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Revision 1

Hanford Site Composite Analysis: Radionuclide Selection for Groundwater Pathway Evaluation

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract 89303320DEM000030

P.O. Box 1464
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Hanford Site Composite Analysis: Radionuclide Selection for Groundwater Pathway Evaluation

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Terms

BBI	Best-Basis Inventory
CA	composite analysis
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
ERDF	Environmental Restoration Disposal Facility
FFTF	Fast Flux Test Facility
IDF	Integrated Disposal Facility
K_d	distribution coefficient
LLBG	low-level burial ground
PA	performance assessment
SIM	Soil Inventory Model
TC & WM EIS	Tank Closure and Waste Management Environmental Impact Statement
WMA	waste management area

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1 Introduction

The updated Hanford Site Composite Analysis (CA) (DOE/RL-2019-52, *Composite Analysis for Low-Level Waste Disposal in the Hanford Site Central Plateau (FY 2020)*) provides an all-pathways dose projection to a hypothetical future member of the public from all planned low-level radioactive waste disposal facilities and potential contributions from all other projected end-state sources of radioactive material left at the Hanford Site following site closure. Its primary purpose is to support the decision-making process of the U.S. Department of Energy (DOE) under DOE O 435.1-1, *Radioactive Waste Management*, related to managing low-level waste disposal facilities at the Hanford Site.

A key aspect of conducting a CA is selecting the radionuclides to be analyzed. This document describes the selection process for radionuclides to be included in the quantitative analysis.

2 Background

The disposed inventory estimate is perhaps the most important component of the CA, as it directly affects the future radiological impacts following site closure. The primary purpose is to estimate radionuclide inventory from site inception to closure. Because of the inclusive nature of a CA, all relevant contaminants are identified and initially considered. Then, subsets of contaminants appropriate for quantitative analysis are selected. Reducing the number of radionuclides for inclusion in the quantitative analysis helps focus budget and resources on simulating only those radionuclides that are likely to contribute to the total dose to the receptor above a threshold value.

3 Screening Methodology

The approaches adopted in the three prior sitewide studies were evaluated to help develop a radionuclide screening process for the CA.

For the Hanford Site CA update, the methodology for selecting radionuclides to be included is based, in part, on the following aspects that influence the scope and approach.

- Use information from past Hanford sitewide studies to guide the methodology for screening radionuclides. The following studies related to waste site evaluation and radionuclides inventories provide valuable insights into the radionuclide selection process:

    1. CA of radionuclides conducted in 1998 and 2001, documented in PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200-Area Plateau of the Hanford Site*, and PNNL-11800 Addendum 1, *Addendum to Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (hereinafter called the 1998 CA)

    2. A sitewide inventory of radionuclides conducted in 2006, documented in PNNL-15829, *Inventory Data Package for Hanford Assessments* (hereinafter called the 2006 Data Package)

    3. A sitewide analysis of cumulative impacts from radionuclides and chemicals documented in DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site*, *Richland, Washington* (hereinafter called the TC & WM EIS)

- Include any new information since the past sitewide studies were conducted, including the following performance assessments (PAs) and the updated Soil Inventory Model (SIM):

    – WCH-520, *Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington* (hereinafter called the ERDF PA)

- RPP-ENV-58782, *Performance Assessment of Waste Management Area (WMA) C, Hanford Site, Washington* (hereinafter called the Waste Management Area [WMA] C PA)
- RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington* (hereinafter called the Integrated Disposal Facility [IDF] PA)
- ECF-HANFORD-17-0079, *Hanford Soil Inventory Model (SIM-v2) Calculated Radionuclide Inventory of Direct Liquid Discharges to Soil in the Hanford Site's 200 Areas* (hereinafter called SIM-v2)

3.1 Approaches Considered in Past Sitewide Studies to Select Radionuclides

The approaches used in past sitewide studies (the 1998 CA, the 2006 Data Package [PNNL-15829], and the TC & WM EIS [DOE/EIS-0391]) are considered in the following sections.

3.1.1 1998/2001 Composite Analysis

In the 1998 CA (PNNL-11800), radionuclides were selected primarily based on those identified as potentially significant contributors to dose in the 200 West and 200 East PAs (WHC-SD-WM-TI-730, *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds* and WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*) and DOE/RL-93-99, *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility*. In addition, other studies were reviewed to identify radionuclides unique to specific types of wastes or closed facilities, and to identify key radionuclides in immobilized low-activity radioactive waste from single- and double-shell tanks and residing in burial grounds. Different radionuclide lists were developed for groundwater and air pathways.

The selection process assumed that sources outside of the Central Plateau would be remediated and not represent significant sources of radionuclides following site closure. It also assumed eight of the nine production reactors would be disposed on the Central Plateau; the ninth reactor had been declared a national historic monument and was expected to remain along the Columbia River.

3.1.2 2006 Data Package

In the 2006 Data Package (PNNL-15829), radionuclides were selected using the data quality objective process. The intent was to identify those radionuclides that had been observed in the environment or had sufficient inventory in waste sites to potentially impact human or ecological health. The screening process reviewed all groundwater monitoring data from 1990 to December 2002 using the following steps:

- Retain all sample results above detection levels.
- Retain all samples not rejected by data quality assurance checks.
- Retain all radionuclides with a half-life greater than 10 years.
- Identify all samples above drinking water standards.
- Identify all radionuclides that have regional or Hanford Site scale distribution (specifically, radionuclides present at more than one or two points in the aquifer).
- Identify all radionuclides with a temporal distribution of more than a single moment in time.
- Add radionuclides that could have a future impact as indicated by performance assessments and environmental impact statement studies.

This process resulted in 16 radionuclides being retained for quantitative analysis.

3.1.3 Tank Closure and Waste Management Environmental Impact Statement

The intent of the TC & WM EIS (DOE/EIS-0391) screening processes was to focus attention on the constituents that control the impacts to groundwater. Separate screening processes were conducted for sites evaluated for cumulative impacts, for the alternatives analysis, and for human health impacts. Contaminants of potential concern (COPCs) assessed for ecological impacts are also summarized in Section 3.1.3.4. Note that cross references and page citations in the following sections are in the TC & WM EIS unless otherwise noted.

3.1.3.1 Cumulative Impacts Analysis

For the sites evaluated under the cumulative impacts analysis, the initial list included radionuclides with half-lives greater than 10 years. Constituents were considered to pose a potential health risk from ingestion if they had a maximum contaminant level or were listed in the Integrated Risk Information System as having a health-based ingestion standard. As described in Appendix S, the screening process was intended to select those constituents appropriate for a groundwater release scenario; thus, for radionuclides, "…only groundwater consumption was considered, release was assumed to be partition limited, and decay during transport was considered" (p. S-16). Relative impacts were based on the distribution of radionuclides in the cumulative impacts inventory. The initial list was screened, removing radionuclides contributing less than 1% of the impacts under drinking water consumption scenarios and chemicals present at levels below health-based limits. The screening resulted in a final set of 14 radioactive constituents (p. S-16).

3.1.3.2 Alternatives Impacts Analysis

For sites evaluated under the alternative analysis, different processes were used to select constituents for tank closure, Fast Flux Test Facility (FFTF) decommissioning, and waste management alternatives.

The Best-Basis Inventory (BBI), which included 46 radionuclides and 24 chemicals, was used as the initial list of constituents to consider for evaluating the tank closure and waste management alternatives. Constituents were screened out if they contributed less than 1% of impacts on drinking water ingestion for the chemicals, and on intruder or drinking water consumption scenarios for the radionuclides. As described in Appendix D:

> Not all constituents are important in the exposure scenarios used to assess TC & WM EIS alternative implementation impacts. Thus, to focus attention on the constituents that control the impacts, DOE performed an initial screening analysis. For radionuclides, groundwater release and direct intrusion scenarios were considered. For the groundwater release screening scenario, only drinking water consumption was considered. Release was assumed partition limited, and decay during transport was considered. For the direct intrusion screening scenario, inadvertent soil ingestion and inhalation pathways were considered.
>
> The analysis estimated relative impacts based on distribution of radionuclides in the BBI for all tanks. Radionuclides contributing less than 1 percent of impacts under intruder or well scenarios were eliminated from the detailed analysis. To screen for hazardous chemicals, drinking water ingestion impacts were estimated for the 24 BBI chemical constituents, and those contributing more than 99 percent of impacts were selected for detailed analysis. In addition, reported tank concentrations were reviewed and compared

> with health-based limits (DOE 2003a)[1]; chemical COPCs, when compared with health-based limits (DOE 2003a), were added to the initial list of screened chemicals." (DOE/EIS-0391, p. D-3).

The screening resulted in 10 radionuclides and 10 chemicals being selected for detailed analysis, listed in Table D-2 in Section D.1). One of the radionuclides, amercium-241, is applied to the intruder scenarios only via the inhalation pathway. Although Appendix D mentions that other COPCs were added to the list from the screening conducted for the cumulative impact analysis (last paragraph, p. D-3), the tables comparing tank alternatives only list 9 radionuclides and 10 chemicals (for examples, see Tables D-35 through D-60).

For the waste management alternatives, three categories of waste were considered: secondary low-level waste and mixed low-level wastes managed at three Hanford facilities; onsite non-*Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (non-CERCLA) waste, non-tank-activity waste; and offsite waste.

Secondary low-level waste and mixed low-level wastes from the operation of three sites were evaluated: low-level burial ground (LLBG) 218-W-5 (Trenches 31 and 34), the Waste Receiving and Processing Facility, and the T Plant complex. To evaluate the waste management alternatives, the same 9 radionuclides and 10 chemicals as the tank alternatives were considered, but only 3 of the chemicals were evaluated because inventories for the other 7 chemicals were not included in the cited report (p. D-129, footnote 'a' to Table D-82).

No screening process was described in Section D.3.5, "Radionuclide and Chemical Inventory Estimates for Onsite Non-CERCLA, Non-Tank-Activity Waste." In the table summarizing the inventory of non-CERCLA, non-tank-activity waste, the same nine radionuclides as in the tank alternatives are reported, but an expanded list of 19 chemicals is reported, based on a Solid Waste Information Tracking System forecast from fiscal year 2006 to fiscal year 2035 as reported in SAIC, 2011, *Waste Inventories Reference Mapping*.

Similarly, no screening process was described in Section D.3.6, "Projected Volumes, Radionuclide and Chemical Inventories for Offsite Waste." Inventories from projected waste volumes that could be shipped to the Hanford Site list the same nine radionuclides as in the tank alternatives but list 15 chemical constituents.

To evaluate the FFTF alternatives, inventories of various radionuclides and chemicals were obtained from existing reports, such as *FFTF Radioactive and Hazardous Materials Inventory* (Section D.2.1), FFTF-18346, *Technical Information Document for the Fast Flux Test Facility Closure Project Environmental Impact Statement*, and Kidd, 2005, *Activation of the FFTF Biological Shield Wall*. The process used to screen the many reported constituents to the selected four radionuclides and three chemical constituents was described as follows: "Matching the list of radionuclides and chemicals identified in the above tables with the COPCs identified in Appendix D, Section D.1.1, resulted in a report of the following radionuclides (in curies)…" (p. D-119). The "above tables" refers to tables of inventories reported from the various sources, with differing numbers of COPCs, from 7 to 31. Section D.1.1, "Current Tank Inventory of Radioactive and Chemical Constituents" includes Table D-2, "Constituents Selected for Detailed Analysis," which lists the 10 radionuclides and 10 chemicals

[1] DOE 2003a from the quoted material references: DOE (U.S. Department of Energy), 2003a, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of Single-Shell Tanks at the Hanford Site, Richland, WA: Inventory and Source Term Data Package*, DOE/ORP-2003-02, Rev. 0, Office of River Protection, Richland, Washington, April 17.

mentioned above. In the FFTF alternatives analysis, four radionuclides and three chemicals were reported in the tables and figures showing the inventories of COPCs.

3.1.3.3 Human Health Impacts Analysis

In Appendix Q, "Long-term Human Health Dose and Risk Analysis," the screening process is described as follows: Using the inventories in Appendix D for the alternatives analysis and Appendix S for the cumulative impacts analysis, relative impacts were estimated based on the distribution of radionuclides in wastes associated with tanks, FFTF decommissioning, the IDF, the proposed River Protection Project Disposal Facility, and cumulative analysis sites. Radionuclides contributing less than one percent of impacts for intruder (inadvertent soil ingestion and inhalation) or drinking water scenarios and chemicals contributing less than one percent of drinking water impacts were screened out. The result was a list of 14 radionuclides and 26 chemical constituents (Table Q-1, p. Q-2).

3.1.3.4 Ecological Impacts Analysis

A screening process to select COPCs to assess ecological impacts was not described in Appendix P, "Ecological Resources and Risk Analysis." Appendix P describes potential ecological impacts of airborne releases during operations and groundwater discharges under various alternatives. Appendix P states "Concentrations of radionuclides and chemicals resulting from deposition of airborne contaminants during construction and operations associated with the alternatives were predicted, as described in Appendix G." (p. P-6). However, Appendix G, "Air Quality Analysis," states "This appendix presents information on the nonradiological air quality impacts that could result from emissions associated with construction, operations, deactivation, and closure activities under the various alternatives…" (p. G-1). The only constituents described in Appendix G are nonradiological ambient air pollutants such as carbon monoxide; PM_{10}; and sulfur dioxide and other pollutants such as benzene, mercury, formaldehyde, and 1,3-butadiene.

Appendix P also describes that predicted seep, sediment pore water, sediment, and surface water "…concentrations were calculated from the modeled groundwater concentrations at the Columbia River resulting from the varying radioactive and chemical COPC inventories in place under the different alternatives (see Appendix O)." (p. P-46). Appendix O, "Groundwater Transport Analysis," describes the particle-tracking method used to implement the contaminant transport model. Radionuclides included in the particle-tracking analysis were the same as the screened COPCs to assess human health in Appendix Q, except that plutonium-239 and uranium-238 were listed instead of plutonium and uranium isotopes. For chemicals, Appendix P again points to Appendix G.

3.1.3.5 Comparison of Different TC & WM EIS Screening Results

The tables of constituents selected for detailed analysis were the same for the human health impacts analysis (Appendix Q, Table Q-1) and the cumulative impacts analysis (Appendix S, Table S-8) as shown in Table 1 of this document, despite key differences in the screening methodologies. The human health impacts screening considered groundwater release and intruder scenarios while the cumulative impacts screening only considered groundwater consumption. In the human health impacts screening, relative impacts were estimated based on the distribution of radionuclides in multiple types of sources (tanks, FFTF decommissioning, waste proposed for disposal at IDF and the River Protection Project Disposal Facility, and cumulative analysis sites), while in the cumulative analysis screening, the distribution of radionuclides was based only from cumulative analysis sites. This suggests the inventories in the cumulative impact waste sites were the major driver of impacts.

Screening processes conducted to evaluate the tank closure alternatives and human health impacts both considered groundwater release and intruder scenarios. However, the tank closure screening was based on

the distribution of radionuclides in the BBI, which includes fewer radionuclides and chemicals than in the initial lists used for the human health screening, and would help explain the shorter screened list for tank closure (Table 1).

Table 1. Selected COPCs Based on Screening Evaluations Conducted in the TC & WM EIS

Analyte	Analysis of Human Health Impacts (Appendix Q, Table Q-1)[a] and Cumulative Impacts (Appendix S, Table S-8)[a]	Analysis of Tank Closure Alternatives (Appendix D, Table D-2)[a]
Radionuclides		
Americium-241	X	X[b]
Carbon-14	X	X
Cesium-137	X	X
Gadolinium-152	X	
Hydrogen-3 (tritium)	X	X
Iodine-129	X	X
Neptunium-237	X	X
Plutonium isotopes	X	X
Potassium-40	X	
Strontium-90	X	X
Technicium-99	X	X
Thorium-232	X	
Uranium isotopes	X	X
Zirconium-93	X	

a. Source: DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

b. Applies to the inhalation pathway for the intruder scenario analyzed in Appendix Q (DOE/EIS-391) but not to the environmental impact statement alternatives analysis (p. D-3).

3.2 Radionuclide Selection

The approach used to select COPCs for the current study began with development of an initial list of potentially important radionuclides based on the evaluations conducted by the 1998 CA (PNNL-11800), the 2006 Data Package (PNNL-15829), the TC & WM EIS (DOE/EIS-0391), and available PAs for the 200 West LLBGs, 200 East LLBGs, ERDF, WMA C, and IDF (WHC-EP-0645, WHC-SD-WM-TI-730, WCH-520, RPP-ENV-58782, and RPP-RPT-59958, respectively). The list is presented in Table 2.

Table 2. Contaminants of Potential Concern Identified from Prior Analyses

COPC	Sitewide Analyses			Performance Assessments				
	CA (PNNL-11800)	2006 Data Package (PNNL-15829)	TC & WM EIS (DOE/EIS-0391)	200 West LLBGs (WHC-EP-0645)	200 East LLBGs (WHC-SD-WM-TI-730)	ERDF (WCH-520)	WMA C (RPP-ENV-58782)	IDF[a] (RPP-RPT-59958)
Americium-241			X[b]					
Carbon-14	X	X	X	X	X	X	X	
Cesium-137		X	X					
Chlorine-36	X	X		X	X	X		
Cobalt-60							X	
Europium-152		X						
Gadolinium-152			X					
Hydrogen-3 (tritium)	X[c]	X	X	X	X	X[d]	X	
Iodine-129	X	X	X	X	X	X	X	X
Molybdenium-93						X		
Neptunium-237		X	X	X	X			
Niobium-93m						X[d]	X	
Niobium-94						X		
Plutonium isotopes			X					
Polonium-209				X				
Potassium-40			X			X		
Protactinium-231		X[e]		X				
Radium-226		X[f]						
Radon-222							X	
Rhenium-187				X	X			
Selenium-79	X	X		X	X		X	
Strontium-90	X[c]	X	X					
Technetium-99	X	X	X	X	X	X	X	X
Thorium-232			X					
Tin-126							X	
Uranium isotopes		X	X	X	X	X	X[h]	

Table 2. Contaminants of Potential Concern Identified from Prior Analyses

COPC	Sitewide Analyses			Performance Assessments				
	CA (PNNL-11800)	2006 Data Package (PNNL-15829)	TC & WM EIS (DOE/EIS-0391)	200 West LLBGs (WHC-EP-0645)	200 East LLBGs (WHC-SD-WM-TI-730)	ERDF (WCH-520)	WMA C (RPP-ENV-58782)	IDF[a] (RPP-RPT-59958)
Uranium-238	X[g]	X	X				X	
Zirconium-93			X					

Note: Complete reference citations are provided in Chapter 5 of this document.

a. 43 radionuclides were included in the IDF Performance Assessment (RPP-RPT-59958) groundwater pathway analysis. However, process model calculations focused almost entirely on I-129 and Tc-99. Impacts due to the remaining radionuclides were evaluated using the integrated system model. Only I-129 and Tc-99 were included here.

b. Table D-1 in the TC & WM EIS (DOE/EIS-0391) indicates that Am-241 applies to intruder analysis scenarios only. Appendix Q and Appendix S do not include this comment.

c. Tritium and Sr-90 were included in dose evaluations based on existing plumes, but were not included in the release and vadose zone modeling.

d. Section 4.2.2 of the ERDF Performance Assessment (WCH-520) states that “Hydrogen-3 and niobium-93m do not exist anywhere in the model domain in significant quantities after 1,000 years and decay to insignificant quantities (less than 1E-14 Ci per Ci source) before reaching the water table.”

e. Pa-231 as a progeny was included in the calculation of U-235 dose.

f. Ra-226 as a progeny was included in the calculation of U-234 and U-238 dose.

g. The contribution of uranium and its progeny to dose was estimated by simulating U-238, approximating the abundance of other uranium isotopes using a single set of isotopic ratios, and assuming uranium daughter products move with the parent.

h. Table D-8 of the WMA C Performance Assessment (RPP-ENV-58782) indicates that the base case analysis included U-232, U-233, U-234, U-235, U-236, and the U-238 daughter products, but these isotopes were not evaluated directly using the STOMP* model.

CA = composite analysis
COPC = contaminant of potential concern
ERDF = Envronmental Restoration Disposal Facility
IDF = Integrated Disposal Facility
LLBG = low-level burial ground
STOMP = Surface Transport Over Multiple Phases
TC & WM EIS = Tank Closure and Waste Management Environmental Impact Statement
WMA = waste management area

*STOMP is a copyright of Battelle Memorial Institute, Columbus, Ohio, and used under the limited Government License.

The initial list in Table 2 was screened to identify key radionuclides that could potentially affect a receptor via the groundwater within 10,000 years after site closure. The initial list was also evaluated against current information on sitewide inventories and contaminant mobility. Short-lived radionuclides with a half-life of less than 10 years were screened out.

The following sections provide information used to support the decision to include or exclude the radionuclides listed in Table 2 during the screening process. Tables 3 and 4 contain the radionuclide half-lives (DOE-STD-1196-2011, *Derived Concentration Technical Standard*) and distribution coefficient (K_d) values used for the previous studies represented in Table 2, respectively. K_d values for the 200 West LLBGs PA (WHC-EP-0645) and the 200 East LLBGs PA (WHC-SD-WM-TI-730) were not included since radionuclides were grouped as nonsorbing, slightly sorbing, moderately sorbing, and strongly sorbing and assigned values of 0, 1, 10, and 100 mL/g, respectively.

Table 3. Half-Life Values for Potentially Important Radionuclides

COPC	Half-Life (Years)
Americium-241	432.2
Carbon-14	5,700
Cesium-137	30.1671
Chlorine-36	3.01E+5
Cobalt-60	5.2713
Europium-152	13.537
Gadolinium-152	1.08E+14
Hydrogen-3 (tritium)	12.32
Iodine-129	1.57E+7
Molybdenium-93	4,000
Neptunium-237	2.14E+6
Niobium-93m	16.13
Niobium-94	20,300
Plutonium-238	87.7
Plutonium-239	24,100
Plutonium-240	6,564
Plutonium-241	14.35
Plutonium-242	3.75E+5
Polonium-209	102
Potassium-40	1.25E+9
Protactinium-231	32,800
Radium-226	1,600
Radon-222	0.0105

Table 3. Half-Life Values for Potentially Important Radionuclides

COPC	Half-Life (Years)
Rhenium-187	4.12E+10
Selenium-79	2.95E+5
Strontium-90	28.79
Technetium-99	2.11E+5
Thorium-230	75,400
Thorium-232	1.41E+10
Tin-126	2.30E+5
Uranium-232	68.9
Uranium-233	1.59E+5
Uranium-234	2.46E+5
Uranium-235	7.04E+8
Uranium-236	2.34E+7
Uranium-238	4.47E+9
Zirconium-93	1.53E+6

Source: DOE-STD-1196-2011, *Derived Concentration Technical Standard*.

COPC = contaminant of potential concern

Table 4. Radionuclide K_d Values from Past Studies

COPC	1998 CA[a]	2006 Vadose Zone Data Package[b]	TC & WM EIS[c]	Parameter Uncertainty for ERDF PA[d]	WMA C PA[e]	IDF PA[f]
Americium-241	300	-	1,900	300	600	300
Carbon-14	5	0	4	0.5	1	5
Cesium-137	1,500	2,000	80	2,000	100	2,000
Chlorine-36	0	0	-	0	-	0
Cobalt-60	1,200	-	-	10	0	2,000
Europium-152	300	200	-	300	10	300
Gadolinium-152	-	-	5	-	-	-
Hydrogen-3 (tritium)	0	0	0	0	0	0
Iodine-129	0.5	0.2	0	0.2	0.2	0.25
Molybdenium-93	-	-	-	0	-	-

Table 4. Radionuclide K_d Values from Past Studies

COPC	1998 CA[a]	2006 Vadose Zone Data Package[b]	TC & WM EIS[c]	Parameter Uncertainty for ERDF PA[d]	WMA C PA[e]	IDF PA[f]
Neptunium-237	15	10	2.5	10	10	15
Niobium-93m	300	-	-	0	0	0
Niobium-94	300	-	-	0	0	-
Plutonium isotopes	200	600	150	600	600	150
Polonium-209	-	-	-	-	-	-
Potassium-40	-	-	15	0	-	-
Protactinium-231	15	-	-	-	300	15
Radium-226	20	-	-	20	10	14
Radon-222	-	-	-	-	0	-
Rhenium-187	-	-	-	-	-	-
Selenium-79	0	5	-	5	0.1	7
Strontium-90	20	22	10	20	10	14
Technetium-99	0	0	0	0	0	0
Thorium-232	1,000	-	3,200	1,000	300	1,000
Tin-126	300	-	-	50	0.5	300
Uranium isotopes	3	0.8	0.6	0.8	0.6	1
Zirconium-93	1,000	-	600	1,000	300	1,000

Note: K_d values reported in mL/g.

a. PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*, Appendix E, Table E.10 (K_d Best Estimates for Low Organic/Low Salts/Near Neutral).

b. PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Table 4.11 (K_d Best estimates for low organic/low salt/near neutral, intermediate impact - sand or groundwater).

c. DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement*, Appendix N, Table N-2.

d. WCH-515, *Parameter Uncertainty for the ERDF Performance Assessment Uncertainty and Sensitivity Analysis*, Table 25. Best estimates for low organic/low salt/near neutral waste chemistry, not impacted sand.

e. RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*, Table 6-11.

f. RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington*, Table 4-33 (best estimates for far field sand sequence with natural recharge [no impact from wastes]).

3.2.1 Radionuclides Screened from the Initial List of COPCs

Americium-241

Only the TC & WM EIS (DOE/EIS-0391) included americium-241 in the list of selected COPCs. Table D-2 in the TC & WM EIS indicates that americium-241 was considered for intruder analysis scenarios only. Appendix Q and Appendix S do not include this limitation. A review of the TC & WM EIS vadose zone simulations showed that americium-241 was included in 211 of the transport simulations, but reached the water table in only one simulation with a cumulative release of only 4.6E-13 Ci.

Reported K_d values for americium-241 in the TC & WM EIS, 1998 CA (PNNL-11800), and the ERDF, WMA C, and IDF PAs (WCH-520, RPP-ENV-58782, and RPP-RPT-59958, respectively) ranged from 300 to 1,900 mL/g.

Because americium-241 has a relatively short half-life and decays to the more mobile neptunium-237, the potential dose significance of ingrowth of neptunium-237 was evaluated. Equations 1 and 2 were used to evaluate the ingrowth of neptunium-237 for a period of 10,000 years at waste site 216-Z-12, which has one of the highest SIM-v2 americium-241 inventories (ECF-HANFORD-17-0079). The resulting limited increase in neptunium-237 activity can be seen in Figure 1. The maximum increase in neptunium-237 activity due to americium-241 decay is relatively small, approximately 1.56 Ci. Table 5 lists values used in Equations 1 and 2 to evaluate the increase in neptunium-237 activity due to americium-241 decay.

$$A_1(t) = {A_1}^0 exp(-\lambda_1 \Delta t) \quad \textbf{(Eq. 1)}$$

$$A_2(t) = \frac{\lambda_2 {A_1}^0}{\lambda_2 - \lambda_1}[exp(-\lambda_1 \Delta t) - exp(-\lambda_2 \Delta t)] + {A_2}^0 \exp(-\lambda_2 \Delta t) \quad \textbf{(Eq. 2)}$$

where:

$A_1(t)$ and $A_2(t)$	=	the parent and daughter activities at time *t,* respectively
λ_1 and λ_2	=	the parent and daughter decay constants, respectively.
Δt	=	the decay time (CP-61786, *Inventory Data Package for the Hanford Site Composite Analysis*)

Because the generated neptunium-237 still has a substantial K_d (10 mL/g before gravel corrections), the generated neptunium-237 remains mostly in the upper part of the vadose zone and does not migrate to the saturated zone. Based on this analysis, the high K_d value, and the minimal groundwater impact predicted by the TC & WM EIS (DOE/EIS-0391) vadose zone simulations, americium-241 will be removed from the list of proposed COPCs.

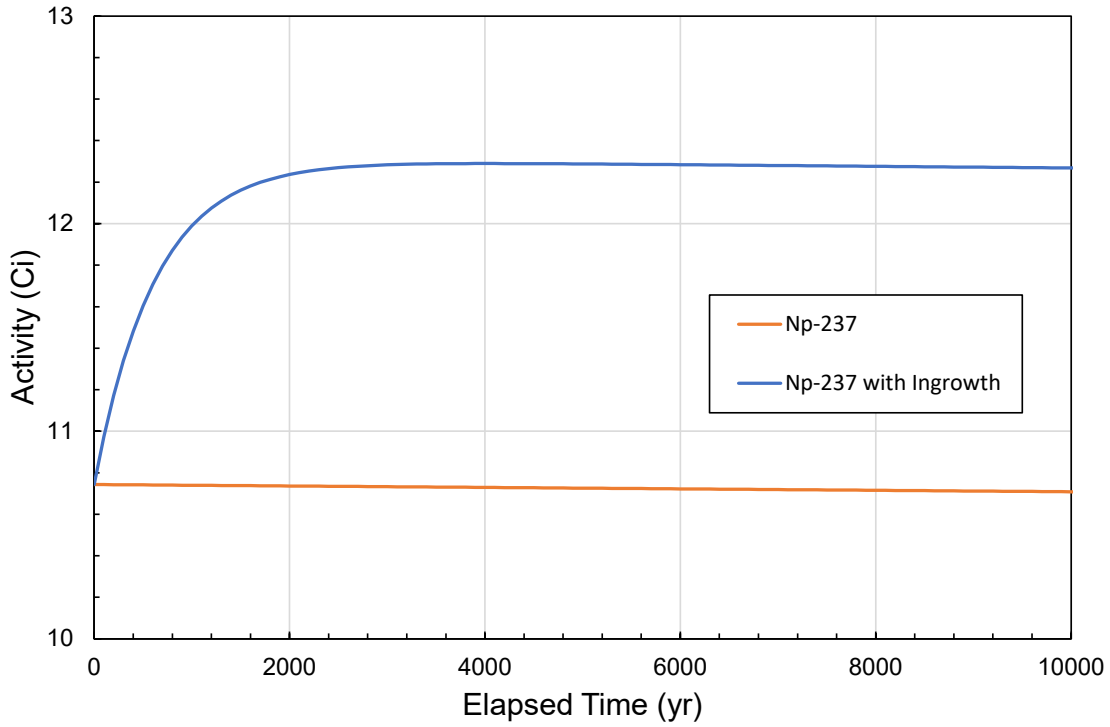

Figure 1. Impact of Ingrowth of Neptunium-237 from Americium-241 at Waste Site 216-Z-12 (assuming the entire inventory is available at time t_0)

Table 5. Values Used in Equations 1 and 2 to Evaluate the Impact of Ingrowth of Neptunium-237 Due to Americium-241 Decay at Waste Site 216-Z-12 (Figure 1)

Parameter	Value
Americium-241 Activity at Time t_0	7,746.25 Ci
Neptunium-237 Activity at Time t_0	10.74 Ci
Americium-241 Decay Constant	1.60E-03/yr
Neptunium-237 Decay Constant	3.24E-07/yr

Cesium-137

Cesium-137 was included in the list of selected COPCs for two of the past sitewide studies: the 2006 Data Package (PNNL-15829) and the TC & WM EIS (DOE/EIS-0391). Reported K_d values for cesium-137 in the TC & WM EIS, the 2006 Data Package, the 1998 CA (PNNL-11800), and the ERDF, WMA C, and IDF PAs (WCH-520, RPP-ENV-58782, and RPP-RPT-59958, respectively) ranged from 80 to 2,000 mL/g. PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*, states that "Under normal Hanford conditions, Cs(I) adsorption is high with K_d values in excess of 1,000 mL/g" and "it appears that Cs(I) transport through the Hanford Site vadose zone and groundwater will be negligible except under conditions of extremely high salt concentration."

A review of the TC & WM EIS vadose zone simulations showed that cesium-137 was included in 250 of the transport simulations, but reached the water table in only three locations (Gable Mountain Pond, the 216-A-5 Crib, and 218-W-2A Burial Ground). However, the TC & WM EIS K_d of 80 mL/g appears to be based on a value from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments,* for IDF vitrified waste for intermediate impact sand. For the same intermediate impact sand and low organic/low salt/near neutral waste chemistry, the "best" value in PNNL-14702 is 2,000 mL/g. PNNL-14702 also states "For cesium, the best estimate K_d value selected for most Hanford impact zones and waste categories is 2,000 ml/g with a range of 200 to 10,000."

Cesium-137, which has a relatively short half-life, decays to barium-137, a stable isotope. Ingrowth of daughter products does not need to be considered for cesium-137.

Based on the high K_d values, cesium-137 will be removed from the list of proposed COPCs.

Cobalt-60

Only the WMA C PA (RPP-ENV-58782) included cobalt-60 in the list of selected COPCs. This PA states that "Among radionuclides, the only contaminant producing nonzero concentrations at 100 m from the WMA C fenceline in the compliance period is ^{99}Tc. Other mobile contaminants such as ^{3}H, ^{60}Co, and ^{93m}Nb decay to insignificant quantities before reaching the water table."

PNNL-13895 states that "The general conclusions that can be drawn from these results are 1) Co(II) is highly immobile under normal Hanford groundwater conditions…"

Based on these observations and a half-life of less than 10 years, cobalt-60 will be removed from the list of proposed COPCs.

Europium-152

Only the 2006 Data Package included europium-152 in the list of selected COPCs. Reported K_d values for europium-152 in the 1998 CA, the 2006 Data Package, and the ERDF and IDF PAs ranged from 200 to 300 mL/g. For the WMA C PA, a K_d value of 10 mL/g was reported for europium-152, which was then excluded from consideration due to the K_d value being greater than 1.5 mL/g. The WMA C PA references PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site,* as the source for the europium-152 10 mL/g K_d value. In PNNL-17154, the 10 mL/g K_d is assigned as the "best" value for all europium isotopes in sand size sediments under intermediate impact conditions. For the same sand size sediments under no impact conditions, the "best" K_d value is 300 mL/g.

Europium-152, which has a relatively short half-life, decays to samarium-152 and gadolinium-152. Samarium-152 is a stable isotope. Gadolinium-152 was screened from the initial list of COPCs. Ingrowth of daughter products does not need to be considered for europium-152.

Based on the high K_d values, europium-152 will be removed from the list of proposed COPCs.

Gadolinium-152

Only the TC & WM EIS included gadolinium-152 in the list of selected COPCs. In the inventory tables in the TC & WM EIS, only one site was reported with an inventory of gadolium-152, 3.39×10^{-3} Ci at the 218-W-3A Burial Ground. A review of the TC&WM EIS vadose zone simulations showed that gadolinium-152 did not emerge to groundwater in 10,000-year evaluation period. Because there was no impact to groundwater for the single gadolinium-152 source, gadolinium-152 will be removed from the list of proposed COPCs.

Molybdenum-93

Only the ERDF PA (WCH-520) included molybdenum-93 in the list of selected COPCs. Since molybdenum-93 was identified as a selected COPC in only a single PA, composite impacts do not need to be evaluated. Molybdenum-93 will be removed from the list of proposed COPCs.

Niobium-93m

Niobium-93m was included in the list of selected COPCs for two PAs: the ERDF PA and the WMA C PA (RPP-ENV-58782). The ERDF PA states that "Hydrogen-3 and niobium-93m do not exist anywhere in the model domain in significant quantities after 1,000 years and decay to insignificant quantities (less than 1 E-14 Ci per Ci source) before reaching the water table." The WMA C PA states that "Among radionuclides, the only contaminant producing nonzero concentrations at 100 m from the WMA C fenceline in the compliance period is ^{99}Tc. Other mobile contaminants such as ^{3}H, ^{60}Co, and ^{93m}Nb decay to insignificant quantities before reaching the water table." Based on the lack of impact at the water table for these two PAs, niobium-93m will be removed from the list of proposed COPCs.

Niobium -94

Only the ERDF PA included niobium-94 in the list of selected COPCs. Since niobium-94 was identified as a selected COPC in only a single PA, composite impacts do not need to be evaluated. Niobium-94 will be removed from the list of proposed COPCs.

Plutonium isotopes

Only the TC & WM EIS (DOE/EIS-0391) included plutonium in the list of selected COPCs. A review of the TC & WM EIS vadose zone simulations showed that plutonium-239 was included in 264 of the transport simulations, but reached the water table in only three locations (Gable Mountain Pond, the 216-A-5 Crib, and waste site 200-E-78). Total cumulative releases to the water table were 2.65E-3 Ci for Gable Mountain Pond, 1.92E-6 Ci for the 216-A-5 Crib, and 1.58E-6 Ci for waste site 200-E-78.

Reported K_d values for plutonium isotopes in the TC & WM EIS, the 1998 CA (PNNL-11800), the 2006 Data Package (PNNL-14702), and the ERDF, WMA C, and IDF PAs (WCH-515, RPP-ENV-58782, and RPP-RPT-59958, respectively) ranged from 150 to 600 mL/g. PNNL-13895 states that "Based on the limited data available for Pu, it appears that Pu will be fairly immobile except at very low pH values or high ethylenediaminetetraacetic acid concentrations."

The potential dose significance of ingrowth of plutonium daughter products was evaluated using Equations 1 and 2. For waste site 216-Z-1A, which has the highest SIM-v2 inventory (ECF-HANFORD-17-0079) for each of the plutonium isotopes, the maximum increase in activity for any of the uranium isotopes generated by decay of plutonium-238, plutonium-239, plutonium-240, and plutonium-242 is less than 0.2 Ci over 10,000 years, an insignificant increase in total activity. Decay of plutonium-240 to uranium-236 resulted in a maximum increase of approximately 0.18 Ci in uranium-236 activity (Figure 2). Table 6 lists values used in Equations 1 and 2 to evaluate the increase in uranium-236 activity due to plutonium-240 decay.

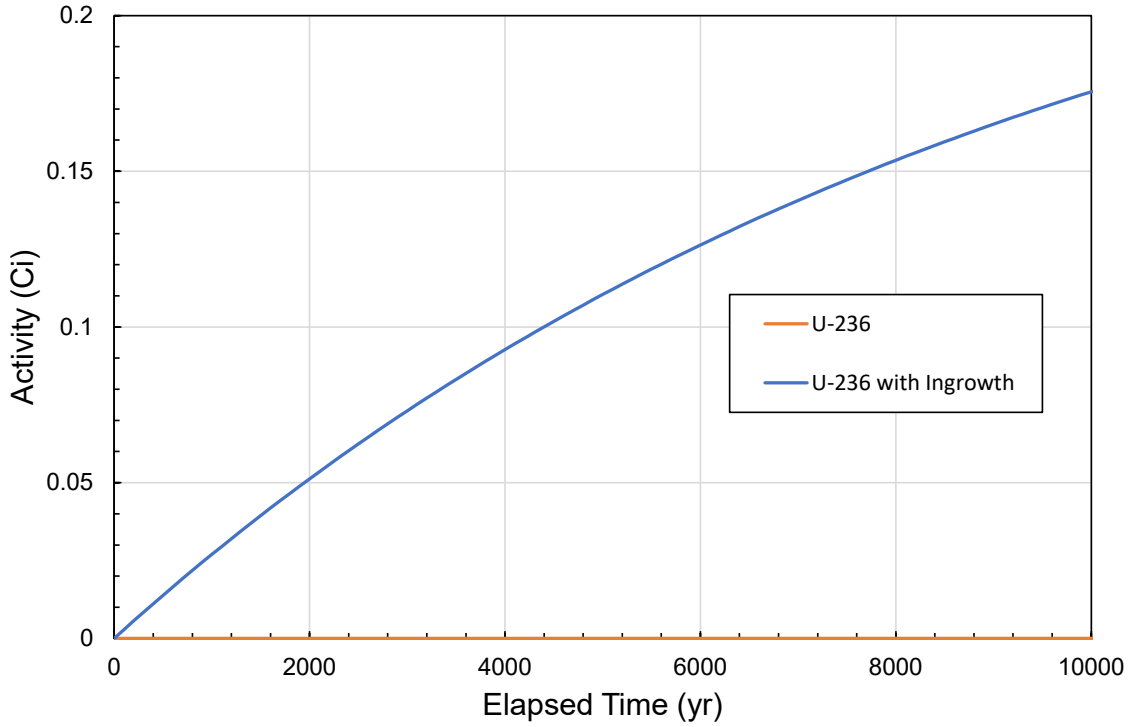

Figure 2. Impact of Ingrowth of Uranium-236 from Plutonium-240 at Waste Site 216-Z-1A (assuming the entire inventory is available at time t_0)

Table 6. Values Used in Equations 1 and 2 to Evaluate the Impact of Ingrowth of Uranium-236 due to Plutonium-240 Decay at Waste Site 216-Z-1A (Figure 2)

Parameter	Value
Plutonium-240 Activity at Time t_0	959.74 Ci
Uranium-236 Activity at Time t_0	0.00 Ci
Plutonium-240 Decay Constant	1.06E-04/yr
Uranium-236 Decay Constant	2.96E-08/yr

Plutonium-241 decays to americium-241 which, in turn, decays to neptunium-237. As noted previously, americium-241 was screened from the initial list of COPCs due to high K_d values and minimal predicted groundwater impact. Waste site 216-Z-12, which has one of the highest SIM-v2 inventories (ECF-HANFORD-17-0079) for plutonium-241, americium-241, and neptunium-237, was used to evaluate the impact of plutonium-241 decay on neptunium-237 activity. Figure 3 compares waste site 216-Z-12 neptunium-237 activities over a period of 10,000 years for no ingrowth, ingrowth due to americium-241 inventory only, and ingrowth due to plutonium-241 and americium-241 inventories. Table 7 lists values used in Equations 1 and 2 to evaluate the increase in neptunium-237 activity due to plutonium-241 and americium-241 decay.

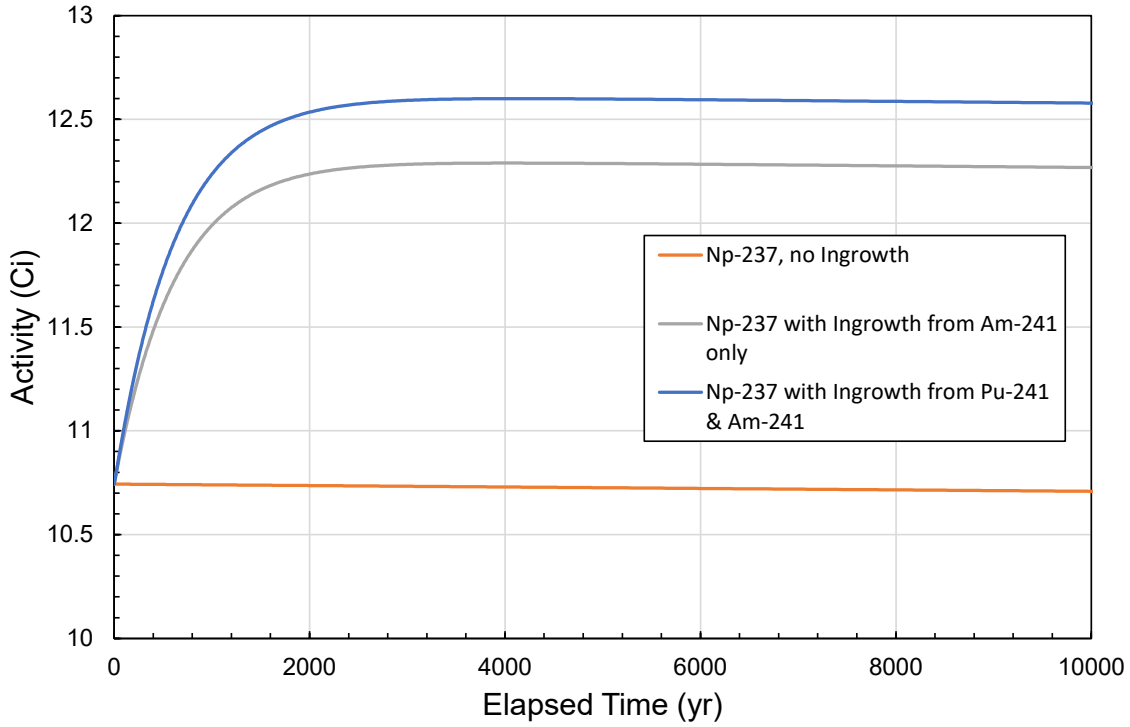

Figure 3. Impact of Ingrowth of Neptunium-237 from Americium-241 Only and from Plutonium-241 and Americium-241 at Waste Site 216-Z-12 (assuming the entire inventory is available at time t_0)

Table 7. Values Used in Equations 1 and 2 to Evaluate the Impact of Ingrowth of Neptunium-237 due to Plutonium-241 and Americium-241 Decay at Waste Site 216-Z-12 (Figure 3)

Parameter	Value
Plutonium-241 Activity at Time t_0	46428.50 Ci
Americium-241 Activity at Time t_0	7746.25 Ci
Neptunium-237 Activity at Time t_0	10.74 Ci
Plutonium-241 Decay Constant	4.83E-02/yr
Americium-241 Decay Constant	1.60E-03/yr
Neptunium-237 Decay Constant	3.24E-07/yr

The increase in neptunium-237 activity due to plutonium-241 and americium-241 decay is approximately 1.87 Ci. The increase in neptunium-237 activity due to americium-241 decay only is approximately 1.56 Ci. The difference between these two values (0.31 Ci) is the impact of plutonium-241 on to neptunium-237 activity. As noted previously, the generated neptunium-237 has a substantial K_d of 10 mL/g (before gravel corrections). As a result, neptunium-237 remains mostly in the upper part of the vadose zone and does not migrate to the saturated zone.

Based on this analysis, the high K_d value, and the minimal groundwater impact predicted by the TC & WM EIS (DOE/EIS-0391) vadose zone simulations, plutonium will be removed from the list of proposed COPCs.

Polonium-209

Only the 200 West LLBGs PA (WHC-EP-0645) included polonium-209 in the list of selected COPCs. Since polonium-209 was identified as a selected COPC in only a single PA, composite impacts do not need to be evaluated. Polonium-209 will be removed from the list of proposed COPCs.

Potassium-40

Potassium-40 was included in the list of selected COPCs for the TC & WM EIS and the ERDF PA (WCH-520). A review of the TC & WM EIS vadose zone simulations showed that potassium-40 did not reach groundwater in any of the 10 transport simulations where it was included. The ERDF PA states "For K-40 and Rn-222, there is no limit calculated because K-40 occurs naturally in the soils (it was not generated during the Hanford reactor operations)…". Based on the lack of impact to groundwater, potassium-40 will be removed from the list of proposed COPCs.

Protactinium-231

Protactinium-231 was included in the list of selected COPCs for the 2006 Data Package (PNNL-15829) and the 200 West LLBG PA (WHC-EP-0645). Protactinium-231 as a progeny will be included in the calculation of uranium-235 dose. Protactinium-231 will be removed from the list of proposed COPCs.

Radon-222

Only the WMA C PA (RPP-ENV-58782) included radon-222 in the list of selected COPCs. The WMA C PA indicates that radon-222 was included to complete the uranium decay chain to calculate radon flux. Since radon flux calculations will not be included as part of the groundwater pathway evaluation for the CA, and radon-222 has a half-life of less than 10 years, radon-222 will be removed from the list of proposed COPCs.

Selenium-79

Selenium-79 was included in the list of selected COPCs for two of the past sitewide studies (1998 CA and 2006 Data Packages), and three PAs (200 West LLBGs PA, 200 East LLBGs PA, and WMA C PA). Although selenium-79 was predicted to be a groundwater dose contributor in some of the earlier studies, this would not be the case for K_d values currently considered to be appropriate for selenium-79. As discussed in Appendix A of this document, the understanding of selenium-79 K_d has progressed over time. During the early studies, the K_d for selenium-79 was assumed to be 0 mL/g (i.e., no retardation). Current estimates, based on site-specific data, are higher, ranging from 3 to 10 mL/g (PNNL-13895), assuming low selenium concentrations and near neutral conditions. In the immediate vicinity of waste sites, the selenium K_d may be lower due to higher selenium concentrations or basic conditions, but throughout most of the vadose zone, conditions favoring the higher K_d range should apply.

Also, the SIM-v2 inventory (Appendix J in ECF-HANFORD-17-0079) for selenium-79 was less than 2.3 Ci for all historical liquid discharges. Based on the relatively high K_d, limited inventory, exclusion from the TC & WM EIS (DOE/EIS-0391) list of COPCs, and lack of impact for studies with higher K_d values (DOE/ORP-2000-24, *Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version*, the ERDF PA [WCH-520], and the IDF PA [RPP-RPT-59958]), selenium-79 will be removed from the list of proposed COPCs.

Thorium-232

Only the TC & WM EIS included thorium-232 in the list of selected COPCs. A review of the TC & WM EIS vadose zone simulations showed that thorium-232 did not reach groundwater in any of the 195 transport simulations where it was included.

Reported K_d values for thorium-232 in the TC & WM EIS, the 1998 CA, and the ERDF, WMA C, and IDF PAs ranged from 300 to 3,200 mL/g. Also, the SIM-v2 inventory (ECF-HANFORD-17-0079) for thorium-232 was less than one hundredth of a Ci for all historical liquid discharges included in the SIM-v2. Based on the high K_d values and low inventory, thorium-232 will be removed from the list of proposed COPCs.

Tin-126

Only the WMA C PA included tin-126 in the list of selected COPCs[2]. Since tin-126 was identified as a selected COPC in only a single PA, composite impacts do not need to be evaluated. Tin-126 will be removed from the list of proposed COPCs.

Zirconium-93

Only the TC & WM EIS included zirconium-93 in the list of selected COPCs. A review of the TC & WM EIS vadose zone simulations showed that zirconium-93 did not reach groundwater in any of the 170 transport simulations where it was included.

Reported K_d values for zirconium-93 in the TC & WM EIS, the 1998 CA, and the ERDF, WMA C, and IDF PAs ranged from 300 to 1,000 mL/g.

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[2] Tin-126 (Sn-126) has been excluded from most analyses related to waste management and tank closure activities on the Central Plateau of the Hanford Site. The basis for excluding Sn-126 from the TC&WM EIS (DOE/EIS-0391), the ERDF PA (WCH-520) and IDF PA (RPP-RPT-59958, Rev. 1) was the high K_d of Sn-126 on the sand-sized sediments characteristic of the H2 sand as recommended in PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*. For example, PNNL-17154, Table 3.4 recommends a "non-impacted, best-estimate" K_d of 50 mL/g which is the same as the IDF PA “reasonably conservative” far field non-impacted K_d (RPP-RPT-59958, Rev. 1, Table 4-33) which is slightly higher than the IDF “reasonably conservative” far field impacted K_d (Table 4-33) of 40 mL/g. A K_d of this magnitude would preclude Sn-126 from being transported to groundwater within the 10,000-yr simulation period.

The WMA C PA (RPP-ENV-58782, “Performance Assessment of Waste Management Area C, Hanford Site, Washington”) assumed a lower Sn-126 K_d value of 0.4 mL/g for the H2 sand and included Sn-126 in the WMA C PA. The lower K_d values was derived from a sand-size K_d of 0.5 mL/g recommended in PNNL-17154, Table 3.3 when the K_d is assumed to be impacted by waste disposed. The use of this alternative K_d value in the WMA C PA had no significant impact on the predicted dose as illustrated in RPP-ENV-58782, Figure 7-30.

Whether the vadose zone pore water chemistry is assumed to be impacted or not by the waste, the release and transport of Sn-126 is not significant and Sn-126 can be excluded from the CA.

Zirconium-93 decays to niobium-93, a stable isotope. Ingrowth of daughter products does not need to be considered for zirconium-93.

Based on these high K_d values, zirconium-93 will be removed from the list of proposed COPCs.

3.2.2 Radionuclides Retained from the Initial List of COPCs

Tritium, iodine-129, neptunium-237, technetium-99, and the uranium isotopes are known leading dose contributors and, as such, will be retained in the final list of COPCs. Carbon-14, chlorine-36, and rhenium-187 were included in multiple studies where they were predicted to be groundwater dose contributors. These radionuclides will be retained in the final list of COPCs. Since strontium-90 is found in groundwater in the 200 Area in concentrations that exceed the drinking water standard (DOE/RL-2016-67, *Hanford Site Groundwater Monitoring Report for2016*), strontium-90 will be retained in the final list of COPCs. Additionally, radium-226 will be retained and thorium-230 will be added to evaluate the decay chain: uranium-234 > thorium-230 > radium-226. Table 8 shows the initial list of potential COPCs and the reason for retaining or removing each radionuclide from the final COPC list.

Table 8. COPC Screening Results

COPC	Rationale
Retain	
Carbon-14	Key contributor to dose.
Chlorine-36	Key contributor to dose.
Hydrogen-3 (tritium)	Key contributor to dose.
Iodine-129	Key contributor to dose.
Neptunium-237	Key contributor to dose.
Radium-226	Added decay chain U-234 > Th-230 > Ra-226.
Rhenium-187	Dose contributor in the 200 East LLBGs PA (WHC-SD-WM-TI-730) and the 200 West LLBGs PA (WHC-EP-0645).
Strontium-90	Current groundwater concentrations.
Technetium-99	Key contributor to dose.
Uranium isotopes	Key contributor to dose.
Add	
Thorium-230	Added decay chain U-234 > Th-230 > Ra-226.
Eliminate	
Americium-241	High K_d values.
Cesium-137	High K_d values.
Cobalt-60	Half-life less than 10 yr.
Europium-152	High K_d values.

Table 8. COPC Screening Results

COPC	Rationale
Gadolinium-152	No impact to groundwater for the TC & WM EIS (DOE/EIS-0391).
Molybdenium-93	Only identified in the ERDF PA (WCH-520), so composite impacts do not need to be evaluated.
Niobium-93m	No impact to groundwater for the two PAs (WCH-520 and RPP-ENV-58782) where niobium-93m was evaluated.
Niobium-94	Only identified in the ERDF PA (WCH-520, so composite impacts do not need to be evaluated.
Plutonium isotopes	High K_d values.
Polonium-209	Only identified in the 200 West LLBGs PA (WHC-EP-0645), so composite impacts do not need to be evaluated.
Potassium-40	No impact to groundwater for the TC & WM EIS (DOE/EIS-0391) or ERDF PA (WCH-520).
Protactinium-231	Pa-231 will be included as a progeny in the calculation of U-235 dose.
Radon-222	Half-life less than 10 yr.
Selenium-79	Relatively high K_d, limited inventory, and lack of impact for studies with higher K_d values.
Thorium-232	High K_d values.
Tin-126	Only identified in the WMA C PA (RPP-ENV-58782), so composite impacts do not need to be evaluated.
Zirconium-93	High K_d values.

Note: Complete reference citations are provided in Chapter 5 of this document.

COPC = contaminant of potential concern
ERDF = Environmental Restoration Disposal Facility
K_d = distribution coefficient
LLBG = low-level burial ground
PA = performance assessment
TC & WM EIS = Tank Closure and Waste Management Environmental Impact Statement
WMA = waste management area

4 Summary

This document describes the screening and selection process for radionuclides to include in the Hanford Site CA (DOE/RL-2019-52). This screening approach was based on methods adopted in three prior sitewide studies: the 1998 CA, the 2006 Data Package (PNNL-15829), and the TC & WM EIS. Sixteen radionuclides (Table 9) were selected for the Hanford Site CA groundwater pathway evaluation.

Table 9. Selected Contaminants for Groundwater Pathway Detailed Evaluation

Contaminant	
Carbon-14	Technetium-99
Chlorine-36	Thorium-230
Hydrogen-3 (tritium)	Uranium-232
Iodine-129	Uranium-233
Neptunium-237	Uranium-234
Radium-226	Uranium-235
Rhenium-187	Uranium-236
Strontium-90	Uranium-238

5 References

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Appendix A

Selenium-79 Review

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A1 Documented Selenium-79 Distribution Coefficient Values

This appendix documents a review of selenium-79 distribution coefficient (K_d) values from Hanford Site documents including DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington* (hereinafter called the TC & WM EIS), composite analyses (CAs), performance assessments (PAs), and related or referenced documents. Appendix B of this document lists the K_d values from those documents. Only those K_d values that were identified as sand size or with no size description were included in Appendix B; silt-size, gravel corrected, and carbonate-dominated values were not included.

In the earlier documents reviewed, including WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* (hereinafter called the 200 West LLBGs PA), WHC-SD-WM-TI-730, *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds* (hereinafter called the 200 East LLBGs PA), and PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (hereinafter called the 1998 CA), a selenium-79 K_d of 0 mL/g was used. There is a progression from the assumed value of 0 mL/g in these earlier documents to a value of 4 mL/g (based on site-specific data [DOE/ORP-2000-24, *Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version,* hereinafter called the 2001 ILAW PA]), to a "best" nonimpacted value of 5 or 7 (depending on the document) for the later documents.

Table A-1 lists the least impacted (by waste chemistry) "best" selenium-79 K_d values found for each of the studies being reviewed. At first glance, RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington* (hereinafter called the WMA C PA) looks to be an exception with a value of 0.1 mL/g. However, following the references (see Section A1.5) shows that this value is for the intermediate impact zone.

PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*, provides the following summary regarding selenium:

> **Selenium.** A fair number of Se(VI) K_d values have been determined using natural Hanford sediment and are listed in Table 14. These results indicate that at trace concentrations, adsorption of Se(VI) to Hanford sediment is low to moderate with K_d values ranging from 3 to 10 mL/g. At higher Se(VI) concentrations, the K_d values are lower (0 to 3 mL/g). Acidic conditions increase Se(VI) adsorption, and basic conditions reduce adsorption. This is consistent with the anionic character of Se(VI).

Most of the selenium concentrations in the vadose zone would likely be "trace concentrations," with a K_d of 3 to 10 mL/g based on PNNL-13895.

Table A-1. Selenium K_d Values from Past Studies

COPC	1998 CA[a]	2006 Data Package[b]	200 West LLBGs PA[c]	200 East LLBGs PA[d]	TC & WM EIS[e]	ERDF PA[f]	WMA C PA[g]	IDF PA[h]
Selenium-79	0	5	0	0	Not listed	5	0.1	7

Note: K_d values reported in mg/L.

a. PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site.*

b. PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*.

c. WHC-EP-0645, *Performance Assessment for the Disposal of Low Level Waste in the 200 West Area Burial Grounds*.

d. WHC-SD-WM-TI-730, *Performance Assessment for the Disposal of Low Level Waste in the 200 East Area Burial Grounds*.

e. DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement*.

f. WCH-515, *Parameter Uncertainty for the ERDF Performance Assessment Uncertainty and Sensitivity Analysis*.

g. RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*.

h. RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington*.

CA = composite analysis
COPC = contaminant of potential concern
ERDF = Environmental Restoration Disposal Facility
IDF = Integrated Disposal Facility
K_d = distribution coefficient
LLBG = low-level burial ground
PA = performance assessment
TC & WM EIS = Tank Closure and Waste Management Environmental Impact Statement

A1.1 200 W LLBGs PA, 200 E LLBGs PA, and 1998 CA

The 200 West LLBGs PA (WHC-EP-0645), 200 East LLBGs PA (WHC-SD-WM-TI-730), and 1998 CA (PNNL-11800) predicted that selenium-79 will be a dose contributor. Figures A-1 and A-2 show that groundwater dose for selenium-79 exceeded the technetium-99 dose for the 200 West LLBGs PA and the 200 East LLBGs PA evaluations. For the 1998 CA, the selenium-79 cumulative release is only slightly less than uranium-238 and more than carbon-14 and iodine-129 (Table A-2). All three of these early studies had a selenium-79 K_d of 0 mL/g.

200-W LLBGs C PA (WHC-EP-0645)
1995

Table 4-22. Radionuclide Dose Estimates for Groundwater Pathways.

Radionuclide	All-pathways dose (mrem/yr)	Groundwater dose (mrem/yr)	Population dose (person-rem/yr)	Dose ratios	
				All path/GW	Pop./GW
^{3}H	4.1 E-03	3.6 E-03	NA	1.1	NA
^{14}C	2.7 E+02	1.2 E+02	20	2.2	0.17
^{36}Cl	3.0 E+03	1.7 E+02	360	17	2.1
^{79}Se	8.5 E+02	4.8 E+02	78	1.8	0.16
^{99}Tc	2.5 E+02	7.6 E+01	20	3.3	0.26
^{129}I	2.9 E+04	1.6 E+04	2100	1.8	0.13
^{187}Re	7.0 E-01	4.8 E-01	0.051	1.5	0.11
^{237}Np	1.6 E+03	1.4 E+03	110	1.1	0.076
^{209}Po	3.3 E+01	2.9 E+01	2.3	1.1	0.078
^{231}Pa	4.2 E+04	3.9 E+04	2900	1.1	0.076
U	1.6 E+04	1.4 E+04	1100	1.1	0.080

Figure A-1. Table 4-22 of the 200-W LLBGs PA

200-E LLBGs C PA (WHC-SD-WM-TI-730)
1996

Table 4-14. Radionuclide Dose Estimates for Groundwater Pathways.*

Radionuclide	Drinking Water Dose (mrem/yr)	All-Pathways Dose (mrem/yr)	Dose ratio (All-Pathways/ groundwater)
^{3}H	0.11	0.12	1.1
^{14}C	1,100	2,400	2.2
^{36}Cl	1,510	26,700	17
^{79}Se	4,200	7,400	1.8
^{99}Tc	650	2,100	3.3
^{129}I	141,000	292,000	1.8
^{187}Re	4	6	1.5
^{237}Np	1,964,000	2,216,000	1.1
U	1,209,000	1,330,000	1.1

*These doses are from the base-case analysis assuming a 1-Ci inventory per radionuclide and Category 1 infiltration conditions (5 cm/yr). The values does not represent actual inventory projections and associated doses.

Figure A-2. Table 4-14 of the 200-E LLBGs PA

Table A-2. 1998 CA Cumulative Release from All Sources to the Water Table from 1940 to 3000

Radionuclide	Activity (Ci)
Tc-99	1460
Cl-36	11.67
U-238	8.67
Se-79	8.03
C-14	4.58
I-129	2.1

Source: PNNL-11800, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*.

Note: Estimated from Figures 4.5 to 4.10 from source document.

A1.2 2006 CA (Incomplete)

PNNL-15829, *Inventory Data Package for Hanford Assessments,* references the 2001 ILAW PA (DOE/ORP-2000-24) as the "primary source of the selection data" regarding the inclusion of selenium-79 in the Hanford assessments. A review of the 2001 ILAW PA shows that selenium-79 was not a significant contributor to dose within the 10,000-year evaluation period.

The K_d used for selenium-79 changed from 0 mL/g in the 1998 ILAW PA (DOE/RL-97-69, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment*) to 4.0 mL/g in the 2001 ILAW PA. Section 4.3.6 of the 2001 ILAW PA states:

> "In the 1998 ILAW performance assessment (Mann 1998a), the most restrictive impact was caused by the drinking water dose from beta- and photon-emitting radionuclides. At 10,000 years, this dose was calculated to be 2.0 mrem in a year resulting mainly from ^{99}Tc (75 percent) and ^{79}Se (20 percent). This performance assessment shows much lower numbers at 10,000 years (0.010 mrem/y). The highest value calculated for the beta/photon drinking water dose is 0.013 mrem/year at about 76,500 years. Table 4-4 shows the major contributions at 1,000 years and 10,000 years to the estimated beta and photon drinking water dose at a well 100 m downgradient from the disposal facility. Figure 4-17 shows the time dependence. In this assessment, ^{99}Tc is still the most important radionuclide, contributing approximately 58 percent of the dose at 1,000 and 10,000 years. However, the next most important radionuclide is ^{129}I, which contributes approximately 42 percent at 1,000 and 10,000 years. The switch of selenium and iodine is a direct result of site specific data increasing selenium's K_d from 0. to 4.0 mL/g and decreasing iodine's K_d from 3.0 to 0 mL/g (see Section 3.4.3.3)."

Section 7.7 of the 2001 ILAW PA states:

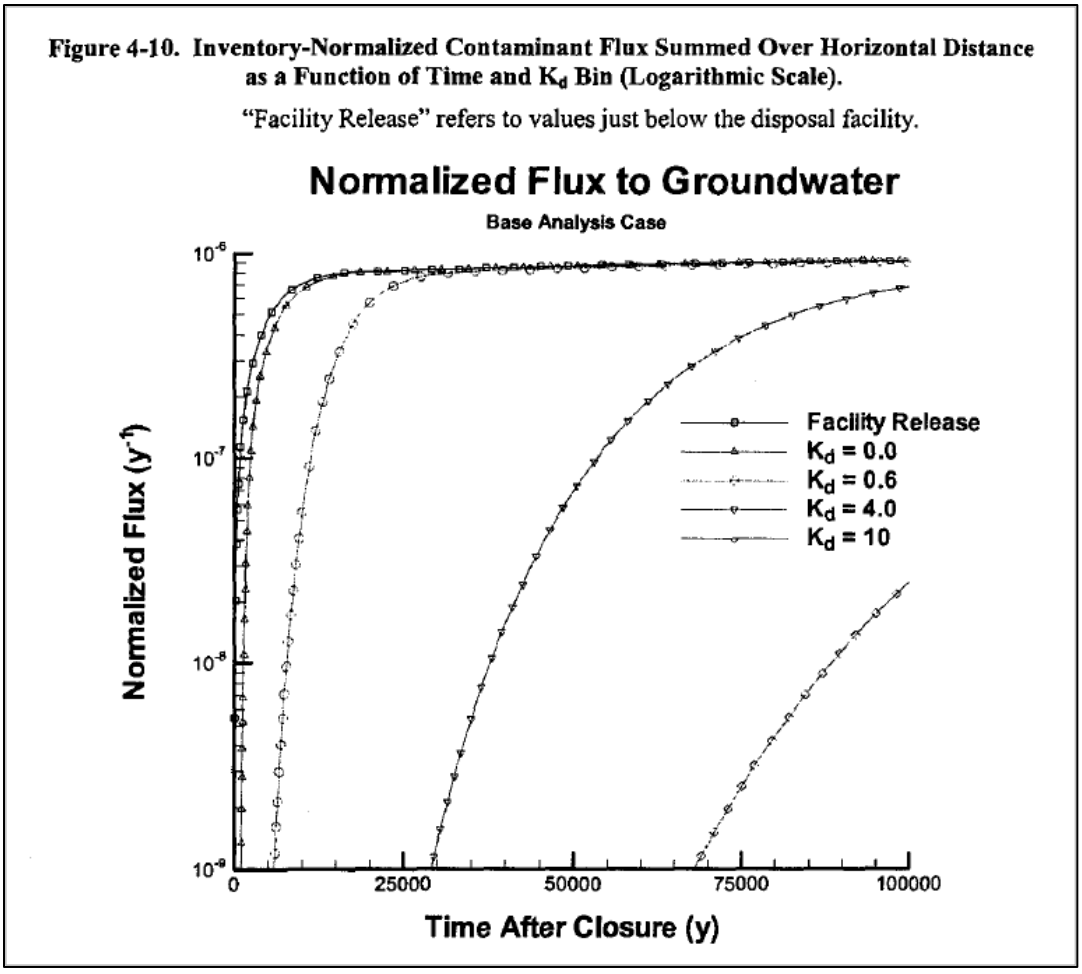
> "In the 1998 ILAW PA, ^{79}Se was assumed to be mobile because no Hanford Site-specific data were available that indicated otherwise. Since then, we have learned that the half-life of ^{79}Se is longer than was believed. Also, disposal-site specific information has shown that selenium transport in the vadose zone is chemically retarded."

Because of this change in the K_d value, selenium-79 does not reach the water table within 10,000 years for the 2001 ILAW PA Base Analysis Case. Section 4.3.4 of the 2001 ILAW PA states:

> "Figure 4-10 shows the contaminant flux summed over horizontal distance as a function of time and K_d bin. Only the mobile contaminants reach the groundwater during the time of compliance (the first 1,000 years). At 10,000 years, the slightly retarded contaminants (K_d = 0.6 mL/g) also are beginning to reach the groundwater, but their inventory-normalized contribution is still approximately one order of magnitude less than the mobile contribution. Higher K_d contaminants ($K_d \geq 4$ mL/g) do not contribute to the estimated doses at 10,000 years and are even less important."

Figure A-3 is a copy of Figure 4-10 from the 2001 ILAW PA. It shows that, for the Base Analysis Case, radionuclides with a K_d of 4.0 mL/g (including selenium-79) do not reach the water table until after 25,000 years.

Based on these observations, selenium-79 should not have been included in the 2006 Data Package (PNNL-15829) screened radionuclide list using the 2001 ILAW PA (DOE/ORP-2000-24) as a basis for selecting selenium-79. With a K_d of 4.0 mL/g, selenium-79 would not have reached the water table within 10,000 years under the 2001 ILAW PA Base Analysis Case. Also, the K_d of 5 mL/g selected for selenium-79 for the incomplete 2006 CA and documented in PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, should result in minimal to no impact to the groundwater from selenium-79.



Source: Figure 4-10 in DOE/ORP-2000-24, *Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version*.

Figure A-3. Inventory-Normalized Contaminant Flux Summed Over Horizontal Distance as a Function of Time and K_d Bin (Logarithmic Scale)

A1.3 TC & WM EIS

Radionuclide screening for the TC & WM EIS (DOE/EIS-0391) is discussed in three of its appendices: D, Q, and S. The following are excerpts from these appendices.

Appendix D:

> "The BBI includes quantity estimates of 46 radionuclides and 24 chemical constituents. Not all constituents are important in the exposure scenarios used to assess TC & WM EIS alternative implementation impacts. Thus, to focus attention on the constituents that control the impacts, DOE performed an initial screening analysis. For radionuclides, groundwater release and direct intrusion scenarios were considered. For the groundwater release screening scenario, only drinking water consumption was considered. Release was assumed to be partition limited, and decay during transport was considered. For the direct intrusion screening scenario, inadvertent soil ingestion and inhalation pathways were considered.

The analysis estimated relative impacts based on distribution of radionuclides in the BBI for all tanks. Radionuclides contributing less than 1 percent of impacts under intruder or well scenarios were eliminated from the detailed analysis."

"The screening of the BBI for the groundwater scenarios resulted in reduction of the original set of 46 radionuclides and 24 chemical constituents to a final set of ten radionuclides and ten chemical constituents that was used in the analysis of the tank waste. However, a screening of the cumulative impacts analysis data resulted in the addition of other COPCs that are not included in Table D–2. Appendix Q provides details on this screening."

Appendix Q:

"The process of impacts analysis is iterative in nature, with execution of initial passes through the steps at a high level so as to screen out less important conditions and produce a manageable set of scenarios for analysis. An initial iteration through the procedure was used to establish the number of constituents to be included in the analysis. For radionuclides in this screening analysis, groundwater release and direct intrusion scenarios were considered. For the groundwater release screening scenario, only drinking water consumption was considered, release was assumed to be partition limited, and decay during transport was considered. For the direct intrusion scenario, inadvertent soil ingestion and inhalation pathways were considered. The analysis involved estimation of relative impacts based on the distribution of radionuclides in all tanks; FFTF decommissioning; waste proposed for disposal at IDF-East, IDF-West, and the RPPDF; and contamination in place at cumulative analysis sites. In reviewing constituents at a given source area, radionuclides contributing in combination less than 1 percent of impacts for intruder or well scenarios were not included in the detailed analysis."

"The screening resulted in reduction of the original set of radioactive and chemical constituents to a final set of 14 radioactive and 26 chemical constituents, which represents both alternatives and cumulative impact sources."

Appendix S:

"The initial list of radionuclides included those with half-lives greater than 10 years, and the initial list of chemicals included those with a health risk from ingestion—that is, they have maximum contaminant levels or are listed in the Integrated Risk Information System as having health-based ingestion standards. Not all the radioactive and chemical constituents on the initial list are important in exposure scenarios used to assess cumulative impacts in this TC & WM EIS. Therefore, to focus attention on constituents that control impacts, an additional screening analysis was performed. The primary focus of that analysis was to consider groundwater release scenarios for cumulative impacts analysis sources and to ensure consistency with the screening done for the alternatives analysis, allowing for cumulative impacts to be added to the alternatives impacts. For radionuclides, only groundwater consumption was considered, release was assumed to be partition limited, and decay during transport was considered. For analysis purposes, estimation of relative impacts was based on the distribution of radionuclides in the cumulative impacts inventory. Radionuclides contributing less than 1 percent of impacts under well scenarios were eliminated from the detailed analysis."

> "As indicated in Table S–8, the screening resulted in reduction of the original set of radioactive and chemical constituents to a final set of 14 radioactive and 26 chemical constituents, which includes those constituents also identified for the alternatives impacts analysis. Appendix Q of this TC & WM EIS provides further description of the screening process for the radioactive and chemical constituents identified for the groundwater analysis."

All three appendices state that radionuclides contributing less than 1% of impacts were eliminated from the detailed analysis. This statement indicates that selenium-79 was determined to contribute little to no impact under the assumptions of the TC & WM EIS.

A1.4 ERDF PA

WCH-520, *Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington* (hereinafter called the ERDF PA), used a selenium-79 K_d of 5 mL/g. Selenium-79 does not reach the water table within the 10,000-year period for the ERDF PA compliance case evaluation, as noted in Section 4.2.3 of the ERDF PA:

> "During the post-compliance period 1,000 to 10,000 years after closure, chlorine-36, technetium-99, niobium-94, molybdenum-93, and iodine-129 breakthrough at the point of compliance (100 m downgradient of the ERDF) as shown in Figure 4-9. Iodine-129 is the only radionuclide with a K_d value greater than zero to do so."

This can be seen in Figure 4-9 of the ERDF PA.

A1.5 WMA C PA

Figure A-4 shows that the WMA C PA (RPP-ENV-58782) predicted a selenium-79 peak groundwater concentration that was half that of uranium-238 and over twice the iodine-129 concentration. The WMA C PA states that "The K_d values are chosen assuming low-salt, near-neutral waste chemistry in the vadose and saturated zone." The selentium-79 K_d of 0.1 mL/g used for the WMA C PA is referenced to PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site.* This value applies to the "Best" value for sand size sediments in the intermediate impact zone (see Tables 3.3, 3.7, 3.9, 3.13, 3.17, 3.21, and 3.23 of PNNL-17154). PNNL-17154 defines the intermediate zone as "Zones in which the acidic or basic nature of the wastes was expected to have been largely neutralized by reaction with the natural sediment." Table 3.4 in PNNL-17154 lists a selenium-79 "Best" K_d of 5 mL/g for sand size sediments in natural pore waters/groundwater. This value is in the range given by PNNL-13895, agrees with the value used in the ERDF PA (WCH-520), and is similar to the value used in RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington* (hereinafter called the IDF PA).

Also, Table 4.11 in PNNL-14702 gives a "Best" selenium-79 K_d value of 5 mL/g for sand size sediments in the intermediate impact zone assuming a low-salt/near-neutral waste chemistry.

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Table 7-3. Summary of Base Case Peak Groundwater Concentrations and Arrival Times for Selected Radionuclides.

Radionuclide or Nonradiological Contaminant	Nominal K_d value (mL/g)	Maximum Concentration during Compliance Time Frame (pCi/L)	Point of Calculation where Maximum Concentration Occurs	Years after Closure of Maximum Concentration	Maximum Concentration during Sensitivity/Uncertainty Time Frame (pCi/L)	Point of Calculation where Maximum Concentration Occurs
Iodine-129	0.2	0	—	6,540	0.004	PoCal 4
Selenium-79	0.1	0	—	3,770	0.01	PoCal 5
Tin-126	0.5	0	—	10,000	0.05	PoCal 5
Technetium-99	0	0.1	PoCal 5	1,550	30	PoCal 4
Uranium-238	0.6	0	—	10,000	0.02	PoCal 3

Source: Table 7-3 in RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*.

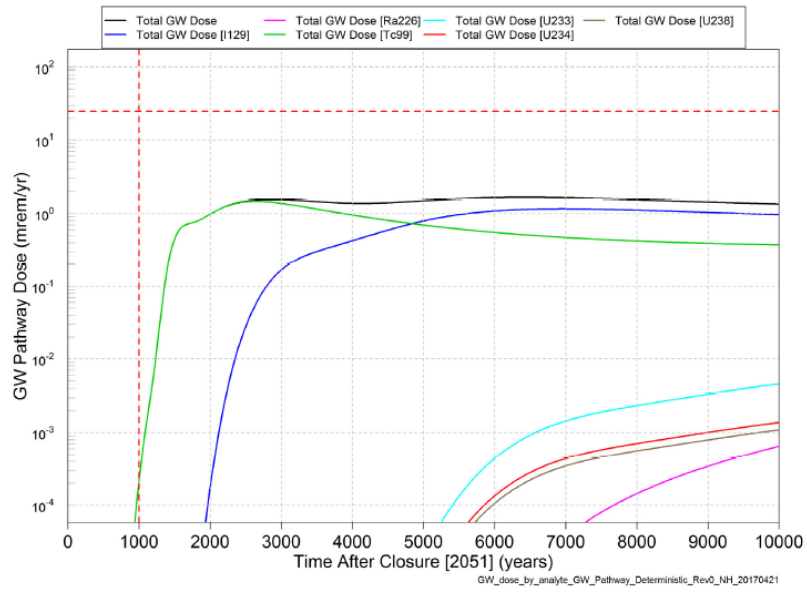
Figure A-4. Summary of Base Case Peak Groundwater Concentrations and Arrival Times for Selected Radionuclides

A1.6 IDF PA

Table 4-33 in IDF PA (RPP-RPT-59958) lists selenium-79 "reasonably conservative" and "best" K_d values of 1 and 2 mL/g for chemically impacted far field in sand, and values of 3 and 7 mL/g for far field in sand with natural recharge (i.e., no impact from wastes). These K_d values are referenced to PNNL-13037, *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*. Based on Figure 1-4 in the IDF PA (shown here as Figure A-5), selenium-79 does not reach the water table within the 10,000-year period.

RPP-RPT-59958, Rev. B Draft

Figure 1-4. Integrated System Model Groundwater Pathway Total Dose by Radionuclide.



Note: Integrated system model dose at 1,000 years is 2.0E-04 mrem/yr and peak dose is 1.65 mrem/yr at 6415 years after closure.

Source: Figure 1-4 in RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington*.

Figure A-5. Integrated System Model Groundwater Pathway Tool Dose by Radionulide

A2 Effects of pH and Ionic Strength on Selenium K_d

PNNL-11964, *Effects of High-pH and High-Ionic Strength Groundwater on Iodide, Pertechnetate, and Selenate Sorption to Hanford Sediments*, and PNNL-14325, *The Influence of Glass Leachate on the Hydraulic, Physical, Mineralogical and Sorptive Properties of Hanford Sediment,* looked at the effects of increased pH and high ionic strength due to leachate from the waste. Table 4 in PNNL-11964 shows that increasing ionic strength, while maintaining pH at approximately 7.7, did not have a large impact on the selenium K_d, showing a small increase with higher ionic strength. Increasing pH from 8.1 to 11.9 sharply decreased selenium K_d from 5.78±0.28 to 0.04±0.00 mL/g, with most of the drop occurring between pH 8.1 and pH 9.9 (Table 7 in PNNL-11964).

The results of the PNNL-14325 batch sorption study (Table 3.14) show selenium-79 K_d values for time 0 that increased with increasing ionic strength. Table 3.14 also shows that there was no sorption after time 0 (10, 90, 180, and 360 days). However, Figure 3.42 in PNNL-14325 shows that, after time 0, the lowest measured pH was about 9.5. This appears to be in agreement with the PNNL-11964 results. PNNL-14325 notes that "as the pH of the glass leachate is neutralized by reactions with the vadose zone sediments, or certainly by the time vadose zone pore water reaches the water table, there would appear to be some adsorption potential for selenate (including ^{79}Se)."

Um and Serne, 2004, "Sorption and Transport Behavior of Radionuclides in the Proposed Low-Level Radioactive Waste Disposal Facility at the Hanford Site," compared selenium-75 (as an analog for selenium-79) K_d values for three different Hanford sediments using uncontaminated Hanford groundwater and simulated glass leachate spiked with individual radionuclides. Table 3 of Um and Serne (2004) shows that K_d values for the three tests with uncontaminated groundwater ranged from 7.14±0.18 to 8.65±0.34 mL/g (pH from 7.6 to 7.7). For the three tests with simulated glass leachate, K_d values ranged from 1.08±0.09 to 2.68±0.12 mL/g (pH from 8.9 to 9.0).

PNNL-13037 includes the following discussion regarding selenium-79 K_d values:

> "In 1998, little Hanford-specific data existed for the adsorption properties of selenium (as selenate or selenite). For the 1998 ILAW PA, it was, therefore, recommended that the K_d values for ^{79}Se be set at 0 mL/g. Between 1998 and 2001, batch K_d studies (Kaplan et al. 1998c) were completed using several Hanford sediments, including IDF borehole 299-E17-21. The solution used in these measurements was uncontaminated groundwater, and the sediments were dominated by sand-sized particles. Kaplan et al. (1998b)[3] also studied the adsorption of ^{75}Se, as a surrogate for ^{79}Se, from Hanford groundwaters with pH values that had been adjusted to higher than normal values. The measurements suggest that some significant adsorption of selenate would be expected for both groundwater and higher pH solutions. Thus, for the 2001 ILAW PA, the "most probable" K_d value for selenium was chosen as 4 mL/g.
>
> More recent work by Kaplan et al. (2003) indicates that selenate adsorption to Hanford sediments is nil for highly alkaline solutions. This is consistent with geochemical principles (see discussion in EPA 1999a and references therein) that suggest that anionic species, such as selenite and selenate, should show reduced sorption at greater-than-neutral pH conditions onto any sediment containing minerals with variably charged adsorption surface sites, such as iron and aluminum hydrous oxide minerals and particle coatings.

[3] Kaplan, 1998b is PNNL-11966, *Radionuclide Distribution Coefficients of Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a*.

Um and Serne[(a)] used an uncontaminated groundwater and a simulated glass leachate based on the composition for the long-term, steady-state chemical composition of glass leachate and vadose zone pore water predicted by the STORM code for the 2001 ILAW PA (see Table 6.2) to study selenate adsorption onto three samples of Hanford formation sediments from another IDF borehole (299-E24-21 [ILAW borehole #2 – C3177]). The K_d values measured by Um and Serne for selenate are described in Section 3.5.3. These tests also contained a trace amount of stable selenate (few parts per billion) that was not present in the earlier studies by Kaplan et al. (1998b, c). Because these earlier studies used only the carrier-free ^{75}Se isotope (which essentially means the mass of selenium present was infinitesimal), we later became concerned that the K_d results might be biased high by not having some selenium mass present. The most recent results by Um and Serne[(a)] corroborate the selenium K_d values obtained by Kaplan et al. (1998c) for natural groundwater and Hanford sediments, but do indicate that selenium K_d values for more alkaline solutions, including simulated glass leachate, are considerably smaller than 4 mL/g, the value recommended in 2001. Thus, for the 2005 IDF PA, we changed (decreased) the K_d value for ^{79}Se for the chemically impacted zones, where the glass leachate forces the pore fluid pH to be elevated above background. No changes were made to the K_d values for selenium for the near field concrete-impacted zone. During preparation of this data package, we determined that for the 2001 data package, the recommended K_d values for the chemically impacted gravel zone had inadvertently not been reduced by the factor of 10 to account for the assumed 90% gravel content. Thus, there is a change (correction) to the recommended 2005 K_d values for this zone.

Um and Serne[(a)] measured the K_d for selenate in simulated glass leachate onto IDF borehole sediments (see Section 3.5.3) and consistently found non-zero K_d values for selenium for six tests. Their values for the simulated glass leachate ranged from 1 to 3 mL/g with good precision. At long time periods, we assume that glass weathering products will adsorb some selenium. Therefore, we recommend that a non-zero K_d is appropriate and chose a K_d value of 1 mL/g for selenate for the long-term near-field zone. Based on the results of Um and Serne, we also are more confident that the "most probable" K_d for ^{79}Se for the chemically unaltered pore water/groundwater fluid can be increased from 4 to 7 mL/g (see Table 6.1). We have not tested selenium adsorption on Hanford sediments that contain significant quantities of gravel-sized material. We, therefore, rely on the conservative gravel-correction factor (see Equation 2.6) and assume that the gravel-dominated sequence at the bottom of the vadose zone and at the upper unconfined aquifer has 90% gravel. This effectively reduces the recommended K_d values in gravel zones by a factor of 10 as listed in Table 6.1. To build in further conservatism, the chemically impacted gravel values were reduced further. It is likely that the chemically impacted sand zone controls the travel time of selenium in the PA calculations."

Based on these studies, it appears that our choice of selenium-79 K_d will be dependent on the expected vadose zone pH beneath the source zones.

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Appendix B

Selenium-79 Distribution Coefficient Review

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B1 Introduction

Table B-1 summarizes the selenium-79 distribution coefficient (K_d) values found in DOE/EIS-0391, *Final Environmental Impact Statement Tank Closure and Waste Management for the Hanford Site, Richland, Washington*, composite analyses, performance assessments, and related or referenced documents. The table includes only the selenium-79 K_d values that were identified as sand size or with no size description; silt-size, gravel corrected, and carbonate-dominated values were not included. Blue shading indicates K_ds that were listed as nonimpacted and/or groundwater (assuming little to no impact for groundwater). K_ds that were identified as intermediate impact or chemically impacted far field were shaded green. K_ds that were identified as high impact or near field were shaded tan. Values are arranged in document date order.

The table includes document number, year published, location in the document, waste chemistry, particle size, impact zone, K_d estimates (Conservative, Best, Min, and Max), and any notes included with the K_d estimates (Comments column). The text "--" indicates that information was not included in the source document.

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Table B-1. Documented Selenium K_d Values

Document	Location	Year	Waste Chemistry	Size	Impact Zone	Conservative	Best	Min	Max	Comments
WHC-EP-0645	Table 3-5	1995	--	--	All zones	--	0	--	--	
WHC-SD-WM-TI-730	Table 3-6	1996	--	--	All zones	--	0	--	--	K_d values are reasonably conservative estimates based on many references including Serne and Wood (1990).
PNNL-11800	Table E.5	1998	High Organic/Very Acidic	--	High Impact	0	0	0	0	K_d values were estimated.
PNNL-11800	Table E.6	1998	High Organic/Very Acidic	--	Intermediate Impact	0	0	0	1	Selenium is a soluble anion. The K_d value was estimated.
PNNL-11800	Table E.10	1998	High Organic/Very Acidic	--	Groundwater	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.6	1998	High Organic/Near Neutral	--	High Impact	0	0	0	1	Selenium is a soluble anion. The K_d value was estimated.
PNNL-11800	Table E.6	1998	High Organic/Near Neutral	--	Intermediate Impact	0	0	0	1	Selenium is a soluble anion. The K_d value was estimated.
PNNL-11800	Table E.10	1998	High Organic/Near Neutral	--	Groundwater	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.8	1998	Very High Salt/Very Basic	--	High Impact	0	0	0	0.2	Technetium, carbon, iodine, selenium, and chlorine are anionic…
PNNL-11800	Table E.9	1998	Very High Salt/Very Basic	--	Intermediate Impact	0	0	0	4	Selenium is anionic. The K_d values were estimated.
PNNL-11800	Table E.10	1998	Very High Salt/Very Basic	--	Groundwater	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.11	1998	Chelates/High Salts	--	High Impact	0	0	0	0.5	Technetium, iodine, selenium, had chlorine are anions…
PNNL-11800	Table E.11	1998	Chelates/High Salts	--	Intermediate Impact	0	0	0	0.5	Technetium, iodine, selenium, and chlorine are anions…
PNNL-11800	Table E.12	1998	Low Organic/Low Salts/Acidic	--	High Impact	0.1	0.2	0.1	2	Anions sorb to iron oxides and kaolinite at lower pH levels.
PNNL-11800	Table E.10	1998	Low Organic/Low Salts/Acidic	--	Intermediate Impact	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.10	1998	Low Organic/Low Salts/Acidic	--	Groundwater	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.10	1998	Low Organic/Low Salts/Near Neutral	--	High Impact	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.10	1998	Low Organic/Low Salts/Near Neutral	--	Intermediate Impact	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11800	Table E.10	1998	Low Organic/Low Salts/Near Neutral	--	Groundwater	0	0	-3.44	0.78	In the Hanford groundwater/sediment system, the K_d values range from-3.44 to 0.78 mL/g (Serne et al., 1993).
PNNL-11966	Table 4, Table 7	1998	Nonimpacted		Groundwater	3.8	6.7	3.75	10.85	
DOE/ORP-2000-24	Table 3-5	2001	Chemically Impacted	Sand	Far field	--	4	--	--	
PNNL-13895	Section 5.3	2003	--	--	Trace Se concentrations	--	--	3	10	
PNNL-13895	Section 5.3	2003	--	--	Higher Se concentrations	--	--	0	3	
PNNL-13037	Table 5.1	2004	Vitrified Waste	--	Near Field	0	1	0	3	Measured the K_d for selenate in synthetic glass leachate onto IDF borehole sediments and found nonzero values consistently for six tests. Values ranged from 1 to 3 mL/g with good precision (Um and Serne, 2004).

Table B-1. Documented Selenium K_d Values

Document	Location	Year	Waste Chemistry	Size	Impact Zone	Conservative	Best	Min	Max	Comments
PNNL-13037	Table 5.3	2004	Cementitious Secondary Wastes- Young Concrete	--	Near Field	1	2	1	800	Estimated. Dominant species for Se and Ru were assumed to SeO4 2- and RuO4 2- respectively (Pourbaix, 1966). Sulfate may be used as an analog for selenate chemical behavior in concrete. Sulfate (or sulfite) is often included in concrete mixes, and therefore it would be expected to be retained strongly by concrete, primarily by coprecipitation constraints. Selenate adsorption, independent of precipitation processes, would be expected to be rather large.
PNNL-13037	Table 5.3	2004	Cementitious Secondary Wastes- Moderately Aged Concrete	--	Near Field	1	2	1	100	
PNNL-13037	Table 5.3	2004	Cementitious Secondary Wastes- Aged Concrete	--	Near Field	0	1	0	300	
PNNL-13037	Table 5.5	2004	Chemically Impacted	Sand	Far Field	1	2	0	10	Anionic. Se K_d measured at the ILAW/IDF site had K_d values of 6.7 ± 0.4 mL/g (Kaplan et al., 1998c). Results of a Se sorption experiment to Hanford sediments in high ionic strength (NaOH and NaOCl4) indicate Se K_d values range from 0 to 18 mL/g; but values for 0.03 NaOH are 0 mL/g and are beyond the causticity of probable glass leachates (Kaplan et al., 2003). K_d values will be chosen from recent tests on IDF borehole sediments with synthetic glass leachate that yielded K_d values which ranged from 1 to 3 mL/g (Um and Serne, 2004).
PNNL-13037	Table 5.6	2004	Natural Recharge (no impact from wastes)	Sand	Far Field	3	7	3	15	Hanford groundwater/sediment system:-3.44 to 0.78 mL/g (Serne at al., 1993). Most recent data using ILAW borehole sediment [299-E17-21] yielded K_d values ranging from 3.75 to 10.85 mL/g and had an average of 6.7±1.9 mL/g (Kaplan et al., 1998a). More recent data for ILAW borehole 299-E24-21 yielded a K_d range from 7.1 to 8.65 for six measurements in Hanford groundwater (Um and Serne, 2004). The latter two studies are in excellent agreement. Cantrell et al., 2003 recommends a range of 0 to 3 and 3 to 10 mL/g for Se for “higher” and “low/trace” concentrations of Se for SAC stochastic predictions. Our range is slightly larger but the best and reasonable conservative values we recommend for the IDF deterministic PA activities fit within the range chosen for trace concentrations of Se.
PNNL-13037	Table 5.9	2004	--	--	Unconfined Far Field Aquifer	3	7	3	15	Hanford groundwater/sediment system:-3.44 to 0.78 mL/g (Serne et al., 1993). Most recent data using ILAW borehole sediment [299-E17-21] yielded K_d values ranging from 3.75 to 10.85 mL/g and had an average of 6.7±1.9 mL/g (Kaplan et al., 1998a). More recent data for ILAW borehole 299-E24-21 yielded a K_d range from 7.1 to 8.65 for six measurements in Hanford groundwater (Um and Serne, 2004). The latter two studies are in excellent agreement. Cantrell et al., 2003 recommends a range of 0 to 3 and 3 to 10 mL/g for Se for “higher” and “low/trace” concentrations of Se for SAC stochastic predictions. Our range is slightly larger but the best and reasonable conservative values we recommend for the IDF deterministic PA activities fit within the range chosen for trace concentrations of Se.
PNNL-13037	Table 6.1	2004	--	--	1998 ILAW PA- All zones	0	0	--	--	
PNNL-13037	Table 6.1	2004	Glass	--	1998 ILAW PA- Near field	0	0	--	--	
PNNL-13037	Table 6.1	2004	Concrete	--	1999 ILAW PA- Near field	0	1	--	--	
PNNL-13037	Table 6.1	2004	Chemically Impacted	Sand	2000 ILAW PA	2	4	--	--	
PNNL-13037	Table 6.1	2004	Non-impacted	Sand	2001 ILAW PA	3	7	--	--	
PNNL-14702	Table 4.11	2006	Source Category 1: Very Acidic	--	High Impact (1H)	--	5	3	10	
PNNL-14702	Table 4.11	2006	Source Category 1: Very Acidic	Sand	Intermediate Impact – Sand (1I1)	--	5	3	10	
PNNL-14702	Table 4.11	2006	Source Category 2: Very High Salt/Very Basic	--	High Impact (2H)	--	0	0	0.1	

Table B-1. Documented Selenium K_d Values

Document	Location	Year	Waste Chemistry	Size	Impact Zone	Conservative	Best	Min	Max	Comments
PNNL-14702	Table 4.11	2006	Source Category 2: Very High Salt/Very Basic	Sand	Intermediate Impact- Sand (2I1)	--	0	0	1	
PNNL-14702	Table 4.11	2006	Source Category 3: Chelates/High Salts	--	High Impact (3H)	--	0	0	0.1	
PNNL-14702	Table 4.11	2006	Source Category 3: Chelates/High Salts	Sand	Intermediate Impact- Sand (3I1)	--	0	0	1	
PNNL-14702	Table 4.11	2006	Source Category 4: Low Organic/Low Salt/Near Neutral	--	High Impact (4H)	--	5	3	10	
PNNL-14702	Table 4.11	2006	Source Category 4: Low Organic/Low Salt/Near Neutral	Sand	Intermediate Impact- Sand (4I1)	--	5	3	10	
PNNL-14702	Table 4.11	2006	Source Category 4: Low Organic/Low Salt/Near Neutral	--	Groundwater (4G)	--	5	3	10	
PNNL-14702	Table 4.11	2006	Source Category 5: IDF Vitrified Waste	--	High Impact (5H)	--	1	0	3	
PNNL-14702	Table 4.11	2006	Source Category 5: IDF Vitrified Waste	Sand	Intermediate Impact- Sand (5I1)	--	2	0	10	
PNNL-14702	Table 4.11	2006	Source Category 6: IDF Cementitious Waste	--	High Impact (6H)	--	1	0	300	
PNNL-14702	Table 4.11	2006	Source Category 6: IDF Cementitious Waste	Sand	Intermediate Impact- Sand (6I1)	--	7	3	15	
PNNL-17154	Table 3.3	2008	Waste Management Area A-AX	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.3	2008	Waste Management Area A-AX	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.4	2008	Natural Pore Waters/Groundwater	Sand	Not Impacted	--	5	3	10	From the Appendix -in referenced document: Adequate Hanford data; Last et al. (2006).
PNNL-17154	Table 3.7	2008	Waste Management Area B-BX-BY	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.7	2008	Waste Management Area B-BX-BY	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.9	2008	Waste Management Area C	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.

Table B-1. Documented Selenium K_d Values

Document	Location	Year	Waste Chemistry	Size	Impact Zone	Conservative	Best	Min	Max	Comments
PNNL-17154	Table 3.9	2008	Waste Management Area C	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.13	2008	Waste Management Area S-SX	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.13	2008	Waste Management Area S-SX	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.17	2008	Waste Management Areas T and TX-TY	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at T or TX WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.17	2008	Waste Management Areas T and TX-TY	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at T or TX WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.21	2008	Waste Management Area U	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at T or TX WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.21	2008	Waste Management Area U	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at T or TX WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.23	2008	BC Cribs	Sand	High Impact	--	0	0	3	From the Appendix -in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
PNNL-17154	Table 3.23	2008	BC Cribs	Sand	Intermediate Impact	--	0.1	0	3	From the Appendix in referenced document: ^{79}Se not studied at SST WMAs; estimated no sorption in high impact zones, but allowed some sorption in intermediate zones based on Kaplan sorption versus pH work on IDF sediments.
WCH-515	Table 25	2013	Low-Organic/Low-Salt/Near-Neutral Waste Chemistry	Sand	Not Impacted Sand	--	5	3	10	Reference: PNNL-17154.
RPP-ENV-58782	Table 6-11	2016	Low-Salt, Near-Neutral	< 2mm	--	--	0.1	--	--	Reference: PNNL-17154.
RPP-CALC-61032	Table A-2	2017	Chemically Impacted	Sand	Zone 2a- Far Field	1	2	--	--	Reference: PNNL-13037, Table 5.5.
RPP-CALC-61032	Table A-2	2017	Natural Recharge (no impact from wastes)	Sand	Zone 2b- Far Field	3	7	--	--	Reference: PNNL-13037, Table 5.6.

Table B-1. Documented Selenium K_d Values

Document	Location	Year	Waste Chemistry	Size	Impact Zone	Conservative	Best	Min	Max	Comments
RPP-RPT-59958	Table 4-33	2017 (Draft)	Chemically Impacted	Sand	Far Field	1	2	--	--	Reference: PNNL-13037, Table 5.5.
RPP-RPT-59958	Table 4-33	2017 (Draft)	Natural Recharge (no impact from wastes)	Sand	Far Field	3	7	3	10	Reference: PNNL-13037, Table 5.6.

Note: Reference citations in the 'Comments' column are provided in the reports listed in the 'Document' column.

High Impact or Near Field	
Intermediate Impact or Far Field Chemically Impacted	
Not Impacted	
Not Provided in the Referenced Document	---

IDF = Integrated Disposal Facility
ILAW = immobilized low-activity waste
K_d = distribution coefficient
PA = performance assessment
SAC = System Assessment Capability
SST = single-shell tank
WMA = waste management area

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