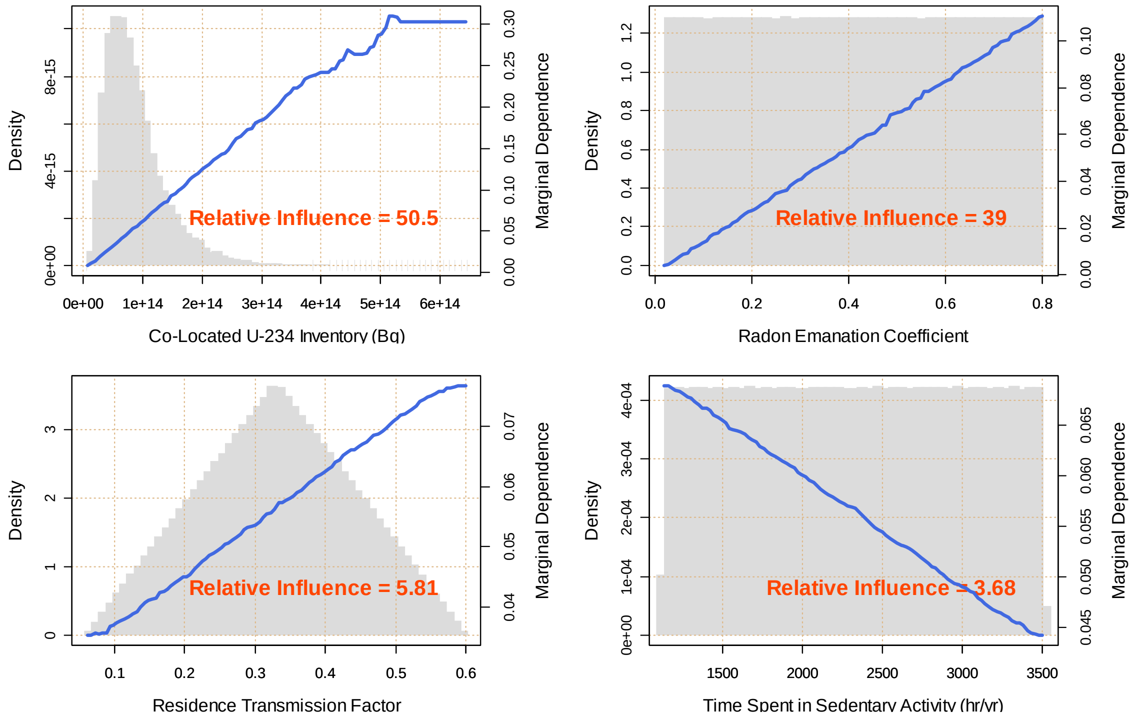


Figure A3.8 Histogram (gray) and marginal dependence (blue) of most sensitive input parameters for resident TEDE at 10,000 years as measured by the relative influence.

The Sobol' SIs indicate strong and approximately equal sensitivity to the ^{234}U inventory and radon emanation coefficient (Table A3.10). Slight sensitivity to the residence gamma transmission factor and time spent in sedentary activity is observed. Significant interactions are present for all the parameters, but again it is likely that these interactions are mostly among the sensitive parameters themselves, rather than unidentified parameters.

Table A3.10 Main and total effects Sobol' SIs for the on site resident TEDE at 10,000 years.

Parameter Description	Main Effects SI	Total Effect SI
^{234}U Co-Located Waste Inventory	0.38	0.57
Radon Emanation Coefficient	0.35	0.54
Residence Gamma Transmission Factor	0.02	0.07
Time Spent in Sedentary Activity	0.01	0.04
Total	0.76	1.22

A3.5 References

Frey, H.C., and S.R. Patil. 2002. Identification and review of sensitivity analysis methods. *Risk Analysis* 22(3): 553-578.

Friedman, J. 2002. Stochastic gradient boosting. *Computational Statistics and Data Analysis* 38: 367-378.

———. 2001. Greedy function approximation: A gradient boosting machine. *The Annals of Statistics* 29(5): 1189-1232.

Ridgeway, G. 2007. Generalized boosted models: A guide to the gbm package [on line]. Available at: http://i-pensieri.com/gregr/papers/gbm-vignette.pdf. Accessed 18 July 2007.

R Project. 2007. The R-project for statistical computing [on line]. Available at: http://www.r-project.org. Accessed 18 July 2007.

Saltelli, A, S. Tarantola, and K.P.S. Chan. 1999. A quantitative model-independent method for global sensitivity analysis of model output. *Technometrics* 41: 39-56.

Shott, G.J., V. Yucel, L. Desotell, G. Pyles, and J. Carilli. 2007. Uncertainty and sensitivity of alternative ^{222}Rn flux density models used in performance assessment. In *Proceedings of the 2007 Waste Management Symposium*, Tucson, AZ: Waste Management Symposium.

Sobol', I.M. 2001. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. *Mathematics and Computers in Simulation* 55: 217-280.

A4 Preparation of Revision 1

Revision 1 to the *Special Analysis of Transuranic Waste In Trench T04C at the Area 5 Radioactive Waste Management Site, Nevada Test Site, Nye County, Nevada* was prepared in response to comments received from the Low-Level Waste Disposal Facility Federal Review Group (LFRG) Review Team. The purpose of the LFRG Review Team was to review the Special Analysis (SA) dated September 2007, to ensure compliance with DOE Order 435.1 and the Nevada Site Office's (NSO) Area 5 Radioactive Waste Management Site low-level waste Disposal Authorization Statement. In addition, the Review Team was requested to review the Special Analysis (SA) to the requirements of 40 CFR 191 to supplement the DOE Order 435.1 compliance review. The LFRG review team utilized the Draft LFRG Manual dated November 2007 and the associated low-level waste and transuranic waste review criteria in the performance of the review.

The Review Team concluded that the inadvertent disposal of TRU in Trench T04C in Area 5 is covered under the Nevada Site Office's Composite Analysis and the NSO's Disposal Authorization Statement dated December 5, 2000 as required by DOE M435.1-1, Chapter IV, P (3), Composite Analysis. The Review Team, however, did identify two key issues and eight secondary issues. Revision 1 was prepared to respond to the key and secondary issues. The following sections describe the key and secondary issues and how revision 1 responds to them.

A4.1 Key Issues

Key Issue 1: 3.2.3.2 Criterion 2: The performance assessment specifies that the dose limit is an annual committed effective dose of 15 mrem to any member of the public in the accessible environment.

Section 3.2.10 in the SA, Member of the Public Exposure Scenarios, identifies the point of compliance for a member of the public being at 100 m from the facility boundary. This is contrary to 40 CFR 191.15 IPR which states that the point of assessment is the accessible environment. 40 CFR 191.12, Definitions, defines the "Accessible Environment" to include the land surface.

NSO shall re-evaluate the IPR dose at the surface of T04C. The review team determined that this criterion was not met.

Response:

The SA, revision 0, calculated the dose to a resident using the on site soil concentration for all radionuclides, except noble gases, and the atmospheric concentrations at the 100-m (330-ft) site boundary. The revised 40 CFR 191 SA model, version 1.002, was modified to calculate the dose using the on site soil concentration for all radionuclides and the on site atmospheric concentration. The primary impact of this change is a significant increase in the dose from external irradiation from ^{214}Pb and ^{214}Bi, which are short-lived progeny of ^{222}Rn deposited in cover soil by diffusing radon gas.

All IPR results, alternative barrier evaluations, uncertainty analyses, and sensitivity analyses were re-evaluated with the revised model. The SA has been revised to include the results for the on site resident dose.

Key Issue 2: 3.2.5.4 Criterion 4: The determination in the current CA that dose from the active LLW disposal facility and all interacting sources of radioactive material, including inadvertently disposed TRU, remains compliant with the performance measures of the CA.

The Special Analysis, Executive Summary, page i, 1st paragraph: It is stated that under DOE M 435.1-1, TRU waste in a regulated disposal site must meet the requirements of 40 CFR 191. This is not the case. In fact this waste was disposed in a Low-Level Waste (LLW) disposal facility in 1986 and the facility must meet the requirements under DOE M 435.1-1 Chapter IV, Low-Level Waste. For waste disposed prior to 1988 that may interact with the active LLW disposal facility in Area 5, the DOE M 435.1-1 requirement that should be met is stated as follows:

> IV. P.(3) Composite Analysis. For disposal facilities which received waste after September 26, 1988, a site-specific radiological composite analysis shall be prepared and maintained that accounts for all sources of radioactive material that may be left at the DOE site and may interact with the low-level waste disposal facility, contributing to the dose projected to a hypothetical member of the public from the existing or future disposal facilities. Performance measures shall be consistent with DOE requirements for protection of the public and environment and evaluated for a 1,000 year period following disposal facility closure. The composite analysis results shall be used for planning, radiation protection activities, and future use commitments to minimize the likelihood that current low-level waste disposal activities will result in the need for future corrective or remedial actions to adequately protect the public and the environment.

The SA under review by the team should have been prepared under the Chapter IV Maintenance requirements for LLW and should defend the argument that the disposal of this TRU waste is within the approved DAS. Since the waste was disposed prior to 1988, the waste should have been included in the NTS CA that is part of the NTS Area 5 DAS. The SA does not state whether the TRU inventory was included in the CA and that the CA Performance Measures continue to be met.

A discussion should be included as to whether the Chapter IV requirements for a CA have been met or not. NTS has not created a TRU disposal facility, because it was discovered that TRU waste was inadvertently disposed in the LLW disposal facility. The 40 CFR 191 SA supplements the argument that the disposal is protective of the public and the environment. The review team determined that this criterion was not met.

Response:

The executive summary, Section 1.2.1, and Section 1.2.2 were revised. The intent of the revisions is to (1) confirm that a CA has been prepared and approved that includes the TRU in T04C, and (2) clarify that the SA considers 40 CFR 191 a relevant appropriate regulation, based on its inclusion in DOE Orders and previous application at the Area 5 RWMS, but not a strictly legally applicable regulation.

A4.2 Secondary Issues

Secondary Issue 1: 3.2.1.4 Criterion 4: The performance assessment accounts for all relevant mechanisms for releasing radionuclides from the waste and making them available for environmental transport, including diffusion, advection, and vapor phase transport. The mechanisms analyzed are justified by reference to relevant studies, available data, and supporting analyses.

NSO should provide a discussion in the SA on the potential transport-enhancing materials in the waste. The review team requested additional information from NTS because the Review Team has a concern that the composition of the waste might enhance mobilization of the radionuclides. The review team determined that this criterion was not met.

Response:

Sections 2.4.2 and 3.2.3 was revised to include a more complete description of the waste form and confirm that no transport enhancing materials are present.

Secondary Issue 2: 3.2.1.5 Criterion 5: The performance assessment presents information on the environment and the disposal system (hydrogeological setting) sufficient to support the analysis present in the performance assessment and justifies the information by reference to relevant studies, available data, or supporting analyses.

Addition of historical discussion of TO4C, T04C-1 and T09C in the SA is needed. NSO should incorporate a description of the TRU waste disposal system, its design and nearby facilities. The review team determined that this criterion was met.

Response:

Section 1.3.4 was revised to more completely describe the history of T04C. Section 2.1.2 was revised to more completely describe the disposal unit.

Secondary Issue 3: 3.2.1.5 Criterion 5c: The performance assessment presents information on the engineered barrier system including, but not limited to, facility design features that address water infiltration, disposal unit cover integrity, and structural stability in detail sufficient to support the analysis, and justifies the information.

NSO should provide clarification in the SA that no credit was taken for the waste containers in the CR or IPRs. The review team determined that this criterion was met.

Response:

Section 3.2.3 was revised to clarify that no credit for container performance is taken for the CR and IPR analyses.

Secondary Issue 4: 3.2.1.6 Criterion 6f: The conceptual model identifies and describes reasonable scenarios for the disturbed performance of the facility, which are consistent with the site- and facility-specific effects of the disposal system's environmental and design attributes, local or regional customs and construction practices (including well-drilling practices), and passive institutional controls.

NSO needs to provide a justification for not considering a basement (environmental and design attributes and local or regional practices/passive institutional controls) in the SA. The review team considered a basement in a resident's home to be a human-induced disruptive event and should either be included in the conceptual model or justified as being not consistent with local practices. The review team determined that this criterion was met.

Response:

Section 3.2.7 was revised to explain that excavation of a basement is not included in the base case analysis because it is not expected to have any impact on the complementary cumulative distribution function for a 4-m (13-ft) thick cover. The small impact is due to a low probability of an intrusion event, low probability of a basement given an intrusion event, and a small consequence for a thick cover.

The alternative barrier analyses, however, include evaluations of thinner covers. Therefore, the CR analysis models for the alternative barrier evaluation were modified to include basement excavation with a frequency of 4 basements per 396 intrusion events. The alternative barrier evaluation sections were revised to reflect these changes.

Secondary Issue 5: 3.2.1.10 Criterion 10: The performance assessment discusses the quality assurance measures applied to the preparation of the analysis and its documentation.

NSO should provide references and a discussion on QA measures to support the SA. The review team determined that this criterion was not met.

Response:

Appendix A2, Quality Assurance, was added to the revised document.

Secondary Issue 6: 3.2.2.7 Criterion 7b: Documentation establishes that retrievability of the waste is feasible.

NSO should include reference to the *Remediation Options for Accidentally Disposed Transuranic Materials in Trench T04C at the Area 5 Radioactive Waste Management Complex, Nevada Test Site* in the SA. The review team determined that this criterion was met.

Response:

Section 1.2.2 was revised to summarize the remediation options considered by the Nevada Site Office and to cite the remediation options position paper.

Secondary Issue 7: 3.2.3.2 Criterion 2a: The performance assessment provides a reasonable expectation that the undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal systems, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts)

IPR doses include radon and progeny, which are not required to be included. NSO should recalculate dose without the radon and progeny contribution. The review team also believes this issue should be resolved by the LFRG. The review team determined that this criterion was not met.

Response:

The 40 CFR 191 SA, version 1.002, model was revised to calculate the dose to an on site resident excluding the dose from inhalation of ^{222}Rn and its short-lived progeny in air, consistent with DOE Manual 435.1-1 which excludes this exposure pathway. The SA document was revised to include the new results. However, moving the point of compliance to directly above the disposal unit has added the new exposure pathway of external irradiation by short-lived ^{222}Rn progeny deposited in cover soil. Consequently, ^{222}Rn remains the most important source of dose to the member of public.

Secondary Issue 8: 3.2.3.8 Criterion 8g: The performance assessment identifies and justifies the dose conversion factor and methodology used in the dose analysis.

NSO should provide a description of the abbreviated decay chains that are used in the dose conversion factors. The review team determined that this criterion was met.

Response:

Section 3.3.4 was revised to describe that some short-lived progeny are assumed to be in secular equilibrium with long-lived parents and that the dose conversion factors of the short-lived progeny are summed with the parents' dose conversion factors. Figure A1.1 in Appendix A1 was added to the document to clarify the use of abbreviated decay chains.

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