Contract No:

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8. INTEGRATION AND INTERPRETATION OF RESULTS

This chapter, together with Appendix H, provides the necessary CWTS inventory limits and trigger values for every parent radionuclide not screened out in Sections 2.3.6, 2.3.7, and 2.3.8. Also provided are details associated with how generic and special waste forms are handled on a DU-specific basis, and a discussion of the conversion of preliminary inventory limits (via transport runs summarized in Chapter 5) into final inventory limits for use in the CWTS limits system. Using the final inventory limits, a projected 2065 CWTS inventory is generated for use in the PA closure analysis outlined in Chapter 9. Key aspects addressed in this chapter include:

- **Section 8.1** establishes the connections between the overall CWTS limits system, the POs, their specific compliance periods, and the use of a SOF approach for the ELLWF.
- **Section 8.2** discusses how the status of ELLWF DUs has evolved since 2008.
- **Section 8.3** provides the inventory limits, trigger values, and dose history time profiles for the GW pathways for every parent radionuclide screened in (see Section 2.3.7.3).
- **Section 8.3.6** demonstrates that GW POs are met for the best-estimate projected closure inventory during the GW compliance period.
- **Sections 8.3.3.1 and 8.4.3** define how and why the worst-case GW and IHI concentration profiles, respectively, are created for every DU.

KEY TAKEAWAYS

- ✓ Parent radionuclides C-14, H-3, I-129, Np-237, Sr-90, and Tc-99 typically have greatest impact on total SOF.
- ✓ At individual DU level, top contributors to maximum SOF are H-3, H-3F, H-3X, I-129, I-129J, Np-237, Tc-99, and Tc-99S.
- ✓ Beta-gamma or gross-alpha GW pathways are limiting for all DUs.
- ✓ The most challenging DUs are the trenches upstream of ET01 in the Eastern section of the ELLWF.
- ✓ ET06, ST17, ST19, ST20, ST21, and ST22 are excluded from PA2022 based on activity capacity reallocation requirements associated with GW plume interactions.
- ✓ A GW pathway is generally limiting by significant margins. Four DUs with margins less than 100X are NR26E, NR07E, LAWV, and ST23. IHI chronic SOF exceeds IHI acute, air, and radon in all four.
- ✓ For IHI pathways, PA2022 limits generally exceed PA2008 limits by two orders of magnitude, mainly due to differences in assumed dynamic compaction of non-crushable containers. PA2008 assumed a no-compaction scenario, while PA2022 assumes dynamic compaction at the end of IC before placement of final closure cap.
- ✓ For air pathway, PA2022 limits generally exceed PA2008 limits but are lower in SA2011. Decrease from SA2011 is mostly due to an increase in value of diffusion coefficients.
- ✓ For radon pathway, PA2022 limits for STs and ETs are generally lower versus PA2008, mostly due to increased PA2022 diffusion coefficient values. For vaults, PA2022 limits are higher than in PA2008, which excluded concrete roofs during the first 25 model years, thereby dramatically increasing flux.
- ✓ There is a significant shift in inventory limits from PA2008 to PA2022. For STs and ETs, the net impact of model upgrades is generally higher inventory limits. For vaults, the new PA2022 model of concrete cracking/degradation leads to inventory limits roughly half those in PA2008.

- **Section 8.4** summarizes the inventory limits and trigger values for the IHI pathways for every parent radionuclide screened in (see Section 2.3.7.2).
- **Section 8.5** provides the inventory limits and trigger values for the air pathway for every parent radionuclide screened in (see Section 2.3.8.1).
- **Section 8.6** reports the inventory limits and trigger values for the radon pathway for every parent radionuclide screened in (see Section 2.3.8.2).
- **Sections 8.3.8, 8.4.5, 8.5.6, and 8.6.6** discuss how the PA modeling approach has changed since PA2008 and its subsequent SAs and UDQEs. The impacts of these modeling changes with respect to inventory limits are also addressed.
- **Section 8.7** discusses the method and results associated with estimating projected 2065 closure inventories for all DUs at the end of ELLWF operations.

A detailed discussion and summary of inventory limits and trigger values for the IHI pathways are provided in Chapter 7 and Appendix G. A complete summary of all the new inventory limits and trigger values will be included in a single, separate Microsoft Excel spreadsheet. The new limits are provided on a time-window basis for every DU and exposure pathway of interest. The preparation of this separate spreadsheet falls under the Performance Assessment Implementation Plan and will be generated upon approval of the inventory limits discussed in this PA.

8.1. PERFORMANCE ASSESSMENT METHODOLOGY ASPECTS

Before focusing on results associated with each exposure pathway, several key aspects are addressed that are somewhat pathway independent. Within this section, the connections between the overall CWTS limits system, the POs, their specific compliance periods, and the use of a SOF approach are established for application to the ELLWF. All exposure pathways associated with GW, IHI, air, and radon are addressed in Sections 8.3, 8.4, 8.5, and 8.6, respectively.

8.1.1. Overall CWTS Limits System

Within the CWTS Limits System there are disposal constraints imposed on all parent radionuclides that pass through the radionuclide screening processes described in Sections 2.3.6, 2.3.7, and 2.3.8. Constraints on progeny are not required because progeny contributions are implicitly handled within each parent radionuclide constraint. The disposal constraints are implemented using pathway-specific “inventory” limits at the DU and parent-radionuclide levels. Given the inventory limits and current existing DU inventories, CWTS computes a current maximum total SOF for each DU, where waste disposals are not allowed to exceed the SWM administrative SOF which is typically set to 0.95. Computed SOFs are based on the following assumptions:

- Acceptable screening processes have been employed, where all screened out radionuclide SOF contributions are negligible (e.g., less than the cutoff value of 0.1%).
- Inventory limits for each parent radionuclide are relatively conservative (e.g., built-in biases are sufficient to accommodate uncertainties and are pessimistically leaning).

- Waste-generator-supplied, parent-radionuclide disposal inventories are relatively conservative (e.g., built-in biases are sufficient to accommodate uncertainties and are pessimistically leaning).

With some degree of confidence, an exceedance in POs will not occur during operations and the post-closure period of performance (Year 0 to Year 1,171) if all three assumptions are generally true. Additional details are provided elsewhere as follows: (1) radionuclide screening processes (Sections 2.3.6, 2.3.7, and 2.3.8); (2) PORFLOW VZ and aquifer modeling by type of DU (Chapters 4 and 5); (3) PORFLOW and GoldSim® sensitivity analyses by type of DU (Chapter 6); and (4) disposal uncertainties (Sections 2.3 and 9.1.2). Deterministic and stochastic closure analyses are provided in Section 9.1.2 to build confidence in the overall limits system.

8.1.2. Performance Objectives and Compliance Periods

The POs employed in this PA to calculate individual inventory limits and corresponding SOFs are listed Table 1-2. The chosen POs are specifically defined for a future MOP. SCDHEC and U.S. EPA drinking water standards are included based on published MCLs, where available, or are derived based on dose coefficient factors and the typical person drinking water consumption rate.

Figure 1-4 presents an overview of the compliance period timeline used in this PA in both absolute and relative time. The compliance period for each exposure pathway is listed in Table 1-2. The specific time periods listed are relative time with respect to the start of ELLWF operations which occurred on September 28, 1994, with burial of the first waste package. The timeline employed in this PA for the ELLWF is consistent with the one used in PA2008 and subsequent SAs. More detailed discussion of POs and compliance periods can be found in Sections 1.7.1 and 1.7.2.

As discussed by Smith et al. (2019), the four primary exposure pathways (GW, IHI, air, and radon) presented in Table 1-2 contain multiple, specific, dose exposure pathways within each. However, each of these four primary exposure pathways are addressed separately. Specifically, SOF contributions within a specific exposure pathway are computed and summed to arrive at a total SOF by pathway. The exposure pathway with the greatest total SOF determines if a waste package can be disposed in each DU. Also, based on key modeling assumptions discussed in Chapters 4 and 5 regarding the waste zone, transport analyses for each primary pathway are isolated from the results associated with other pathways. The SOF approach is discussed in Section 8.1.3; an interpretation of results for each of the four primary exposure pathways is presented in Sections 8.3, 8.4, 8.5, and 8.6 for GW, IHI, air, and radon, respectively.

8.1.3. Sum-of-Fractions Concept

From the parent radionuclide inventory perspective, the "Limits System" employed by the ELLWF is based entirely on the linearity of two equation sets: (1) transport equations that compute concentrations at the various POAs; (2) dose equations that convert the computed concentrations into doses along the various POAs. As discussed below for the GW transport equations, the following two key assumptions are made:

- GW concentrations remain low enough that linear isotherms are applicable.
- GW concentrations remain low enough that liquid-phase solubility limits are not reached.

Note that the overall transport response remains quite linear for limited exceedance of solubility limits. As discussed below, this "near linearity" of the governing equations is taken advantage of when establishing the CWTS inventory limits.

CWTS inventory limits do not explicitly limit the composition of radionuclides within each DU. Instead, the total dose by pathway at and beyond the 100-meter POA boundary surrounding the perimeter of the ELLWF is maintained below its PO. For example, for the beta-gamma pathway, the peak dose both spatially and temporally at and beyond the 100-meter boundary is maintained below its 4 mrem yr^{-1} PO for the entire compliance period (Year 0 to Year 1,171 time window). This operational constraint is achieved by limiting the radionuclide inventory disposed in each DU.

The basic concept of employing a SOF method as a measure of merit has been employed in all prior PA and SA efforts for ELLWF operations. For each of the nine separate exposure pathways listed in Table 1-2, the CWTS system computes a total SOF for each DU and maintains these SOFs to values less than 1.0. For the SOF method to be valid, the following items must be satisfied:

- All GW, IHI, air, and radon transport aspects and computed doses must be associated with linear processes; specifically, linear with respect to radionuclide concentrations. As such, the governing transport equations must be linear equations with respect to GW, waste, or atmospheric radionuclide concentrations.
- For the GW pathways, contributions from all DU sources must be addressed at each point along the 100-meter POA boundary, which is sometimes referred to as a vertical curtain. This involves plume overlap because of lateral dispersion within the aquifer system.
- For the air pathway, contributions from all DU sources must be addressed at each point along the 100-meter POA boundary. This involves plume overlap because of atmospheric dispersion within the regions of interest.

For GW considerations, the linearity of the transport equations is maintained based on an assumption that the aqueous-phase concentrations of species of interest are very dilute. Kinetics at a solid-liquid interface are assumed to be rapid such that local equilibrium is achieved at all time scales. Linear isotherms with the following functional form are employed:

$$Q_i = \left[K_{d,i}\right] \times C_i \qquad \text{Eq. (8-1)}$$

where:

Q_i i^{th} species solid-phase concentration (mmol g^{-1})

$K_{d,i}$ i^{th} species partition (sorption) coefficient (mL g^{-1})

C_i i^{th} species liquid-phase concentration (gmol L^{-1})

The combined concentration from multiple GW plumes at any point within the computational domain is obtained by employing the super-positioning principle. The linearity of the transport equations results from use of a linear isotherm, which applies under sufficiently dilute conditions. For current and expected operations, inventory limits will remain within the linear isotherm range; as such, significant computational advantages can be employed throughout the entirety of the limits and doses analyses. Aqueous radionuclide concentrations are not expected to reach levels where solubility limits will adversely affect these assumptions. Even for some degree of solubility within a waste zone, it has been demonstrated that the linearity assumption can still be employed.

All exposure pathways considered in this PA can be expressed in terms of the following general dose equation (Smith et al., 2019):

$$D_{p,i} = \left[EC_{p,i}\right] \times \left[Exp_{w,i}\right] \times C_{w,i} \qquad \text{Eq. (8-2)}$$

where:

$D_{p,i}$	Annual dose from exposure to contaminant *i* through pathway *p* (mrem yr^{-1})
$EC_{p,i}$	Effective dose coefficient for exposure to contaminant *i* through pathway *p* (mrem pCi^{-1})
$Exp_{w,i}$	Equivalent direct exposure to source material *w* from exposure to contaminant *i* (m^3 yr^{-1})
$C_{w,i}$	Concentration of contaminant *i* in source material *w* (pCi m^{-3})

In the current dose methodology (Smith et al., 2019), the DCFs and consumption rates are assumed to be independent of contaminant aquifer concentrations; therefore, Eq. (8-2) indicates that dose is linearly related to the aqueous-phase GW contaminant concentrations.

To verify that the entire computational strategy being employed in the limits system results in linear responses to variations in buried inventory, a simple test was made for ET02. As of September 28, 2018, the calculated SOF for ET02 was 32.2% based on its current inventory limits as of this date. The future inventory was limited to just two parent radionuclides: H-3 and I-129. The composition of this binary mixture of future inventory was varied from pure component H-3 to pure component I-129. The total SOFs, which is the sum of existing plus future SOFs, are shown in Figure 8-1. The black-dashed line represents the existing SOF on September 28, 2018, while the blue solid line represents the total SOF at every possible composition of the binary mixture of future inventory. As Figure 8-1 indicates, the total SOF is a linear function of DU composition.

Because the total SOF (which directly corresponds to a total dose at the 100-meter POA) is linear with respect to DU composition, imposing inventory constraints on each pure component ensures that any compositional mixture buried is appropriately constrained as well. Within this chapter, a compositional mixture is typically referred to as a “composition vector” that is made up of all parent radionuclides that might exist (or be buried in the future) in a specific DU. This composition vector includes both generic waste form and SWF radionuclides.

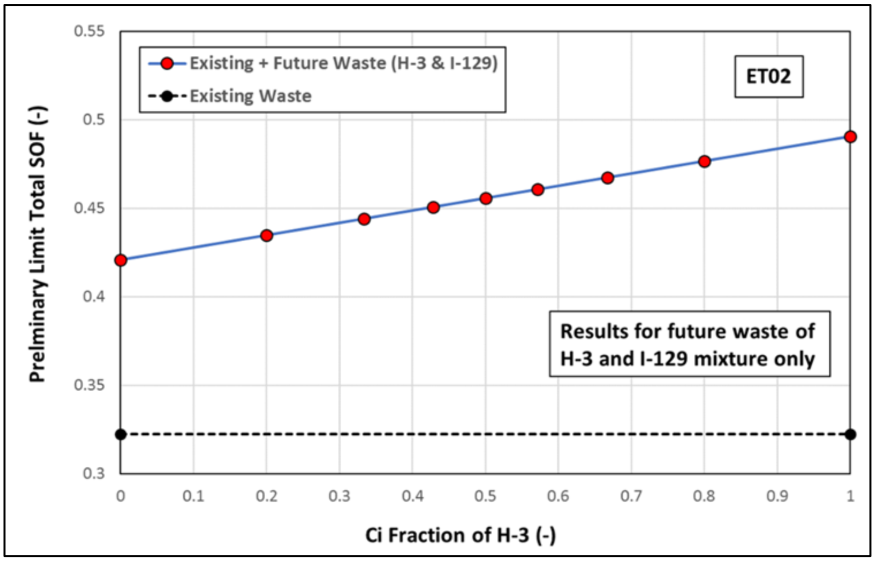


Figure 8-1. Total Sum-of-Fractions in ET02 as Function of Composition for a Simple Binary Mixture of Future Inventory of H-3 and I-129

8.1.4. Parent Radionuclides Requiring Inventory Limits or Trigger Values

Based on efforts detailed in Sections 2.3.6, 2.3.7, and 2.3.8, the original list of 1,252 radionuclides in ICRP-107 (ICRP, 2008) was significantly shortened when process knowledge, burial history, and radiological aspects are factored into the radionuclide screening process. The initial screening process considers only radiological aspects and the potential source of the radiological source (e.g., onsite versus offsite), resulting in a Tier-0 list that is applicable to all five exposure pathways listed in Table 1-2. In the Tier-0 screening, the original list of 1,252 radionuclides reduces to the counts in Table 8-1. Table 8-1 also identifies where most offsite waste streams originate: (1) TPBARS, which are irradiated targets in commercial reactors designed specifically as a H-3 source for the U.S. weapons programs; and (2) Naval Operations, who ship specific reactor components from U.S. Navy reactors to SRS and Hanford. Both offsite waste streams are shipped to SRS in substantially shielded metal casks and buried in the ELLWF. Some degree of credit is taken for their engineered barriers in Tier-4 transport analyses, when warranted.

Table 8-1. Number of Parent Radionuclides in the Tier-0 Lists

Reference DU-Type	Tier-0 List	Offsite Sources
Trench	271	none
LAWV	271	none
ILV	272	TPBARs
NRCDAG and NRCDAS	295	Naval Operations

Based on the methods employed to address dose within a decay chain, only the parent radionuclide at the time of burial requires consideration. This is because all progeny is accounted for in the transport processes and subsequently in the conversion to dose using the SRNL Dose Toolkit (Aleman, 2019). For transport purposes, typically a short chain is employed using a 1-year half-life cutoff while for dose purposes, the chain is extended back to the full chain assuming secular equilibrium when needed.

The details associated with this screening process are provided by Aleman and Hamm (2021). Shortening the Tier-0 lists further requires information that is pathway dependent. Details associated with these additional screening steps are presented in Sections 2.3.6, 2.3.7, and 2.3.8. Two groups of parent radionuclides pass through all steps and fall into two separate categories:

- **Require Inventory Limits –** Parent radionuclides that currently exist in the CWTS inventory database; inventory limits are provided in this chapter.
- **Require Trigger Value Limits –** Parent radionuclides that currently do not exist in the CWTS inventory database; inventory trigger values are given in Appendix H, Section H.5.

The DU-specific required inventory limits and trigger value lists are pathway dependent and are discussed in Sections 8.3, 8.4, 8.5, and 8.6 for GW, IHI, air, and radon, respectively

8.1.5. Parent Radionuclides Contained Within Special Waste Forms

Historically and during future planned ELLWF operations, special packages from waste generators (referred to as SWFs) are and will be disposed in STs, ETs, the ILV, and NRCDAs. In many cases, inventory limits for SWFs are derived based on those created for generic waste form packages. The LAWV currently contains no SWFs; there are no plans for this to change.

A list of all existing SWFs as of March 31, 2021, is provided in Table 8-2. Currently, 23 SWFs reside within the ELLWF. A total of 107 SWF parent radionuclides are contained within the 23 SWFs. Table 8-2 provides the following information on a SWF basis:

- SWF’s designator description employed in CWTS.
- Do future disposal plans exist for the SWF?
- Is dynamic compaction planned over this SWF at the end of IC?
- Parent radionuclides within the SWF requiring inventory limits.
- Radionuclides requiring SWF inventory limits within CWTS for the four primary exposure pathways (78 total for GW, 84 for IHI, 17 for air, and 5 for radon).

Some of the SWFs currently reside within the ELLWF and there are plans for future disposal (e.g., Naval Reactor Main Coolant Pump), while others are simply one-time disposal events (e.g., HWCTR). One SWF, Paducah Cask Depleted Uranium, is screened out of every exposure pathway and will no longer have explicit inventory limits that contribute toward a total SOF.

The SWF “Component-in-Grout [CIG]” is unique because it was not considered a SWF in PA2008 but instead two separate DUs (CIG01 and CIG02). In this PA, the CIG DUs are now ST DUs. Specifically, the CIG01 location is now ST23 while the CIG02 location is now ST24. Thus, no future CIG waste will be disposed in the ELLWF, and the existing CIG waste within ST23 (formerly the CIG01 DU) is now considered a SWF (also referred to as CIG trench segments CIG-1 through CIG-9 in this PA report).

Table 8-2. Special Waste Forms Disposed in E-Area Low-Level Waste Facility as of March 31, 2021

SWF Count	SWF Designator Description	Future Disposal Planned?	Dynamic Compaction Performed?	SWF Radionuclide (110 total)	GW (78)	IHI (84)	Air (17)	Radon (5)
1	Depleted Uranium	Yes	Yes	U-233D		X		
				U-233E		X		
				U-235D	X			
2	Paducah Cask Depleted Uranium	No	No	U-235P				
3	M-Area Glass	No	Yes	U-234G	X	X		X
				U-236G		X		
4	Naval Reactor Main Coolant Pump	Yes	Yes	C-14N	X	X	X	
5	Reactor Heat Exchanger	No	No	C-14X	X	X	X	
				H-3X	X		X	
6	232-F Concrete	No	No	H-3F	X		X	
7	ETP Activated Carbon	No	Yes	H-3C	X		X	
				I-129C	X	X		
8	F-Area Groundwater Dowex Resin	No	Yes	I-129D	X	X		
9	H-Area Groundwater Dowex Resin	No	Yes	I-129E	X	X		
10	H-Area Groundwater Filtercake	No	Yes	I-129F	X	X		
11	F-Area Groundwater CG-8	No	Yes	I-129G	X	X		
12	H-Area Groundwater CG-8	No	Yes	I-129H	X	X		
13	Effluent Treatment Plant GT-73	No	Yes	I-129I	X	X		
14	F-Area Groundwater Filtercake	No	Yes	I-129J	X	X		
15	Mark 50A Targets	No	Yes	I-129R	X	X		
				Sr-90R	X	X		
				Tc-99R	X	X		
16	285-F Cooling Tower	No	Yes	Ra-226T	X	X		X
				Th-230T	X	X		X
17	K and L Basin Resin (SWF contained within CIG and ILV)	No	No	C-14K	X	X	X	
				I-129K	X	X		
				Tc-99K	X	X		
18	Tall Boxes	Yes	Yes	Am-241B	X	X		
				C-14B	X	X	X	
				Cs-137B	X	X		
				H-3B	X		X	
				I-129B	X	X		
				Ni-59B	X	X		
				Np-237B	X	X		
				Pu-239B	X	X		
				Pu-240B		X		
				Pu-241B	X	X		

Table 8-2 (cont'd). Special Waste Forms Disposed in E-Area Low-Level Waste Facility as of March 31, 2021

SWF Count	SWF Designator Description	Future Disposal Planned?	Dynamic Compaction Performed?	SWF Radionuclide (110 total)	GW (78)	IHI (84)	Air (17)	Radon (5)
18	Tall Boxes	Yes	Yes	Sr-90B	X	X		
				Tc-99B	X	X		
				U-233B		X		
				U-234B	X	X		X
19	HWCTR	No	No	Ag-108mH	X	X		
				C-14H	X	X	X	
				Nb-94H		X		
				Ni-59H	X	X		
				Ni-63H	X	X		
				Tc-99H	X	X		
20	Component-in-Grout (CIG)	No	No	Am-241A	X	X		
				Am-242mA		X		
				Am-243A		X		
				C-14A	X	X	X	
				C-14K (A) [1]	X	X	X	
				Cf-249A	X	X		
				Cf-251A		X		
				Cm-245A	X			
				Cm-247A		X		
				Cm-248A		X		
				Cs-135A	X			
				Cs-137A	X	X		
				H-3A	X		X	
				I-129A	X	X		
				I-129K (A) [1]	X	X		
				K-40A	X	X		
				Nb-94A		X		
				Ni-59A	X	X		
				Ni-63A	X	X		
				Np-237A	X	X		
				Pd-107A	X			
				Pu-239A	X	X		
				Pu-240A		X		
				Pu-241A	X	X		
				Ra-226A	X	X		
				Rb-87A	X			
				Sn-126A		X		
				Sr-90A	X	X		
				Tc-99A	X	X		
				Tc-99K (A) [1]	X	X		
				Th-231A	X			
				U-232A		X		
				U-233A		X		
				U-234A	X	X		X
				U-236A		X		

Table 8-2 (cont'd). Special Waste Forms Disposed in E-Area Low-Level Waste Facility as of March 31, 2021

SWF Count	SWF Designator Description	Future Disposal Planned?	Dynamic Compaction Performed?	SWF Radionuclide (110 total)	GW (78)	IHI (84)	Air (17)	Radon (5)
21	NR Casks	Yes	No	Am-241S	X	X		
				Am-243S		X		
				Be-10S	X			
				C-14S	X		X	
				Cl-36S	X			
				Co-60S		X		
				Cs-137S		X		
				H-3S			X	
				I-129S	X			
				Mo-93S		X		
				Nb-93mS		X		
				Nb-94S		X		
				Ni-59S	X	X		
				Ni-63S	X			
21	NR Casks	Yes	No	Np-237S	X			
				Pu-241S	X	X		
				Ra-226S				
				Sn-121mS		X		
				Sn-126S		X		
				Sr-90S		X		
				Tc-99S	X			
				U-235S	X			
				Zr-93S		X		
22	TEF TPBAR	Yes	No	Ar-39T	X			
				C-14T			X	
				Cs-137T		X		
				H-3T	X		X	
23	IP2 Tritium Box	No	No	H-3R	X		X	

Notes:

1 Three SWF radionuclides (C-14K, I-129K, and Tc-99K) that are within the "K and L Basin Resin" SWF (No. 17) are also contained within the newly designated CIG SWF (No. 20).

In Table 8-2, one unique SWF resides inside another SWF ("K and L Basin Resin"). This SWF is disposed in the ILV (SWF No. 17 in Table 8-2) but is also located in ST23 inside the CIG SWF (SWF No. 20 in Table 8-2). No future disposal of this SWF is planned within the ELLWF.

8.2. STATUS OF DISPOSAL UNITS

The status of the ELLWF DUs has evolved since 2008. DUs have been renamed, repurposed, added, split, and excluded. A brief overview is provided in Table 8-3. As Table 8-3 indicates, there were a total of 29 DUs in the ELLWF when PA2008 was approved. The number of ELLWF DUs has changed several times since 2008 as follows:

- **List Before Developing PA2022:** Four future STs (ST12, ST13, ST15, and ST16) are repurposed into four future ETs (ET03, ET04, ET05, and ET06, respectively) and consideration is given to adding three DUs in the adjoining Plot 8.

- **Initial List Employed During PA2022 Development Effort:** ST21 is split into two DUs (ST21 and ST22), while the Plot 8 DUs are determined to be ETs (ET07, ET08, and ET09).
- **Final List Constituting the ELLWF for PA2022:** Six trench DUs (ET06, ST17, ST19, ST20, ST21, and ST22) from the initial list are excluded based on activity-capacity reallocation requirements associated with GW plume interactions.

Table 8-3. Evolving Status and Naming of E-Area Low-Level Waste Facility Disposal Units

DU Count	DU Listing				DU Status (as of 03/31/2021)
	PA2008	Before PA2022	PA2022 Initial List	PA2022 Final List	
1	ST01	ST01	ST01	ST01	Closed
2	ST02	ST02	ST02	ST02	Closed
3	ST03	ST03	ST03	ST03	Closed
4	ST04	ST04	ST04	ST04	Closed
5	ST05	ST05	ST05	ST05	Closed
6	ST06	ST06	ST06	ST06	Open
7	ST07	ST07	ST07	ST07	Open
8	ST08	ST08	ST08	ST08	Open
9	ST09	ST09	ST09	ST09	Open
10	ST10	ST10	ST10	ST10	Future
11	ST11	ST11	ST11	ST11	Future
12	ST12	ET03	ET03	ET03	Open
13	ST13	ET04	ET04	ET04	Future
14	ST14	ST14	ST14	ST14	Open
15	ST15	ET05	ET05	ET05	Future
16	ST16	ET06	ET06	Excluded	--
17	ST17	ST17	ST17	Excluded	--
18	ST18	ST18	ST18	ST18	Future
19	ST19	ST19	ST19	Excluded	--
20	ST20	ST20	ST20	Excluded	--
21	ST21	ST21	ST21	Excluded	--
22	--	--	ST22	Excluded	--
23	CIG01	ST23	ST23	ST23	Open
24	CIG02	ST24	ST24	ST24	Future
25	ET01	ET01	ET01	ET01	Closed
26	ET02	ET02	ET02	ET02	Open
27	--	DU8A	ET07	ET07	Future
28	--	DU8B	ET08	ET08	Future
29	--	DU8C	ET09	ET09	Future
30	LAWV	LAWV	LAWV	LAWV	Open
31	ILV	ILV	ILV	ILV	Open
32	NR07E	NR07E	NR07E	NR07E	Closed
33	NR26E	NR26E	NR26E	NR26E	Open
Total Number of DUs	**29**	**32**	**33**	**27**	**27**

Notes:

DUs repurposed or determined before PA2022 are shaded in orange. DUs excluded from the final PA2022 list based on activity-capacity reallocation requirements associated with GW plume interactions are shaded in red.

The operational status (closed, open, or future) of each of the 27 DUs included on the final PA2022 list is shown in the last column in Table 8-3.

The decision to exclude the six trenches from PA2022 is made based on activity-capacity aspects; specifically, the adverse aquifer flow field beneath the eastern sector of the ELLWF results in increased GW plume overlap. Details associated with the process employed are provided in Appendix H, Section H.1.1.6.

8.3. GROUNDWATER PATHWAYS

Results associated with the GW pathways are presented in this section. Supporting information and key data for the GW pathways are provided in Appendix H, Section H.1. As listed in Table 1-2, the following five specific GW pathways are considered:

- **Beta-Gamma Pathway (GWP - BG):** Compliance period is Year 0 to Year 1,171 where 100-meter POA applies.
- **Gross-Alpha Pathway (GWP - GA):** Compliance period is Year 0 to Year 1,171 where 100-meter POA applies.
- **Radium Pathway (GWP - Rad):** Compliance period is Year 0 to Year 1,171 where 100-meter POA applies.
- **Uranium Pathway (GWP - Uran):** Compliance period is Year 0 to Year 1,171 where 100-meter POA applies.
- **All-Pathways Pathway (AP):** – Compliance period is Year 171 to Year 1,171 where 100-meter POA applies.

GW concentrations at the 100-meter POA downgradient of the DUs will be subject to potentially significant plume mixing from neighboring DUs, which is explicitly accounted for using GW-specific plume interaction factors (GW PIFs).

The interpretations below employ the results from Chapter 5 of PORFLOW aquifer flow and transport simulations based upon the nominal PA parameter settings. Maximum GW concentrations at the 100-meter POA reported in Chapter 5 are preliminary because they do not account for the potential of GW plume overlap.

"Nominal PA settings" implies that some modeling parameters are not at their best estimate values but instead, include some degree of conservatism (i.e., they are pessimistically leaning). Three key embedded conservatisms employed throughout all GW transport analyses are the following modeling assumptions:

- All waste is buried at one specific point in time at the burial time of the first package.
- No decay of radionuclides occurs before burial, which is the period from radiological assessment by waste generators to actual time of burial.
- Release of radionuclides from the waste zone due to volatilization and excavation processes is zero.

Note that the third assumption isolates the GW analyses from the IHI, air, and radon transport analyses. To assist in establishing GW PIF values for each DU, a specific CWTS Emulator has been created; details are provided in Appendix H, Section H.8. ET03 was chosen to illustrate the application of the CWTS Emulator; results for ET03 are provided in Appendix H, Section H.8.4.

8.3.1. Parent Radionuclides Requiring Inventory Limits

The list of parent radionuclides requiring inventory limits for the GW pathways is based on the radionuclide screening process described for the GW pathways in Section 2.3.7 as well as the list of SWFs in Table 8-2. A total of 107 unique parent radionuclides (29 generic waste form and 78 SWF radionuclides) are listed in Table 8-4.

Table 8-4. List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Groundwater Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Generic Waste Form	26	19	20	0	12
Ag-108m	X	X	X		
Am-241	X	X	X		X
Ar-39			X		
Be-10	X				
C-14	X	X	X		X
Ca-41		X			
Cf-249	X		X		
Cl-36	X	X	X		X
Cm-245	X	X	X		
Cs-135	X				
Cs-137	X	X	X		
H-3	X	X	X		X
I-129	X	X	X		X
K-40	X	X	X		
Ni-59	X	X	X		X
Ni-63	X	X	X		X
Np-237	X	X	X		X
Pa-231	X				
Pd-107	X				
Pu-239	X	X	X		
Pu-241	X	X	X		X
Ra-226	X	X	X		
Rb-87	X				
Sr-90	X	X	X		X
Tc-99	X	X	X		X
Th-230	X				
Th-231	X				
U-234	X				
U-235		X	X		X

Table 8-4 (cont'd). List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Groundwater Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Special Waste Form	59	1	8	10	11
U-235D		X	X		
C-14N	X				
H-3C	X				
H-3F	X				
H-3R			X		
I-129C			X		
I-129D	X				
I-129E	X				
I-129F	X				
I-129H	X				
I-129I	X				
I-129J	X				
I-129G	X				
U-234G	X				
Ar-39T			X		
H-3T			X		
C-14X	X				
H-3X	X				
Ra-226T	X				
Th-230T	X				
I-129R	X				
Sr-90R	X				
Tc-99R	X				
C-14K			X		
I-129K			X		
Tc-99K			X		
Am-241B	X				
C-14B	X				
Cs-137B	X				
H-3B	X				
I-129B	X				
Ni-59B	X				
Np-237B	X				
Pu-239B	X				
Pu-241B	X				
Sr-90B	X				
Tc-99B	X				
U-234B	X				
Ag-108mH	X				
C-14H	X				
Ni-59H	X				
Ni-63H	X				
Tc-99H	X				
Am-241A	X				
C-14A	X				
C-14K(A)	X				
Cf-249A	X				
Cm-245A	X				

Table 8-4 (cont'd). List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Groundwater Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Special Waste Form (cont'd)					
Cs-135A	X				
Cs-137A	X				
H-3A	X				
I-129A	X				
I-129K(A)	X				
K-40A	X				
Ni-59A	X				
Ni-63A	X				
Np-237A	X				
Pd-107A	X				
Pu-239A	X				
Pu-241A	X				
Ra-226A	X				
Rb-87A	X				
Sr-90A	X				
Tc-99A	X				
Tc-99K(A)	X				
Th-231A	X				
U-234A	X				
Am-241S				X	X
Be-10S					X
C-14S				X	X
Cl-36S				X	X
I-129S				X	X
Ni-59S				X	X
Ni-63S				X	X
Np-237S				X	X
Pu-241S				X	X
Tc-99S				X	X
U-235S				X	X
Total Number Radionuclides	**85**	**20**	**28**	**10**	**23**

Notes:

[a] SWFs planned for future disposals are shaded in orange.

Inventory limits are also required for existing parent radionuclides within SWFs that have no expected future disposals. This is required so that a current total SOF can be computed for each DU to give a complete accounting of all waste buried within the ELLWF.

The list of generic waste form radionuclides provided in Table 8-4 for the trench reference DU-type is utilized for every individual slit and engineered trench (15 STs and 8 ETs). A breakdown of where each SWF resides within these 23 STs and ETs is provided in Table 8-5, along with the number of SWF radionuclides per DU.

Table 8-5. Burial Locations of Special Waste Form Radionuclides Within Each Trench Disposal Unit Requiring an Inventory Limit for Groundwater Pathways

SWF Radionuclide [a]	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST14	ST18	ST23	ST24	ET01	ET02 thru ET09
C-14N	X	X	X	X	X	X	X	X	X	X	X	X	X				
H-3F	X																
H-3C			X				X										
I-129C			X				X										
I-129D		X														X	
I-129E																X	
I-129F	X																
I-129H		X		X												X	
I-129I		X	X	X												X	
I-129J	X	X	X	X	X		X									X	
I-129G		X														X	
U-234G		X															
I-129R					X												
Sr-90R					X												
Tc-99R					X												
Ra-226T						X											
Th-230T						X											
C-14X									X								
H-3X									X								
Ag-108mH												X					
C-14H												X					
Ni-59H												X					
Ni-63H												X					
Tc-99H												X					
Am-241B								X	X	X							
C-14B								X	X	X							
Cs-137B								X	X	X							
H-3B								X	X	X							
I-129B								X	X	X							
Ni-59B								X	X	X							
Np-237B									X	X							
Pu-239B									X	X							
Pu-241B									X	X							
Sr-90B								X	X	X							
Tc-99B								X	X	X							
U-234B									X	X							
C-14K(A)														X			
I-129K(A)														X			
Tc-99K(A)														X			
Am-241A														X			
C-14A														X			
Cf-249A														X			
Cm-245A														X			
Cs-135A														X			
Cs-137A														X			
H-3A														X			
I-129A														X			
K-40A														X			
Ni-59A														X			

Table 8-5 (cont'd). Burial Locations of Special Waste Form Radionuclides Within Each Trench Disposal Unit Requiring an Inventory Limit for Groundwater Pathways

SWF Radionuclide [a]	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST14	ST18	ST23	ST24	ET01	ET02 thru ET09
Ni-63A														X			
Np-237A														X			
Pd-107A														X			
Pu-239A														X			
Pu-241A														X			
Ra-226A														X			
Rb-87A														X			
Sr-90A														X			
Tc-99A														X			
Th-231A														X			
***Total Number Radionuclides* (60)**	**4**	**7**	**5**	**4**	**5**	**3**	**4**	**9**	**15**	**13**	**1**	**6**	**1**	**24**	**0**	**6**	**0**

Notes:

[a] SWFs planned for future disposals are shaded in orange.

Note that the following two SWF identifiers represent different SWFs depending on where they reside:

- "T" represents cooling towers in ST06 and TPBAR in the ILV.
- "D" represents depleted uranium, in general, for uranium isotopes with the exception of SWFs in ST23 (specifically, CIG trench segments) and in ST09 and ST10 (specifically, tall boxes) where "E" represents depleted uranium.

8.3.2. Trigger Values

Trigger-value radionuclides are typically radionuclides that do not have explicit CWTS inventory limits and are on a separate watch list. DU-specific "trigger values" may exist for each GW, IHI, air, and radon exposure pathway; those for GW are presented in this section. If a trigger value is exceeded, its radionuclide is considered for inclusion in CWTS, which generally requires an SA to generate final inventory limits via Tier-3 or Tier-4 analyses. Details associated with trigger values are provided by Aleman and Hamm (2020).

As discussed in Section 2.3.7, radionuclides with no current inventory, but which are not eliminated during the radionuclide screening process for the GW pathways, are assigned preliminary trigger values. The preliminary trigger values are specific to reference DU-type (see Table 2-28), and to account for plume overlap contributions from neighboring DUs, final DU-specific trigger values are computed using PIFs as follows:

$$L_{DU,i}^{trig-GW} = \frac{L_{DU-type,i}^{prem-trig-GW}}{\eta_{DU}^{GW}} \qquad \text{Eq. (8-3)}$$

where:

$L_{DU,i}^{trig-GW}$	Final inventory trigger value for GW pathway for i^{th} parent radionuclide in disposal unit *DU* (Ci)
$L_{DU-type,i}^{prem-trig-GW}$	Preliminary inventory trigger value for GW pathway for i^{th} parent radionuclide in reference *DU-type* (Ci)
η_{DU}^{GW}	GW PIF for disposal unit *DU* (unitless)

The list of parent radionuclides requiring trigger values for the GW pathways (GW trigger values) was developed during the radionuclide screening process (Section 2.3.7). Table 2-28 lists these preliminary GW trigger values by reference DU-type. Application of Eq. (8-3), on the other hand, generates the final GW trigger values. Final GW trigger values for every DU are provided in Appendix H, Section H.5.1.

8.3.3. Preliminary Inventory Limits and Worst-Case Preliminary Concentrations

Preliminary, DU-specific, inventory limits for the GW pathways are provided for every generic waste form and SWF parent radionuclide requiring an inventory limit. These preliminary inventory limits are based on nominal PA transport runs in PORFLOW as reported in Chapter 5. The nominal PA settings represent the compliance case where some model parameter settings are defined based on pessimistically leaning arguments [i.e., for many parameters their settings are at their most probable and defensible (MPAD) values]. In the overall computational approach employed in this PA, the generic waste form limits are Tier-3 analyses while the SWF limits are either Tier-3 or, if warranted, Tier-4 analyses. The following three types of transport analyses are used to generate inventory limits for the GW pathways:

- **Generic Waste Form (Tier 3):** Buried waste where no additional engineered barriers are included in the computational VZ model (e.g., no mass-transfer limitations are imposed to account for a radionuclide's waste container walls.
- **Simple SWF (Tier 3 or 4):** Buried waste where additional engineered barriers are employed in the computational VZ model and can be addressed in a simple manner (e.g., use of special K_d values to better account for increased sorption to local materials, such as radionuclides contained within an ion-exchange resin).
- **Complex SWF (Tier 3 or 4):** Buried waste where additional engineered barriers are utilized in the computational VZ model to address multiple barriers (e.g., waste encapsulated within welded metal containers with significant wall thickness, such as the NR shipping casks or reactor process HX vessels).

For DUs such as the LAWV and ILV, the concrete walls that form the vault structure are explicitly included in the VZ conceptual model, while additional barriers are employed using the terminology above. For example, H-3 contained within TPBARs in the ILV is identified as H-3T, and the casks housing the TPBARs are explicitly included in the VZ model. In this example, a separate standalone model computes H-3 source release from the target rods; output from the standalone model is then input to PORFLOW as a time-dependent source term (see Chapters 4 and 5 for details).

All DUs residing within the ELLWF have operating inventory limits. Currently closed DUs contribute to neighboring open and/or future DUs, thereby increasing their total SOFs. Neighboring DUs also increase a closed unit's total SOF.

For each parent radionuclide requiring an inventory limit for the GW pathways within a specified DU, a multistep process is employed as follows to compute preliminary inventory limits by GW pathway (i.e., beta-gamma, gross-alpha, radium, uranium, and all-pathways):

- Maximum GW concentrations at the 100-meter POA are generated using PORFLOW, where each scenario of interest is considered separately (e.g., intact versus subsidence scenarios for the closure cap and waste zone).

- From these multiple scenarios, a worst-case concentration time-history file is created.
- The worst-case file containing the concentration of the parent radionuclide and its short-chain progeny is expanded into a full-chain history file by assuming secular equilibrium for each chain member whose half-life is under the 1-yr threshold cutoff value.
- The full-chain history files are next converted into dose time-history files using the SRNL Dose Toolkit (Aleman, 2019) where all pathways (i.e., beta-gamma, gross-alpha, radium, uranium, and all-pathways) are considered separately.
- Preliminary inventory limits for the GW pathways are computed for each pathway and time-window combination based on the peak dose within the time window and the pathway-specific PO.

Details associated with the various scenarios being considered in this PA and the resulting worst-case files are provided below.

8.3.3.1. Worst-Case Preliminary Groundwater Concentrations

For DUs with multiple scenarios to consider, a "worst case" is defined. The worst-case concentration profile represents a composite of all scenarios considered. At each point in time, the GW concentration is set to the maximum value ranging over the set of multiple scenarios being composited. The use of multiple scenarios provides flexibility in addressing a range of possible operating conditions. A description of the required worst-case profiles is provided below for each reference DU-type.

8.3.3.1.1. Worst-Case Concentration Profiles for Slit and Engineered Trenches

Multiple scenarios exist for slit and engineered trenches, which requires worst-case scenarios to be established. The scenarios of interest are listed in Table 8-6 and are based on the existing or future potential of non-crushable containers being buried within a given trench unit. Most waste containers contain voids. A non-crushable container is classified according to its structural integrity with respect to dynamic compaction (specifics are provided in WACs and SWM operating procedures). A container defined as non-crushable has a reasonable expectation of remaining intact after dynamic compaction but collapses its voids later because of aging processes (e.g., corrosion of metal walls).

Two cases of interest are as follows:

- **Intact Surface Conditions:** Crushable containers only with zero subsidence potential are disposed in a designated DU.
- **Subsided Surface Conditions:** Non-crushable containers having subsidence potential are disposed in a designated DU.

A parameter defined as "percent area of the waste zone containing non-crushable containers" allows for a range of possible non-crushable container percentages to be considered. When a worst-case is developed from the intact closure-cap scenario and a specified upper-bound percent area (X%) of non-crushable containers, then the entire range from 0% to X% of non-crushable container area is allowed for that DU.

As Table 8-6 indicates, all DUs, except ST01 and ET03, will contain non-crushable containers, which will therefore require worst-case concentration profiles to be generated. By developing a worst case from the intact scenario (Case01) and the subsidence scenario (Case11 where the subsidence potential is set to its upper limit of non-crushable container content), the entire range of subsidence potential from 0% to the DU's allowable upper bound is accounted for in the inventory limit calculations. This provides flexibility in SWM ELLWF operations.

Table 8-6. Scenarios Considered and Subsidence Potential in Slit and Engineered Trenches

PIF Aquifer Cutout	DU	Scenario		Percentage Area of Non-Crushable Containers (%)
		Intact	Subsided	
West	ET07	X	X	2.0
	ET08	X	X	2.0
	ET09	X	X	2.0
	ET03	X	NA [a]	0.0
	ET04	X	X	2.0
	ST08	X	X	2.0
	ST09	X	X	2.0
	ST10	X	X	2.0
	ST11	X	X	2.0
Center	ST01	X	NA [a]	0.0
	ST02	X	X	2.0
	ST03	X	X	4.9
	ST04	X	X	3.6
	ST23	X	X	2.0
	ST24	X	X	2.0
	ST05	X	X	0.54
	ST06	X	X	2.0
	ST07	X	X	2.0
East1	ET02	X	X	2.0
	ET01	X	X	2.0
	ST14	X	X	2.0
	ET05	X	X	2.0
	ET06	X	X	2.0
	ST17	X	X	2.0
	ST18	X	X	2.0
	ST19	X	X	2.0
	ST20	X	X	2.0
	ST21	X	X	2.0
	ST22	X	X	2.0

Notes:

[a] NA = Subsided case not applicable because DU contains no non-crushable containers; therefore, only intact transport analyses are required.

Dynamic compaction is employed at the end of IC; however, all non-crushable containers are assumed to remain intact. Over time, due to degradation processes, these initially non-crushable containers begin to fail, which leads to subsidence of the waste zone and final closure cap. Within the PORFLOW analyses, it is pessimistically assumed that all non-crushable containers fail (subside) together in the first year following the end of IC. This results in a maximum infiltration rate at the cap surface.

Details addressing the computation of concentration profiles are given below. Worst-case concentration profiles for six parent radionuclides (C-14, I-129, Ni-59, Ni-63, Sr-90, and Tc-99) disposed in ST14 are shown in Figure 8-2, Figure 8-3, and Figure 8-4 for illustration purposes because they are representative of all slit and engineered trenches.

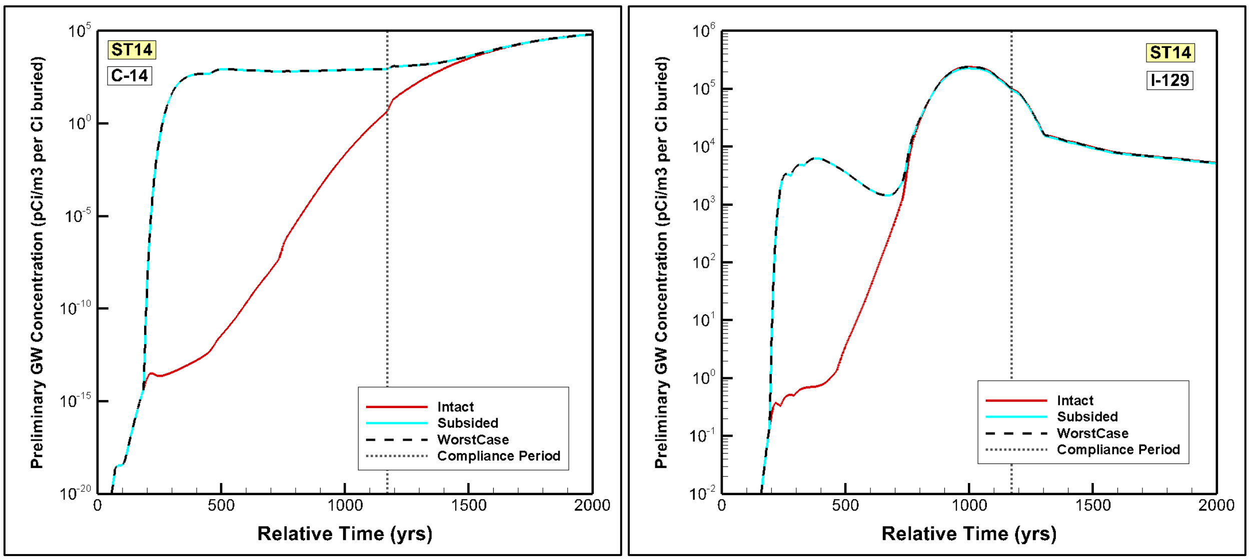


Figure 8-2. Preliminary Groundwater Concentrations of C-14 and I-129 at 100-meter POA for ST14

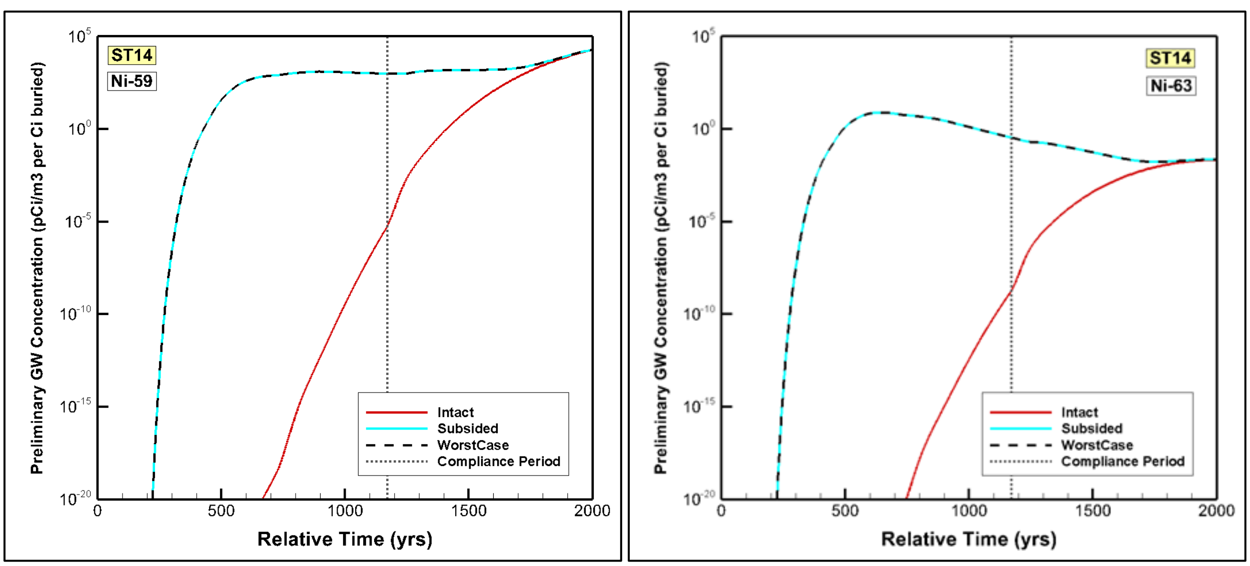


Figure 8-3. Preliminary Groundwater Concentrations of Ni-59 and Ni-63 at 100-meter POA for ST14

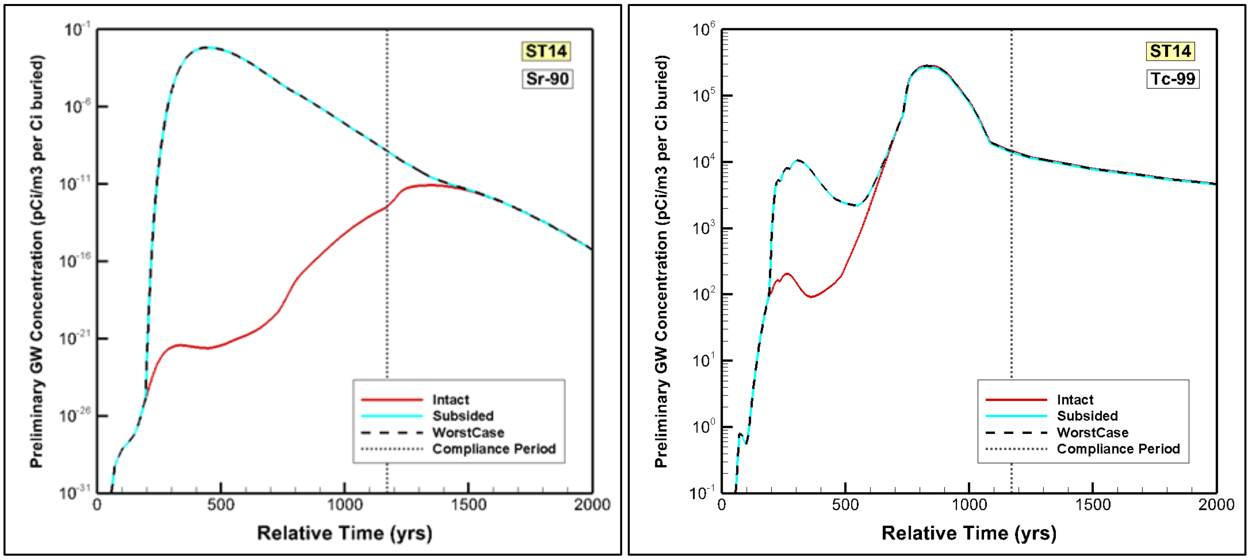


Figure 8-4. Preliminary Groundwater Concentrations of Sr-90 and Tc-99 at 100-meter POA for ST14

As these examples illustrate, significant concentration time history differences are observed when comparing the intact (red curves) and subsidence (cyan curves) scenarios at the 100-meter POA. The black-dashed curves represent the worst-case values (i.e., maximum concentration at each point in time) employed in obtaining preliminary inventory limits. The area between the two endpoint scenarios represents the wide range of partial subsidence results from 0% up to X% as defined in Table 8-6.

8.3.3.1.2. Worst-Case Concentration Profiles for Component-in-Grout Trench Segments

For models of trench segments CIG-1 through CIG-9, the worst-case concentration profiles are established using the intact and subsided scenarios listed in Table 8-7. For CIG-1 through CIG-3, there is zero subsidence potential, thus the intact case alone defines the worst case. For CIG-4 through CIG-7, the potential for subsidence exists; however, at the current time, reinforced concrete slabs are not installed.[1] The worst case for each CIG trench segment is obtained by extracting the maximum concentration at the 100-meter POA from the intact and subsidence scenarios assuming no reinforced concrete slab is present. Accounting for the intact and subsidence scenarios ensures that the maximum possible concentration is always used, thereby allowing the conclusion to be drawn that reinforced concrete slabs for CIG-4 through CIG-7 are not needed to meet POs. Lastly, both CIG-8 and CIG-9 have a reinforced concrete slab and, therefore, the worst case is obtained from the intact and subsidence scenarios assuming slabs are present.

[1] Note that a sensitivity case is explored assuming installation of a reinforced concrete slab over CIG-4 through CIG-7 in calendar year 2022.

Table 8-7. Scenarios Considered for Component-in-Grout Trench Segments

CIG Trench Segment	Scenario		
	Intact	Subsidence	
		No Concrete Slab	Concrete Slab Present
CIG-1	X	NA	NA
CIG-2	X	NA	NA
CIG-3	X	NA	NA
CIG-4	X	X	X
CIG-5	X	X	X
CIG-6	X	X	X
CIG-7	X	X	X
CIG-8	X	NA	X
CIG-9	X	NA	X

Notes:

NA: Scenario is not applicable

Overall worst-case concentration profiles are computed from the individual worst-case concentration profiles for CIG-1 through CIG-9 for each CIG parent radionuclide. Preliminary maximum GW concentration profiles for the nine CIG trench segments as well as the overall maximum concentration profiles are displayed in Figure 8-5 for H-3A and I-129A, and Figure 8-6 for Sr-90A and Tc-99A.

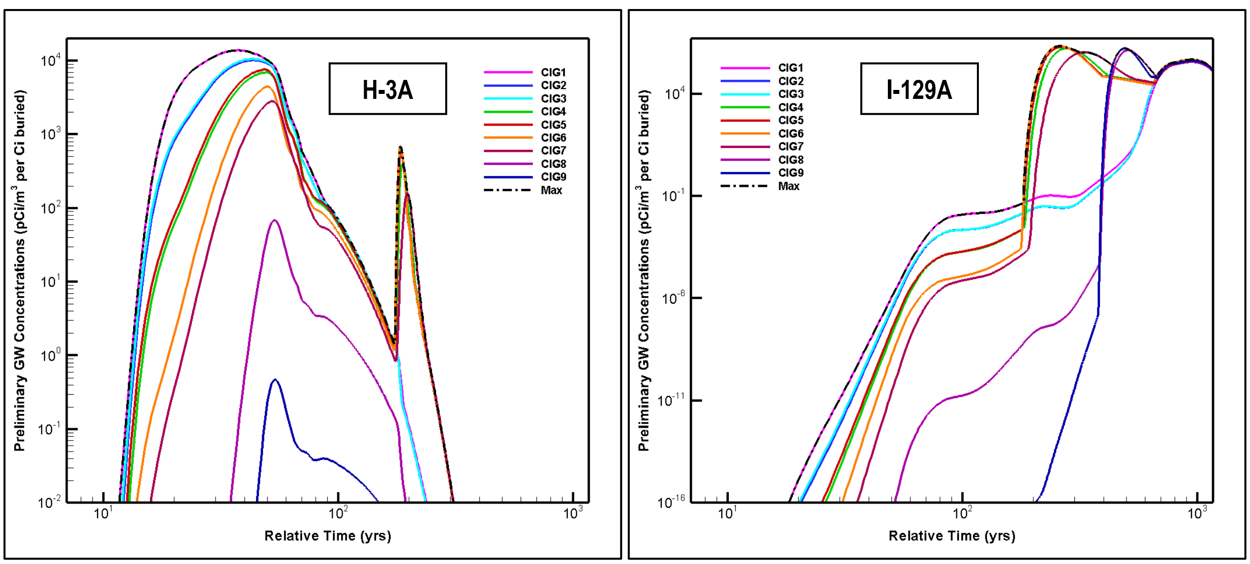


Figure 8-5. Preliminary Groundwater Concentrations of H-3A (left) and I-129A (right) at 100-meter POA for ST23

Inventory limits for H-3A computed using the maximum concentration profile in Figure 8-5 are too restrictive for ST23 disposal operation. To alleviate this problem, actual H-3A inventories for each CIG trench segment (normalized to 1 Ci buried for all nine segments versus 1 Ci buried per segment) are applied to flux-to-the-water-table source terms in the PORFLOW aquifer transport model simulations for the intact and subsidence scenarios with no reinforced concrete slabs. The intact, subsidence, and worst-case scenario concentration profiles for H-3A, based on actual inventories per CIG trench segment, are shown in Figure 8-7. This approach reduces the maximum H-3A concentration from 13,781 to 871 pCi m^{-3} per Ci buried.

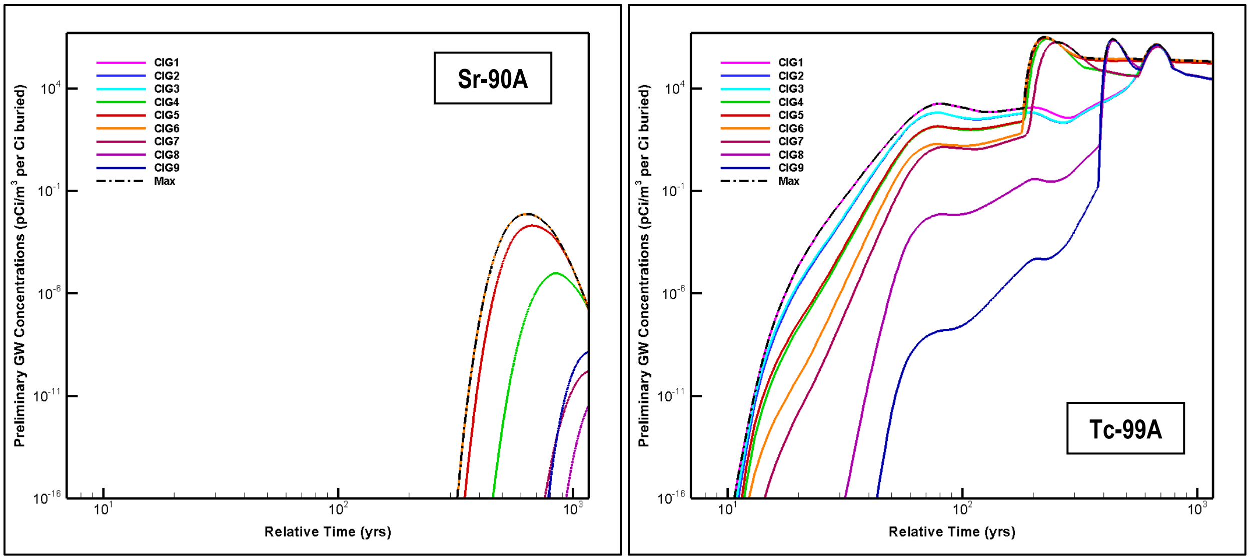


Figure 8-6. Preliminary Groundwater Concentrations of Sr-90A (left) and Tc-99A (right) at 100-meter POA for ST23

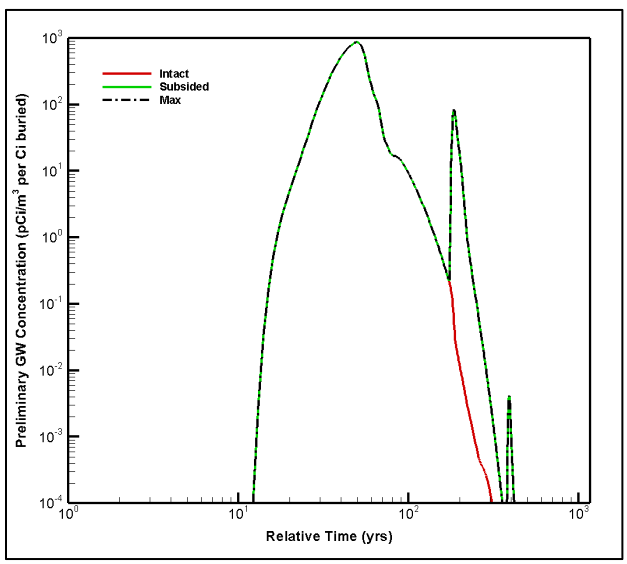


Figure 8-7. Revised Preliminary Groundwater Concentrations of H-3A at 100-meter POA for ST23

8.3.3.1.3. Worst-Case Concentration Profiles for Intermediate-Level and Low-Activity Waste Vaults

For the LAWV and ILV, only a single scenario exists for each; therefore, the worst-case is set to the nominal PA case for each vault.

8.3.3.1.4. Worst-Case Concentration Profiles for NR07E and NR26E

For NR07E and NR26E, multiple worst-case scenarios must be established as listed in Table 8-8.

Table 8-8. Scenarios Considered in Naval Reactor Component Disposal Area Units

PIF Aquifer Cutout	DU	Bolted Container (Generic Waste Form)		Cask (SWF)	
		Time 1	Time 2	Metal 1	Metal 2
West	NR26E	Early Hydraulic Failure	Late Hydraulic Failure	Inconel	Zircaloy
East2	NR07E	NA	NA	Inconel	Zircaloy

For the generic waste form parent radionuclides within bolted containers, the worst case accounts for any hydraulic failure time between the two bounding times considered. For SWF parent radionuclides within welded casks, the worst case allows for any combination of Inconel and Zircaloy components to be disposed in existing and future casks.

NR07E

NR07E is a closed DU that received offsite NR components from ongoing naval operations in welded steel casks; non-welded containers do not exist in NR07E. Only SWF parent radionuclide inventory limits are required for NR07E. In computing GW concentrations for establishing preliminary inventory limits, two separate reactor component materials are considered as discussed in Sections 4.7 and 5.4: Inconel and Zircaloy.

To determine preliminary inventory limits, worse-case preliminary concentration profiles are generated for each component material for input into the SRNL Dose Toolkit (Aleman, 2019). The worst-case concentration profile for Tc-99S (black-dashed curve) disposed in welded casks is shown in Figure 8-8. In this case, components made from Inconel represent the worst case across the entire compliance period.

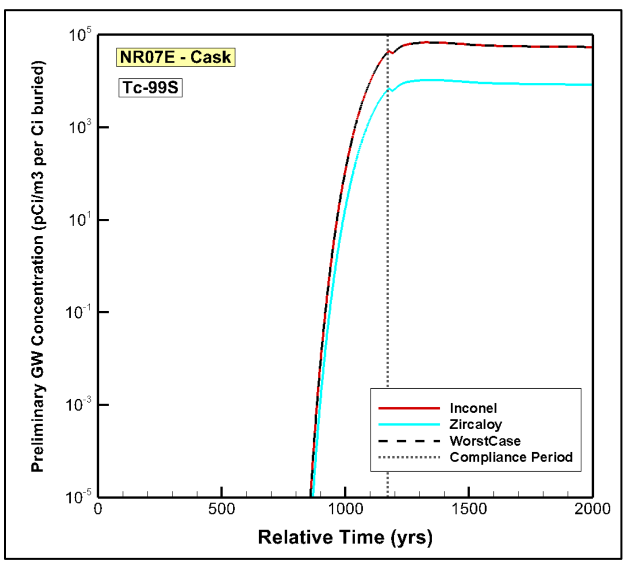


Figure 8-8. Preliminary Groundwater Concentrations of Tc-99S at 100-meter POA for NR07E Welded Casks

NR26E

NR26E is an open DU that has received, and expects to continue to receive, offsite NR components in both bolted containers and welded casks from ongoing naval operations. Both generic waste form and SWF parent radionuclide inventory limits are required as follows:

- **Generic Waste Form:** Parent radionuclides residing in bolted containers not defined as casks
- **SWF:** Parent radionuclides residing in welded casks

In computing GW concentrations to establish preliminary inventory limits, two separate scenarios are considered for both waste forms as listed in Table 8-8 and explained in detail in Sections 4.7 and 5.4:

- **Generic Waste Form:** Early and late hydraulic failure of the containers
- **SWF:** Inconel and Zircaloy components

To determine preliminary inventory limits, worse-case preliminary concentration profiles are generated for each waste form for input into the SRNL Dose Toolkit (Aleman, 2019). The worst-case concentration profiles (black-dashed curves) for Tc-99 and Tc-99S for bolted containers and welded casks are shown in Figure 8-9.

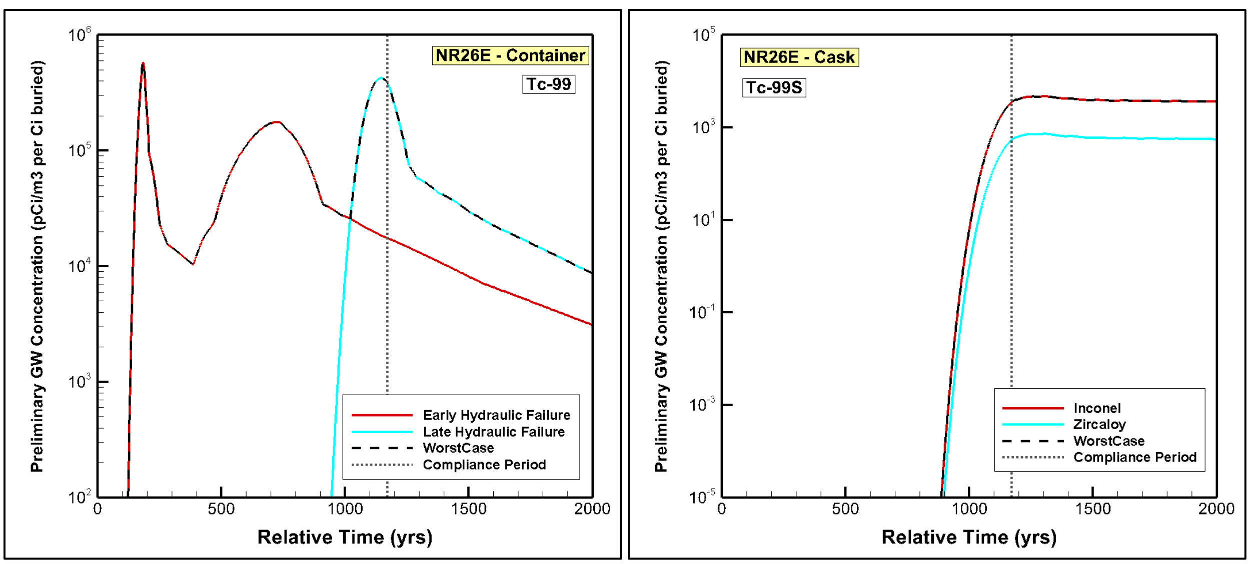


Figure 8-9. Preliminary Groundwater Concentrations of Container Tc-99 (left) and Cask Tc-99S (right) at 100-meter POA for NR26E

As for NR07E, cask components made from Inconel represent the worst case throughout the entire compliance period. On the other hand, the worst-case scenario for bolted containers switches from early hydraulic failure over most of the compliance period to late hydraulic failure around Year 1,000.

8.3.3.2. Preliminary Inventory Limits

Preliminary inventory limits for the GW pathways are presented in Appendix H, Section H.1.3, for all 33 DUs. Preliminary limits are provided for the five GWP pathways with some of the GWP pathways having multiple time windows. In all cases, the selected time windows encompass the entire compliance period for each pathway and are non-overlapping. For example, STs and ETs have the following eight separate pathway and time-window combinations:

- **Beta-Gamma**: 3 time windows (BG1, BG2, and BG3)
- **Gross-Alpha:** 1 time window
- **Radium:** 1 time window
- **Uranium:** 1 time window
- **All-Pathways:** 2 time windows (AP1 and AP2)

The logic employed in setting up the various time windows is provided in Appendix H, Section H.1.2. In many cases, the activity capacity of a DU is dependent upon the number of time windows employed. An increase in the number of time windows results in an increase in a DU's activity capacity (i.e., an increase in its inventory limit for the GW pathways). The numbers chosen are limited because of trade-offs with diminishing return as tracking increases.

The preliminary limits focus on one DU in isolation and do not address potential GW plume overlap from neighboring DUs. To address plume overlap, Section 8.3.4 describes the aquifer GW PIFs that are applied as simple multipliers on the preliminary inventory limits to convert them into final inventory limits for the GW pathways to be inserted directly into the CWTS limits system.

In creating the preliminary inventory limits, PORFLOW-based VZ and aquifer transient transport simulations are performed (Chapters 4 and 5). Parent radionuclides contained within generic waste forms during Tier-3 analyses do not explicitly account for engineered barriers. On the other hand, in many cases for SWFs, various engineered features are addressed via Tier-4 analyses. The decision to choose the added complexity of a Tier-4 vs. Tier-3 analysis depends on how acceptable the Tier-3 SOFs are with respect to POs. If the Tier-3 inventory limits are considered acceptable, no follow-on Tier-4 analyses are performed. In addition, as mentioned earlier, some of the existing SWFs have no planned future disposals. To highlight the various options assumed for each parent radionuclide, a color shading scheme (as defined in Table 8-9 and Table H-8) is employed in the inventory limit tables provided in Appendix H, Sections H.1.3 and H.1.4. Table 8-9 and Table H-8 indicate how generic waste form and SWF radionuclides are addressed in the CWTS limits system based on waste form type, future burial plans, and handling within the transport modeling process.

Table 8-9. Handling of Generic and Special Waste Form Parent Radionuclides in Limits System

Shading Legend for Table 8-35	Waste Form	Plans for Future Burial?	Type of Inventory Limit
	Generic	Yes	Generic
	SWF	Yes	SWF
	SWF	Yes	Generic
	SWF	No	SWF
	SWF	No	Generic

Notes:

Shading is employed in subsequent tables to indicate how a SWF is treated in computing its inventory limits.

8.3.4. Aquifer Plume Overlap

Within the CWTS inventory system, GW inventory limits are imposed on a range of parent radionuclides. The CWTS inventory limits are DU specific and independent of the status of neighboring DUs. This is accomplished using GW PIFs that explicitly account for the potential of aquifer plume overlap among neighboring DUs.

To compute the DU-specific GW PIFs, the following sets of information must be utilized:

- A quantitative measure of the potential spreading of an aquifer plume from one DU to others at the POAs, which is represented by GW PIPs.
- DU-specific inventory limits that do not account for the impacts from neighboring DUs, which are represented by the preliminary GW inventory limits.
- Activity-capacity requirements imposed by existing plus future ELLWF operations, which are represented by both PO requirements at the POAs and SWM expectations.

Setting GW PIF values is not unique; an iterative process is employed using the three information sets above. The process employed and results are discussed below. More details are provided in Appendix H, Section H.1.1.

The PIPs are maximum concentration profiles along a specific POA. In this development, the POAs of interest are the North and South 100-meter POAs surrounding the ELLWF. The PIPs are also DU-, radionuclide-, and time-period-specific, where a combination scheme is employed to reduce the dependence down to DU specific only.

The GW PIFs account for plume overlap among neighboring DUs and reallocate activity capacity among DUs.

The major impacts associated with the new PIPs and GW PIFs are as follows:

- **East Sector**: Direction of the aquifer flow field dominates
- **West and Center Sectors**: Lateral dispersion dominates

GW PIFs convert "preliminary" CWTS inventory limits into "final" CWTS inventory limits by the following simple relationship:

$$L_{DU,i}^{GW-final} = \frac{L_{DU,i}^{GW-prelim}}{\eta_{DU}^{GW}} \qquad \text{Eq. (8-4)}$$

where:

$L_{DU,i}^{GW-final}$	Final GW inventory limit for i^{th} parent radionuclide in a specific *DU* (Ci)
$L_{DU,i}^{GW-prelim}$	Preliminary GW inventory limit for i^{th} parent radionuclide in a specific *DU* (Ci)
η_{DU}^{GW}	GW aquifer PIF for a specific *DU* (unitless)

Because of GW plume overlap, a trade-off in activity capacity exists between DUs. To compute optimal GW PIFs, the process of setting DU capacity allocation (i.e., activity versus volume capacities by DU) considers a wide variety of aspects. Figure 8-10 presents an overview of the basic relationship among key variables.

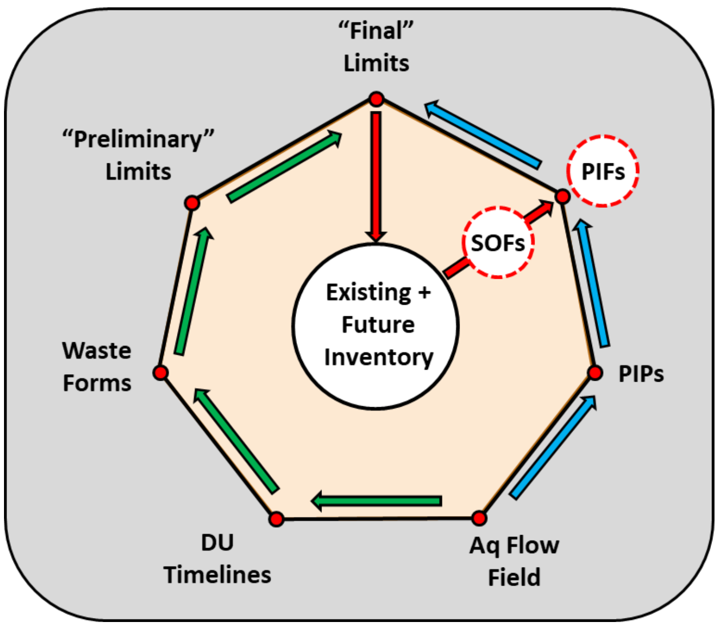


Figure 8-10. Basic Relationship Among Key Variables and Disposal Unit Capacity Allocation

As Figure 8-10 indicates, starting with an aquifer flow field beneath the ELLWF, the general flow of information follows two basic paths:

- PIPs → PIFs → Final Limits (blue arrows)
- DU Timelines → Waste Forms → Preliminary Limits → Final Limits (green arrows)

Following the green arrows, the aquifer flow field (Section 3.5.3 and Appendix C), DU timelines, waste forms (both generic and special), and preliminary inventory limits (Chapters 4 and 5) are fixed information in the allocation process. The GW PIFs, final inventory limits, and total final DU inventories (existing plus future), as constrained by POs along the POAs, existing closed DU capacities, and SWM future expectations, are all coupled in an iterative process based primarily on reviewing maximum total SOFs by DU.

GW PIF assignments address all of the above-mentioned items. In the process, six DUs within the East1 sector must be excluded to maintain existing plus future capacity needs (see Appendix H, Section H.1.1.6, for details). PIPs generation and GW PIF assignments are discussed in Sections 8.3.4.1 through 8.3.4.4.

8.3.4.1. Groundwater Plume Interaction Profiles

Concentration profiles along the 100-m POA are employed to quantitatively account for the spread of an aquifer plume emanating from one DU onto neighboring DUs. Conservative (pessimistically leaning) GW PIPs are generated for every ELLWF DU as detailed in Appendix H. Sections H.1.1.1, H.1.1.2, and H.1.1.3 describe how the GW PIPs are generated and present graphs showing how the PIPs are distributed along the 100-m POA. The concentration plumes used to extract the GW PIPs are presented in Appendix C, Section C.1.2.

8.3.4.2. Plume Interaction Concept

Aquifer concentration profiles from neighboring DU sources along the 100-meter POA can overlap due to aquifer flow direction and lateral dispersion. The concentration profiles are spatially 2-D (i.e., 3-D plumes sliced by a stationary 2-D vertical curtain that represents the 100-meter POA) and inherently vary in time because a fixed quantity of inventory was buried in the upstream DUs at some earlier time (see Chapters 4 and 5 for details).

To simplify the analysis, to provide burial timing flexibility, and to establish a bounding approach, PIPs are computed using steady-state aquifer transport analyses for a constant source tracer. The impact of comingling plumes from neighboring DUs (assumed to be operating up to their inventory limits) on a specific DU is accounted for using a PIF that is DU specific:

$$C_{DU,i}^{Limit} = \left[\eta_{DU}^{GW}\right] \times C_{DU,i}^{PF} \qquad \text{Eq. (8-5)}$$

where:

$C_{DU,i}^{Limit}$ Combined concentration at 100-meter POA for i^{th} parent radionuclide in a specific *DU* (pCi L^{-1})

η_{DU}^{GW} GW PIF for a specific *DU* (unitless)

$C_{DU,i}^{PF}$ PORFLOW-calculated concentration at 100-meter POA for i^{th} parent radionuclide in a specific *DU* (pCi L^{-1})

As Eq. (8-5) indicates, an increase in the values of the PIFs will result in an increase in well concentrations along the 100-meter POA. To illustrate how a GW PIF is computed for a specific DU, Figure 8-11 displays two extreme configurations for hypothetical DUs, DU-1 and DU-2, where:

1. DU-1 is completely isolated from its neighbor, DU-2, so there is zero comingling of plumes within the 100-meter POA boundary.
2. DU-1 is completely downstream of its neighbor, DU-2 so that DU-1's plume is completely encompassed by the plume from DU-2.

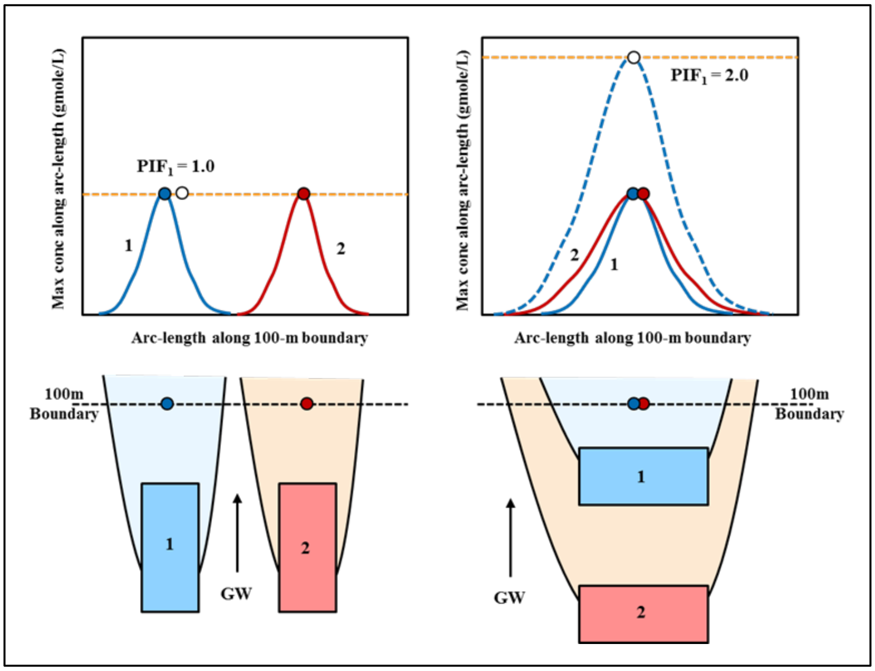


Figure 8-11. Illustration of How a Plume Interaction Factor is Related to Neighboring Disposal Units

These two configurations represent the two extremes when viewing the alignment between DUs relative to GW flow direction, which is a key aspect when considering plume interaction among neighboring DUs. In Figure 8-11, the configuration on the left produces a PIF of ~1.0 for DU-1, while the configuration on the right produces a PIF approaching 2.0. Here, no consideration is given for activity capacity aspects and objectives. In computing PIFs for PA2008, most ELLWF DUs were arranged more like the configuration on the left but with some degree of plume interaction taking place. Increasing a DU's PIF will impose more restrictive inventory limits on that DU while helping to increase inventory limits within neighboring DUs (i.e., an action to reallocate activity capacity). Trade-offs such as this are used to address the adverse aquifer flow field beneath the eastern sector of the ELLWF (see Appendix H, Section H.1.1, for details).

8.3.4.3. Assessment of Activity Capacity

To establish optimal GW PIFs, an activity assessment of historical ELLWF operations and future waste generator forecasts are considered. For example, as of March 31, 2021, three key assumptions are as follows:

1. Seven closed DUs (ST01-ST05, ET01, and NR07E) where total SOFs must be maintained within administrative limits (either 0.95 or 1.0).

2. Five TPBAR casks are disposed in the ILV, and to eliminate the future need for another ILV, the current ILV must accommodate up to ~36 TPBAR casks.
3. Complete utilization of each DU is achieved wherein the DU becomes activity limited before reaching its volume capacity.

SWM operates each active DU to make optimal use of available volume capacity (Assumption #3). The waste inventory is distributed among the available DUs to maximize buried activity where an administrative activity level (i.e., a limit on a DU's maximum total SOF) is imposed. Table 8-10 provides the status of each closed and open ELLWF DU.

Table 8-10. Activity and Volume Capacity Status of Open and Closed E-Area Low-Level Waste Facility Disposal Units as of March 31, 2021

Sector (cutout)	DU	Status [03/31/2021]	PA SOF Administrative Limit	Total SOF [03/31/2021]	Volume Filled [03/31/2021]	Activity / Volume Ratio [03/31/2021]
West	ET03	Open	95%	74%	93%	0.8
	NR26E	Open	95%	3%	12%	0.2
	ST08	Open	95%	89%	95%	0.9
	ST09	Open	95%	85%	94%	0.9
	ILV	Open	95%	9%	59%	0.2
Center	ST01	Closed	95%	85%	100%	0.9
	ST02	Closed	95%	87%	100%	0.9
	ST03	Closed	95%	89%	100%	0.9
	ST04	Closed	95%	95%	100%	0.9
	ST23	Open	95%	44%	28%	1.6
	ST05	Closed	100%	100%	100%	1.0
	ST06	Open	95%	82%	91%	0.9
	ST07	Open	95%	55%	66%	0.8
East1	ET02	Open	95%	76%	79%	1.0
	ET01	Closed	95%	87%	100%	0.9
	ST14	Open	95%	90%	90%	1.0
	LAWV	Open	95%	13%	32%	0.4
East2	NR07E	Closed	95%	3%	100%	0.03

Notes:
Open DUs are shaded in green; closed DUs are shaded in gray.

As of March 31, 2021, there are 7 closed and 11 open DUs. All but ST05 had their administrative activity limit set to 0.95. The total SOFs listed in Table 8-10 represent the maximum SOF value across all time windows and exposure pathways (i.e., CWTS-computed values). A CWTS emulator worksheet developed in Microsoft Excel[2] for this PA emulates the process employed in CWTS for determining each DU's maximum total SOF (see Appendix H, Section H.8, for details).

[2] Microsoft, Excel, and Word are trademarks of the Microsoft group of companies.

The estimated cumulative volume of waste packages is also listed. The last column in Table 8-10 represents a utilization factor (ratio) indicating the degree to which a DU's activity capacity has been utilized. The average values of this utilization factor by reference DU-type are as follows:

- **Trench:** 0.90
- **LAWV and ILV:** 0.28
- **NRCDAG and NRCDAS:** 0.13

As these average values indicate, SWM has maintained a high utilization factor for trenches; however, activity capacity remains unused in the vaults and NRCDAs.

8.3.4.4. Groundwater Plume Interaction Factors

The DU-specific, composited PIPs discussed above provide conservative estimates of plume overlap among neighboring DUs. The composited PIPs directly address parent radionuclides (and their progeny) at a DU level and over the four time periods associated with the GW compliance periods.

Application of the DU-specific PIPs, and the preliminary GW inventory limits, allows for an estimate of the DU-specific PIFs to be made. The allocation of activity capacity among the various DUs that comprise the ELLWF is not unique. For example, activity capacity can in principle be reduced in one DU and then added to its neighboring DU(s). Thus, additional information, such as SWM operational expectations, are factored into the GW PIF determination process.

As the GW PIPs provided in Appendix H, Section H.1.1.3, indicate, GW plume overlap is generally limited to only those neighboring DUs in the vicinity of a given DU. To a large extent, this partial decoupling allows activity assessments to be made by West, Center, East1, and East2 sector.

The red-dashed curves in Figure H-30 through Figure H-56 (Appendix H, Section H.1.1.3) represent the PIPs across the North and South curtains for all ELLWF DUs. They are the composited and smoothed PIPs that are only DU specific. As such, they implicitly capture the variabilities associated with differences among a DU's parent radionuclide list and the aquifer flow field changes over time.

The overall maximum total SOF along the North curtain is expressed as:

$$S^{North}(x) = \sum_{k=1}^{N_{DU}} \left[\frac{SOF_k^{max}}{\eta_k^{GW}} \right] \left[P_k^{North}(x) \right] \qquad \text{Eq. (8-6)}$$

where:

S^{North} Total SOF along the North curtain (unitless)
x Arc-length along North curtain represented by x-y grid indexing (unitless)
N_{DU} Number of DUs contributing to the North curtain along the 100-meter POA (unitless)

SOF_k^{max} Maximum total SOF for k^{th} DU (unitless)

η_k^{GW} GW PIF for k^{th} DU (unitless)

P_k^{North} Normalized PIP along the North curtain for k^{th} DU (unitless)

The terms within the first bracket establish a factor that scales the PIPs (i.e., term in second bracket) for each DU. A similar expression is used to represent the total SOF along the South curtain. These expressions and other calculational details are discussed in Appendix H, Section H.8, where a CWTS emulator has been developed to assist in GW PIF assignments.

Eq. (8-6) (as well as a comparable equation for the South curtain that is not shown) addresses the following two aspects:

1. **GW PIF Evaluation**: Assignment of GW PIFs by DU is independent of a DU's composition and inventory, and the maximum total SOF for every DU is set to 1.0. The maximum SOF along either the North or South curtain is constrained to not exceed 1.0 at any location along these curtains.
2. **Activity Capacity Assessment**: For specified DU inventories, computed maximum total SOFs for each DU are considered to assess activity capacity objectives for certain DUs (e.g., maintaining closed units within PO constraints, and satisfying future disposal objectives for certain open DUs, such as projected TPBAR casks needs for the ILV).

For a specified inventory and GW PIF within a DU, its maximum total SOF is computed by employing a calculational scheme consistent with the methods utilized in CWTS. A CWTS emulator was developed in Microsoft Excel for this PA and is utilized as discussed in Appendix H, Section H.8. By way of example for ET03, Section H.8 also provides details on the calculation of a maximum total SOF using the CWTS emulator.

The two aspects above are considered in arriving at the final GW PIFs. GW PIFs are assigned for every ELLWF DU where reallocation of activity capacity is performed to meet overall operational objectives. The computed final GW PIFs are provided in Table 8-11. To meet most of the operational objectives, six of the original 33 DUs are excluded from future operations based on this PA. The six include ET06, ST17, ST19, ST20, ST21, and ST22.

Table 8-11. List of Computed Groundwater Plume Interaction Factors for All E-Area Low-Level Waste Facility Disposal Units

PIF Aquifer Cutout	DU [a]	Status	GW PIF (unitless)
West	ET07	Future	2.000
	ET08	Future	2.000
	ET09	Future	2.150
	ET03	Open	6.000
	ET04	Future	6.800
	NR26E	Open	6.000
	ST08	Open	7.050
	ST09	Open	2.253
	ST10	Future	5.200
	ILV	Open	2.561
	ST11	Future	4.000
Center	ST01	Closed	1.825
	ST02	Closed	18.985
	ST03	Closed	15.352
	ST04	Closed	16.270
	ST23	Open	1.800
	ST24	Future	1.550
	ST05	Closed	14.680
	ST06	Open	3.000
	ST07	Open	7.000
East1	ET02	Open	6.380
	ET01	Closed	4.684
	ST14	Open	13.040
	ET05	Future	14.000
	LAWV	Open	3.970
	ST18	Future	8.354
East2	NR07E	Closed	20.000

Notes:

Open DUs are shaded in green; closed DUs are shaded in gray; future DUs are unshaded.

[a] Excludes future DUs ET06, ST17, ST19, ST20, ST21, and ST22.

In the process of assigning GW PIFs via application of the CWTS emulator worksheet, the total future inventory is computed. Based on the GW PIFs in Table 8-11, the calculated, projected closure inventories are reported in Table 8-12.

Table 8-12. Existing (as of March 31, 2021) and Projected Closure Inventories for Consolidated Waste Tracking System

PIF Aquifer Cutout	DU [a]	Status	Total Existing Inventory (Ci)	Total Projected Future Inventory (Ci)	Total Projected Inventory at Closure (Ci)
West	ET07	Future	--	286.66	286.66
	ET08	Future	--	379.60	379.60
	ET09	Future	--	414.06	414.06
	ET03	Open	114.35	210.44	324.78
	ET04	Future	--	544.11	544.11
	NR26E	Open	2.41E+05	5.19E+07	5.22E+07
	ST08	Open	45.79	77.84	123.63
	ST09	Open	271.97	73.96	345.93
	ST10	Future	--	416.52	416.52
	ILV	Open	2.27E+06	1.19E+07	1.41E+07
	ST11	Future	--	399.82	399.82
Center	ST01	Closed	17.12	--	17.12
	ST02	Closed	40.74	--	40.74
	ST03	Closed	63.46	--	63.46
	ST04	Closed	76.38	--	76.38
	ST23	Open	7.451E+03	6.543E+02	8.105E+03
	ST24	Future	--	362.82	362.82
	ST05	Closed	96.77	--	96.77
	ST06	Open	63.32	379.10	442.41
	ST07	Open	51.56	61.32	112.88
East1	ET02	Open	212.18	70.53	282.71
	ET01	Closed	102.46	--	102.46
	ST14	Open	3,453.26	82.55	3,535.81
	ET05	Future	--	48.88	48.88
	LAWV	Open	4.28E+05	9.62E+05	1.39E+06
	ST18	Future	--	89.58	89.58
East2	NR07E	Closed	2.95E+05	--	2.95E+05

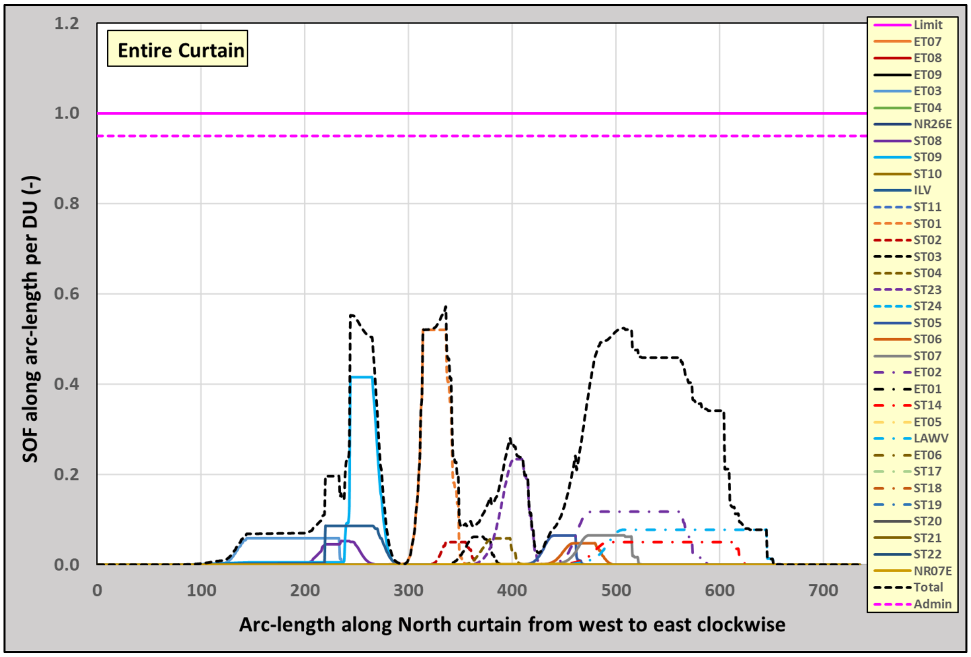
Notes:

Open DUs are shaded in green; closed DUs are shaded in gray; future DUs are unshaded.

[a] Excludes future DUs ET06, ST17, ST19, ST20, ST21, and ST22.

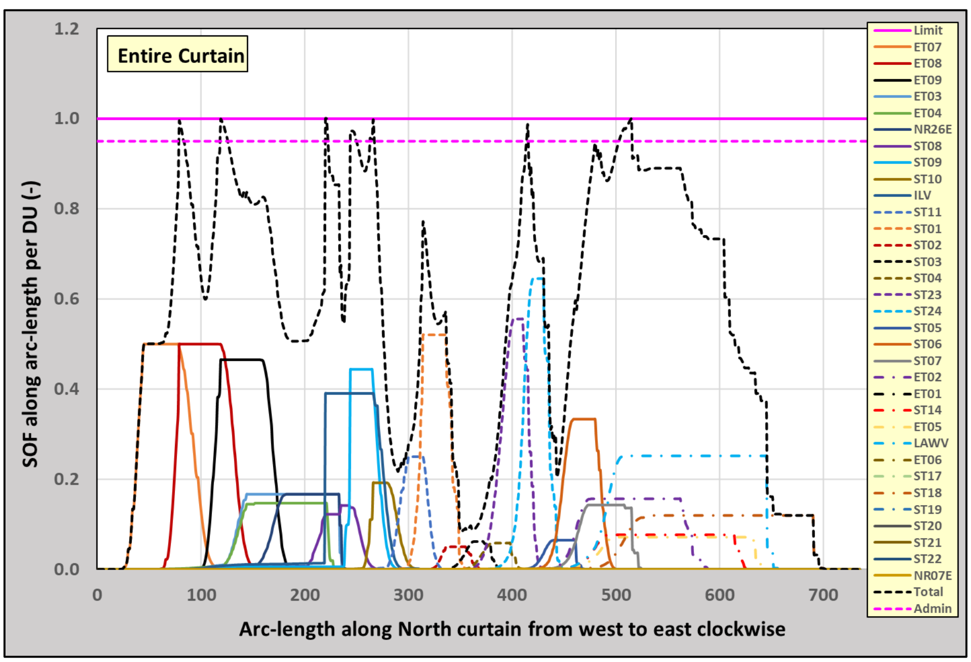
The total SOF along the North curtain is computed via Eq. (8-6) using GW PIFs in Table 8-11, existing and future DU inventories in Table 8-12, and individual DU-specific PIPs. Results across the entire North curtain from this set of calculations are provided in Figure 8-12 for existing CWTS inventories as of March 31, 2021 and in Figure 8-13 for projected CWTS closure inventories.

In the actual sequence of calculations, GW PIFs are determined without requiring specification of DU inventories; however, to finalize their values, activity capacity assessments are also performed.



Notes: Maximum total SOF (dashed black curve); all 27 DU SOF contributors (varying colored/patterned curves per legend); PO SOF limit = 1.0 (solid magenta line); administrative SOF limit = 0.95 (dashed magenta line).

Figure 8-12. Total Sum-of-Fractions Along North Curtain (100-meter POA) Based on Existing Consolidated Waste Tracking System Inventories as of March 31, 2021, and Time-Windowing Inventory Limits



Notes: Maximum total SOF (dashed black curve); all 27 DU SOF contributors (varying colored/patterned curves per legend); PO SOF limit = 1.0 (solid magenta line); administrative SOF limit = 0.95 (dashed magenta line).

Figure 8-13. Total Sum-of-Fractions Along North Curtain (100-meter POA) Based on Projected Consolidated Waste Tracking System Closure Inventories and Time-Windowing Inventory Limits

In assigning GW PIFs, the initial goal is to utilize as much of the available activity capacity as possible, subject to PO and operational constraints. As indicated in Figure 8-13 by the sharp peaks in the black-dashed curve, six locations along the North curtain approach a maximum total SOF equal to 1.0. The following observations are made based upon the Microsoft Excel CWTS emulator results for ST24:

- ST24 is a future DU with future disposals.
- The BG1 time window (Year 0 to Year 171) for the beta-gamma pathway is most limiting with respect to maximum total SOF = 1.0, followed by the BG2 time window (Year 171 to Year 1,000) with total SOF = 0.380.
- H-3 (generic waste form) is the largest contributor to BG1 with SOF = 1.000, followed by Np-237 (generic waste form) with SOF = 0.260 in the gross-alpha time window.

Total SOFs plots consistent with Figure 8-13 but with an enlarged arc-length scale are provided in Appendix H, Section H.1.1.5. Appendix H, Section H.1.1, addresses key aspects associated with generating PIPs and then GW PIFs. Appendix H, Section H.8, describes the supporting Microsoft Excel CWTS emulator worksheet developed to confirm the response when new inventory limits are added to the CWTS limits system.

8.3.5. Final Inventory Limits

Final DU-specific inventory limits are provided for every generic waste form and SWF parent radionuclide requiring an inventory limit for the GW pathways. These final inventory limits are based on the nominal PA (compliance case) PORFLOW transport runs presented in Chapter 5. The resulting preliminary inventory limits for the GW pathways computed from these PORFLOW simulations are converted into final inventory limits when plume overlap and desired activity capacities are accounted for in the model.

A final inventory limit for the GW pathways is computed by applying a DU-specific GW PIF that explicitly accounts for neighboring plume overlap as given by Eq. (8-4). The DU-specific GW PIF accounts for the following two aspects:

- Plume overlap[3] resulting from the aquifer flow field direction and plume dispersion by neighboring DUs.
- Activity-capacity allocation[4] needs among certain DUs.

To meet overall ELLWF activity-capacity objectives, six DUs originally defined as “future DUs” are excluded from further consideration in this PA. These six are deferred for potential deployment at a future date beyond this PA and will require a follow-on SA. Details associated

[3] A physical aspect resulting from the local GSA flow field and surface infiltration changes due to cover degradation.
[4] An administrative aspect whereby disposal objectives are maintained to achieve long-term objectives.

with the removal of the following DUs are provided in Appendix H, Section H.1.1.6: ET06, ST17, ST19, ST20, ST21, and ST22.

As discussed in Appendix H, Section H.1.1.6, the need to exclude these specific DUs from further consideration in PA2022 is based on activity-capacity allocation needs caused by the adverse aquifer flow field beneath the eastern sector of ELLWF. Based on the pessimistically leaning aquifer GW PIF approach employed, the resulting GW plume overlaps devalue several upstream DUs in the eastern sector, which leads to their exclusion. The need to exclude some DUs is a direct result of the underlying assumption employed in the GW PIF approach. Activity capacities of these six DUs are unaffected for the non-GW exposure pathways.

Eq. (8-4) applies to all parent radionuclides, both generic waste form and SWF, within a DU that passed through the GW radionuclide screening process discussed in Section 2.3.7. Inventory limits are not required for progeny because their dose contributions are included in the parent radionuclides' dose calculations. The abbreviated chain used in the PORFLOW transport analyses is expanded using secular equilibrium assumptions and then full-chain contributions are rolled up to their parent radionuclide's total.

The final inventory limits for the GW pathways are presented in Appendix H, Section H.1.4, for all remaining DUs (33 – 6 = 27 DUs). The same list of parent radionuclides provided for preliminary limits is also required for the final limits. The same list of pathways and time windows is required as provided in Appendix H, Section H.1.4.

8.3.6. Dose History Time Profiles

GW dose history time profiles are generated for each DU for each pathway of interest. Dose history time profiles are based on the preliminary GW concentration data obtained from the SRS Dose Toolkit (Aleman, 2019) and discussed in Chapter 5. Worst-case concentration profiles are computed based on the various scenarios considered for each DU. To account for GW plume overlap from neighboring DUs (i.e., scaling up contributions), the DU-dependent GW PIFs are then applied to the preliminary dose history time profiles. Selective results of the final dose history time profiles are presented in this section; remaining figures and additional details are provided in Appendix H, Section H.1.5.

To compute estimated dose history time profiles along the 100-meter POA projected to ELLWF closure, the following equation is employed:

$$D^{j}_{DU,i}\left(t\right) = I^{Tot}_{DU,i} \times \left[\eta^{GW}_{DU} \times \hat{d}^{\,j}_{DU,i}\left(t\right)\right] \qquad \text{Eq. (8-7)}$$

where:

$D^{j}_{DU,i}$ GW dose for j^{th} pathway and i^{th} parent radionuclide in a specific *DU* (dose or concentration)

t Time (yr)

$I_{DU,i}^{Tot}$ Total projected closure inventory of i^{th} parent radionuclide in a specific *DU* (Ci)

η_{DU}^{GW} GW PIF for a specific *DU* (unitless)

$\hat{d}_{DU,i}^{j}$ GW preliminary dose factor for j^{th} pathway and i^{th} parent radionuclide in a specific *DU* (dose or concentration per Ci buried)

The product of terms within the brackets represents the GW dose (or concentration) factor for the j^{th} pathway and i^{th} parent radionuclide in a specific DU per curie of parent radionuclide buried. The dose factors are scaled up based on the projected closure inventories. The total dose (or concentration) for a specific pathway is then computed as the arithmetic sum of the individual dose contributions from the parent radionuclides that require inventory limits for the GW pathways within a given DU:

$$D_{Tot}^{j}\left(t\right)=\sum_{i=1}^{N_{DU}} D_{DU,i}^{j}\left(t\right) \qquad \text{Eq. (8-8)}$$

where:

D_{Tot}^{j} GW total dose for j^{th} pathway in a specific *DU* (dose or concentration)

N_{DU} Number of parent radionuclides in a specific *DU* with inventory limits for the GW pathways (unitless)

The total projected closure inventories included in Eq. (8-7) represent (1) deterministic values that demonstrate DU compliance with respect to all pathway-dependent POs; and (2) stochastic values (Chapter 9) that demonstrate the maximum SOF along the 100-meter POA where the DU composition vector and inventory uncertainties (i.e., uncertainty and bias in waste generator inventory values entering the CWTS system) are addressed using distribution functions to account for their uncertainties.

8.3.7. Projected Total Sum-of-Fractions at Closure

To demonstrate that the ELLWF meets GW POs, a final, best-estimate, upper-bound total SOF is computed based on the projected closure inventory presented in Section 8.7.1.2. Both generic waste form and SWF parent radionuclides are addressed.

A comparison of the computed total SOFs by DU is provided below. Two sets of SOFs are provided as follows:

1. Table 8-13: Total SOFs by DU and GW pathway based on the time-windowing inventory limits.
2. Table 8-14: Total SOFs by DU and GW pathway based on the dose history time profiles (i.e., effectively 1-yr time windows).

For example, there are three beta-gamma time windows (BG1, BG2, and BG3) for STs and ETs under the time-window approach. On the other hand, there are effectively 1,171 time windows for the dose history time profiles.

Table 8-13. Maximum Total Sum-of-Fractions for Groundwater Pathways by Disposal Unit Based on Upper-Bound Estimate of Disposal Unit Closure Inventories Using Time-Window-Based Approach

DU	Total Projected Inventory at Closure (Ci)	Maximum Total SOF Along 100-meter POA [a]				
		Beta-Gamma	Gross-Alpha	Radium	Uranium	All-Pathways
ET07	286.66	0.426	1.000	0.001	0.000	0.122
ET08	379.60	0.516	1.000	0.001	0.000	0.122
ET09	414.06	0.550	1.000	0.001	0.000	0.122
ET03	324.78	0.316	1.000	0.000	0.000	0.123
ET04	544.11	1.000	0.092	0.000	0.000	0.061
NR26E	5.22E+07	1.000	0.000	0.000	0.000	0.096
ST08	123.63	1.000	0.011	0.000	0.000	0.016
ST09	345.93	1.000	0.026	0.000	0.000	0.063
ST10	416.52	1.000	0.130	0.000	0.000	0.074
ILV	1.41E+07	1.000	0.000	0.000	0.000	0.010
ST11	399.82	1.000	0.066	0.000	0.000	0.056
ST01	17.12	0.950	0.000	0.000	0.000	0.001
ST02	40.74	0.950	0.022	0.000	0.000	0.035
ST03	63.46	0.950	0.441	0.000	0.000	0.102
ST04	76.38	0.950	0.141	0.000	0.000	0.083
ST23	8.105E+03	1.000	0.086	0.000	0.000	0.048
ST24	362.82	1.000	0.263	0.000	0.000	0.035
ST05	96.77	0.950	0.410	0.000	0.000	0.058
ST06	442.41	1.000	0.752	0.000	0.000	0.094
ST07	112.88	1.000	0.474	0.000	0.000	0.059
ET02	282.71	0.972	1.000	0.000	0.000	0.122
ET01	102.46	1.000	0.047	0.000	0.000	0.007
ST14	3535.81	1.000	0.060	0.000	0.000	0.020
ET05	48.88	0.697	1.000	0.000	0.000	0.121
LAWV	1.39E+06	1.000	0.000	0.000	0.000	0.009
ST18	89.58	1.000	0.070	0.000	0.000	0.012
NR07E	2.95E+05	0.138	0.000	0.000	0.000	0.015

Notes:

[a] All total SOFs are rounded off by 0.05% (e.g., most radium and uranium pathway values show up as zero).

Table 8-14. Maximum Total Sum-of-Fractions for Groundwater Pathways by Disposal Unit Based on Upper-Bound Estimate of Disposal Unit Closure Inventories Using Dose History Time Profiles

DU	Total Projected Inventory at Closure (Ci)	Maximum Total SOF Along 100-meter POA [a]				
		Beta-Gamma	Gross-Alpha	Radium	Uranium	All-Pathways
ET07	286.66	0.354	1.000	0.001	0.000	0.122
ET08	379.60	0.343	1.000	0.001	0.000	0.122
ET09	414.06	0.337	1.000	0.001	0.000	0.122
ET03	324.78	0.311	1.000	0.000	0.000	0.123
ET04	544.11	0.766	0.092	0.000	0.000	0.050
NR26E	5.22E+07	0.930	0.000	0.000	0.000	0.095
ST08	123.63	0.963	0.011	0.000	0.000	0.009
ST09	345.93	0.804	0.026	0.000	0.000	0.052
ST10	416.52	0.855	0.129	0.000	0.000	0.057
ILV	1.41E+07	1.000	0.000	0.000	0.000	0.009
ST11	399.82	0.837	0.066	0.000	0.000	0.046
ST01	17.12	0.950	0.000	0.000	0.000	0.001
ST02	40.74	0.737	0.022	0.000	0.000	0.031
ST03	63.46	0.615	0.441	0.000	0.000	0.066
ST04	76.38	0.704	0.141	0.000	0.000	0.071
ST23	8.105E+03	0.646	0.086	0.000	0.000	0.034
ST24	362.82	1.000	0.263	0.000	0.000	0.033
ST05	96.77	0.698	0.410	0.000	0.000	0.053
ST06	442.41	0.817	0.752	0.000	0.000	0.092
ST07	112.88	0.975	0.474	0.000	0.000	0.058
ET02	282.71	0.493	1.000	0.000	0.000	0.121
ET01	102.46	0.993	0.047	0.000	0.000	0.006
ST14	3535.81	1.000	0.060	0.000	0.000	0.019
ET05	48.88	0.576	1.000	0.000	0.000	0.121
LAWV	1.39E+06	1.000	0.000	0.000	0.000	0.009
ST18	89.58	1.000	0.070	0.000	0.000	0.010
NR07E	2.95E+05	0.138	0.000	0.000	0.000	0.015

Notes:

[a] All total SOFs are rounded off by 0.05% (e.g., most radium and uranium pathway values show up as zero).

The precent increase in the computed total SOF by DU and pathway for the time-window-based inventory limits versus using dose history time profiles is presented in Table 8-15. The comparison indicates that the time-window-based inventory limits are pessimistically leaning for the majority of DUs as highlighted by orange shading.

Table 8-15. Percent Increase in Estimated Total Sum-of-Fractions by Disposal Unit When Time-Windowing-Based Approach is Employed

DU	Total Projected Inventory at Closure (Ci)	Percentage Based on Computed Maximum Total SOF Along 100-meter POA [a]				
		Beta-Gamma	Gross-Alpha	Radium	Uranium	All-Pathways
ET07	286.66	20.3%	0.0%	5.7%	0.0%	0.2%
ET08	379.60	50.7%	0.0%	9.0%	0.0%	0.2%
ET09	414.06	63.3%	0.0%	11.4%	0.0%	0.1%
ET03	324.78	1.8%	0.0%	NA	0.0%	0.4%
ET04	544.11	30.6%	0.4%	0.0%	0.0%	20.7%
NR26E	5.22E+07	7.6%	0.0%	NA	0.0%	1.2%
ST08	123.63	3.8%	0.2%	0.0%	0.0%	77.5%
ST09	345.93	24.3%	0.0%	0.0%	0.0%	21.7%
ST10	416.52	16.9%	0.7%	0.0%	0.0%	30.1%
ILV	1.41E+07	0.0%	NA	NA	NA	0.0%
ST11	399.82	19.5%	0.3%	0.0%	0.0%	20.7%
ST01	17.12	0.0%	0.0%	NA	0.0%	21.7%
ST02	40.74	28.8%	0.1%	0.0%	0.0%	13.0%
ST03	63.46	54.4%	0.1%	0.0%	0.0%	53.2%
ST04	76.38	34.9%	0.0%	0.0%	0.0%	17.0%
ST23	8.105E+03	54.8%	0.0%	0.0%	0.0%	42.8%
ST24	362.82	0.0%	0.0%	0.0%	0.0%	5.7%
ST05	96.77	36.0%	0.0%	0.0%	0.0%	8.4%
ST06	442.41	22.3%	0.0%	0.0%	0.0%	2.4%
ST07	112.88	2.6%	0.0%	0.0%	0.0%	1.3%
ET02	282.71	97.1%	0.0%	0.0%	0.0%	0.2%
ET01	102.46	0.7%	0.0%	0.0%	0.0%	9.0%
ST14	3535.81	0.0%	0.0%	0.0%	0.0%	5.1%
ET05	48.88	21.1%	0.0%	0.0%	0.0%	0.1%
LAWV	1.39E+06	0.0%	NA	NA	NA	0.0%
ST18	89.58	0.0%	0.0%	0.0%	0.0%	19.1%
NR07E	2.95E+05	0.0%	0.0%	NA	NA	0.0%

Notes:

Orange shading: Total SOF based on time-windowing inventory limits is greater than total SOF based on dose history time profiles.

[a] Values shown are the percent increase in total SOF for each DU when the time-based windowing limits are compared to the values obtained based on the 1-year time-step dose history profiles.

The following observations are made based on Table 8-13 through Table 8-15:

- Total SOFs for the radium and uranium pathways are negligible when compared to other GW pathways.
- Total SOF for the beta-gamma pathway dominates for LAWV, ILV, NR07E, and NR26E.
- Total SOF for either the beta-gamma or gross-alpha pathway dominates for STs and ETs.
- Total SOFs for all-pathways are significantly lower than values for the beta-gamma pathway.

The ratio of total SOF for the beta-gamma pathway to total SOF for all-pathways (i.e., SOF-BG / SOF-AP ratio) is listed by reference DU-type in Table 8-16.

Table 8-16. Ratio of Total Sum-of-Fractions for Beta-Gamma Pathway to All-Pathways by Reference DU-Type

Reference DU-Type (Avg)	Basis	
	Dose History Time Profiles	Time Windows
Overall	79.8	69.2
Trench	83.6	71.2
LAWV and ILV	106.6	105.7
NRCDAG and NRCDAS	9.7	10.0

In summary, the two dominant GW pathways of interest are beta-gamma and gross-alpha.

The next two sections discuss results for ET04 and ST01. These two example DUs reflect the general behavior of the majority of DUs as follows:

- ET04 is a future ET where a capacity reduction is observed with the time-windowing approach.
- ST01 is a closed ST where no capacity reduction is observed.

A complete set of dose history time profiles is provided in Appendix H, Section H.1.5.

8.3.7.1. Sum-of-Fractions Comparison for ET04

For future trench ET04, the time-window-based approach yields a peak beta-gamma dose that is ~31% higher than the actual dose history time profile results as shown in Table 8-15. Maximum total SOFs for ET04 are listed for the two methods in Table 8-13 and Table 8-14. To illustrate how the SOFs are computed, the dose history time profile for ET04's beta-gamma pathway is shown in Figure 8-14 (semi-log plot) and Figure 8-15 (linear plot). Similar plots are provided in Appendix H, Section H.1.5, for all DUs, including other significant GW pathways of interest.

The non-zero dose contributions are the result of future disposals only (544.11 Ci total future inventory). Using the time-windowing approach, this future inventory yields a SOF of 1.0 at the 100-meter POA. In Figure 8-14 and Figure 8-15, only contributors whose peak dose exceeds 1% of the 4 mrem yr^{-1} PO are shown. These include H-3, I-129, Ni-63, Sr-90, Tc-99, and Total.

Three beta-gamma time windows, which apply for all STs and ETs, are also highlighted:

- BG1 - Year 0 to Year 171
- BG2 – Year 171 to Year 1,000
- BG3 – Year 1,000 to Year 1,171

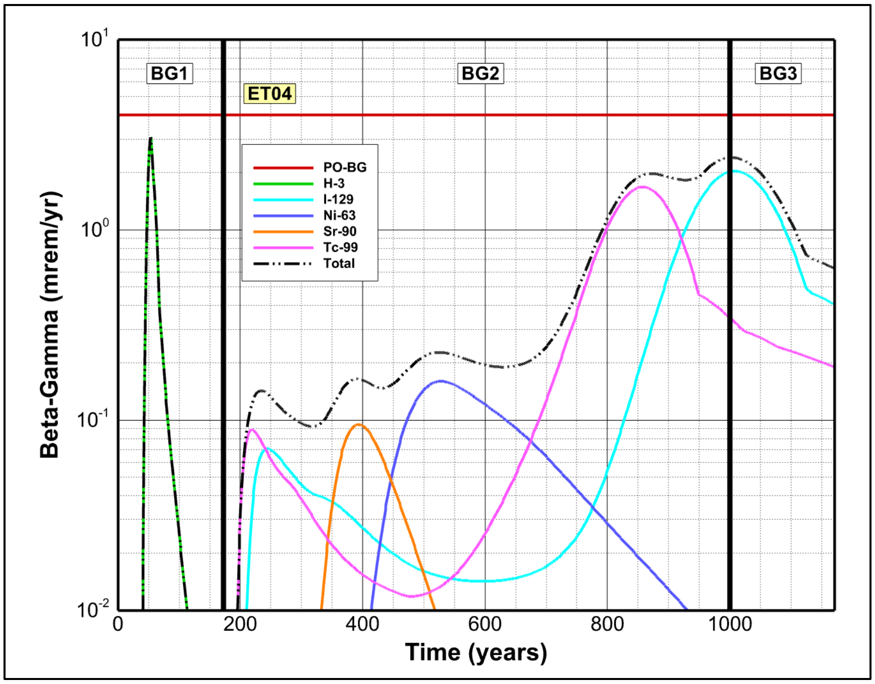


Figure 8-14. Maximum Groundwater Beta-Gamma Dose at 100-meter POA for ET04 (semi-log)

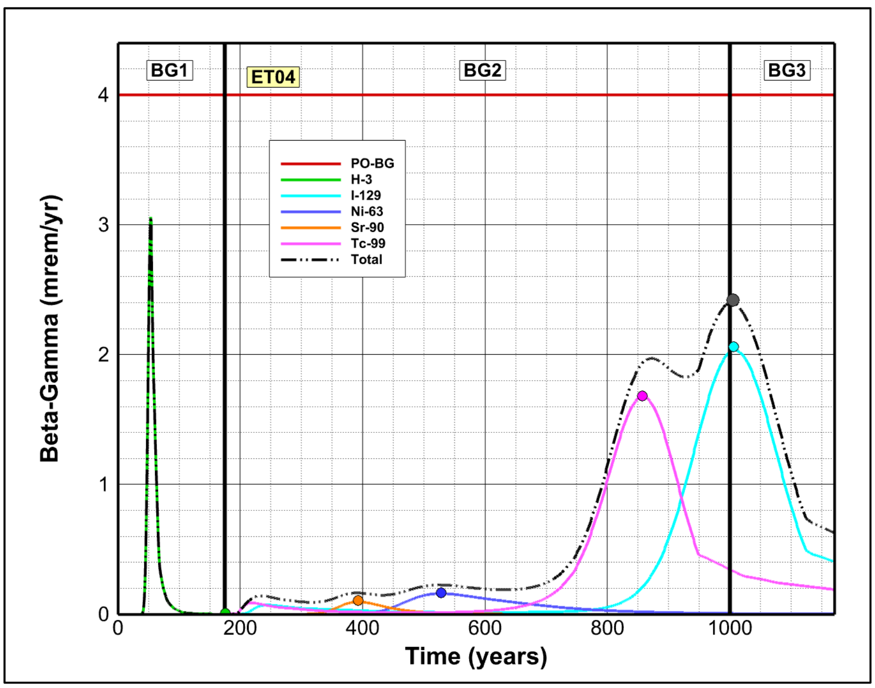


Figure 8-15. Maximum Groundwater Beta-Gamma Dose at 100-meter POA for ET04 (linear)

Only the top-five parent radionuclides contributing to beta-gamma dose are included in Figure 8-14 and Figure 8-15. Appendix H, Section H.1.5, provides graphs for the complete set of parent radionuclides. The black-dashed curve represents the arithmetic sum of beta-gamma dose at each point in time (i.e., all dose history time profiles are generated using 1-year time steps). The other curves are for the top-five contributors to beta-gamma dose whose peak values within time window BG2 are marked with a colored bullet in Figure 8-15. With a short half-life of 12.3 years, H-3 does not appear graphically within the BG2 time window because of its decay.

Table 8-17 provides a summary of beta-gamma dose (and corresponding SOF) based on the time-windowing approach and dose history time profiles. H-3, which peaks at ~53 years with a SOF=0.766 within the BG1 time window, represents the most-limiting condition for ET04 when dose history time profiles are used. However, when employing the time-windowing approach, the most-limiting condition occurs within BG2 where the total SOF equals 1.0.

Table 8-17. Comparison of Maximum Total Sum-of-Fractions for ET04 for Time-Window and Dose History Time Profile Approaches

Radionuclide	Time Window								
	BG1			BG2			BG3		
	Relative Year	Dose (mrem yr^{-1})	SOF	Relative Year	Dose (mrem yr^{-1})	SOF	Relative Year	Dose (mrem yr^{-1})	SOF
Time-Window Approach									
H-3	53	3.0622	0.7655	171	1.89E-04	0.0000	1,000	2.43E-27	0.0000
I-129	171	5.47E-08	0.0000	1,000	2.0210	0.5053	1,008	2.0350	0.5088
Ni-63	171	1.15E-47	0.0000	528	0.1597	0.0399	1,000	0.0058	0.0014
Sr-90	171	7.58E-36	0.0000	393	0.0947	0.0237	1,000	6.25E-08	0.0000
Tc-99	171	0.0003	0.0001	858	1.6793	0.4198	1,000	0.3443	0.0861
Remaining	--	6.20E-15	0.0000	--	0.0450	0.0112	--	0.0317	0.0079
Total SOF	**BG1**	**3.0625**	**0.7656**	**BG2**	**4.0000**	**1.0000**	**BG3**	**2.4169**	**0.6042**
Dose History Time Profiles									
Total SOF	**53**	**3.0622**	**0.7655**	**1,000**	**2.3981**	**0.5995**	**1,003**	**2.3999**	**0.6000**

Note: Maximum total SOF shaded in orange.

For ET04, the use of only three beta-gamma time windows results in an ~31% reduction in potential disposal capacity. The reduced capacity can be retrieved if additional time windows are used.

8.3.7.2. Sum-of-Fractions Comparison for ST01

For closed trench ST01, the time-window-based approach yields a maximum total SOF that is approximately equal to the actual dose history time profile results as shown in Table 8-15. Maximum total SOFs for ST01 are listed for the two methods in Table 8-13 and Table 8-14. To illustrate how the SOFs are computed, the dose history time profile for ST01's beta-gamma pathway is shown in Figure 8-16 (semi-log plot) and Figure 8-17 (linear plot). The non-zero dose contributions are from existing disposals only (17.12 Ci total inventory). ST01's PIF has been adjusted to yield a final maximum total SOF of 0.95, which is the current SWM administrative limit. In Figure 8-16 and Figure 8-17, only contributors whose peak dose exceeds 1% of the 4 mrem yr^{-1} PO are shown. These include H-3F, H-3, I-129, I-129J, and Total.

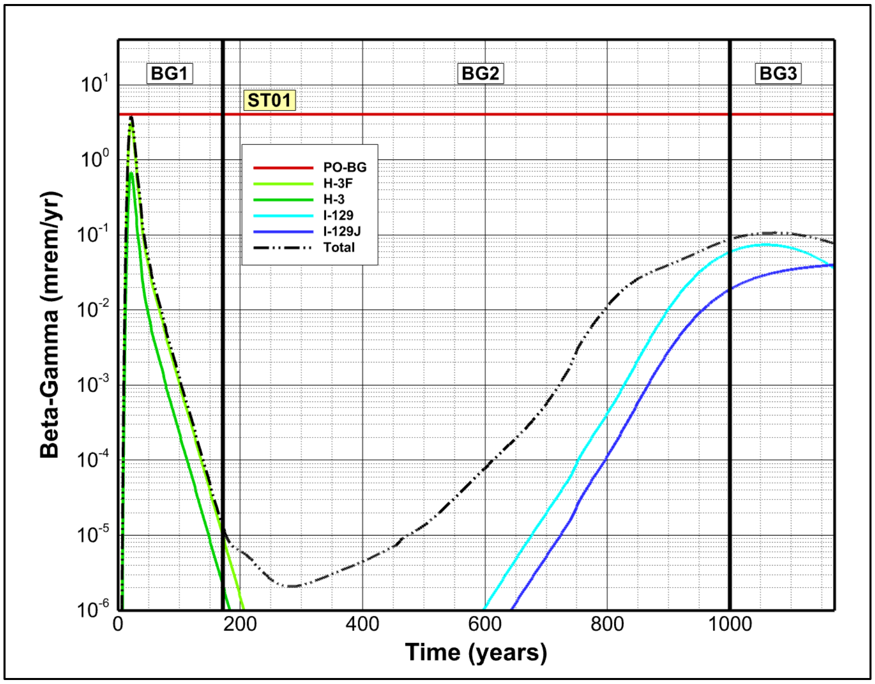


Figure 8-16. Maximum Groundwater Beta-Gamma Dose at 100-meter POA for ST01 (semi-log)

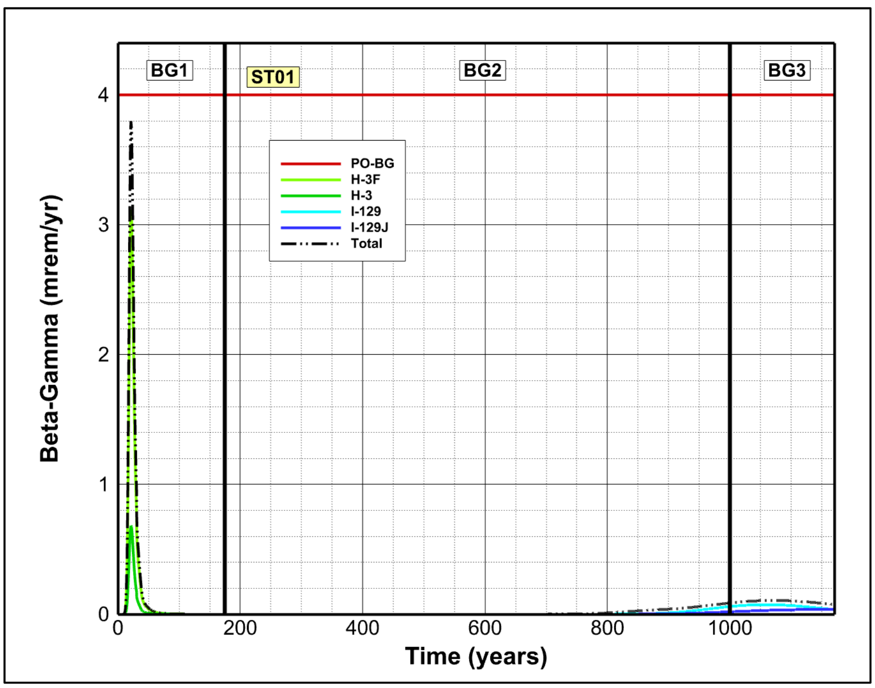


Figure 8-17. Maximum Groundwater Beta-Gamma Dose at 100-meter POA for ST01 (linear)

Only the top-four parent radionuclides contributing to beta-gamma dose are included in Figure 8-16 and Figure 8-17. Appendix H, Section H.1.5, provides graphs for the complete set of parent radionuclides. The black-dashed curve represents the arithmetic sum of beta-gamma dose at each point in time. SWF H-3F and generic waste form H-3 contribute 82% and 18% of the beta-gamma peak dose in the BG1 time window, respectively. I-129 and SWF I-129J contribute 56% and 18% of the beta-gamma peak dose in the BG2 time window, respectively. Their contributions in the BG3 time window are 60% and 32%, respectively. H-3F and H-3 do not contribute to the BG2 and BG3 time windows because of their short half-life of 12.3 years.

Table 8-18 provides a summary of beta-gamma dose (and corresponding SOF) based on the time-windowing approach and dose history time profiles. H-3F and H-3, which peak at ~21 years with a SOF=0.950 within the BG1 time window, represents the most-limiting condition for ST01 when dose history time profiles are used. When employing the time-windowing approach for ST01, the most-limiting condition is consistent with the dose history time profiles.

Table 8-18. Comparison of Maximum Total SOF for ST01 for Time-Window and Dose History Time Profile Approaches

Radionuclide	Time Window								
	BG1			BG2			BG3		
	Relative Year	Dose (mrem yr^{-1})	SOF	Relative Year	Dose (mrem yr^{-1})	SOF	Relative Year	Dose (mrem yr^{-1})	SOF
Time-Window Approach									
H-3F	21	3.1160	0.779	171	1.00E-05	0.0000	1,000	3.63E-28	0.0000
H-3	21	0.6826	0.171	171	2.19E-06	0.0000	1,000	7.96E-29	0.0000
I-129	171	1.44E-10	0.000	1,000	0.0591	0.0148	1,059	0.0738	0.0184
I-129J	171	3.69E-11	0.000	1,000	0.0188	0.0047	1,171	0.0398	0.0099
Remaining	--	1.07E-06	0.000	--	0.0271	0.0068	--	9.43E-03	0.0024
Total SOF	**BG1**	**3.7986**	**0.950**	**BG2**	**0.1049**	**0.0262**	**BG3**	**0.1230**	**0.0307**
Dose History Time Profiles									
Total SOF	**21**	**3.7986**	**0.950**	**1,000**	**0.0872**	**0.0218**	**1,073**	**0.1066**	**0.0266**

Note: Maximum total SOF shaded in orange.

For ST01, the use of only three beta-gamma time windows does not result in a reduction in potential disposal capacity. Little to no gain is achieved by increasing the number of time windows.

For every DU of interest, Appendix H, Section H.1.5, provides linear and semi-log dose history time profiles for all GW pathways making a significant contribution to dose.

8.3.8. Comparison to Prior Performance Assessment Results

In this section, PA2022 final inventory limits for the GW pathways are compared to limits derived in PA2008 and subsequent SAs and UDQEs. More detail is provided in Appendix H, Section H.6. The PORFLOW VZ and aquifer flow and transport models are changed since PA2008 and the subsequent SAs and UDQEs. Some changes are significant, which has resulted in significant shifts in estimated inventory limits. In general, prior modeling efforts are more pessimistically leaning than those in this PA; however, some aspects of the PA2022 models are more pessimistically leaning (e.g., a more robust PIF method in this PA addresses weaknesses in prior PIF analyses). Key differences in inventory limits are discussed below and in Appendix H, Section H.6, for each reference DU-type. An overall interpretation is also provided.

8.3.8.1. Slit and Engineered Trenches

Updated and improved datasets, a revised GSA flow model, progression in ELLWF operations, and numerous SAs, UDQEs, and technical investigations have jointly provided new insights from which inputs and assumptions have been derived in developing the PA2022 updated conceptual model for STs and ETs. The intent is to incorporate inputs and assumptions that remove unnecessary pessimistic conservatism (e.g., water-table depth that is half the measured distance) and capture the reality of ELLWF's operations (e.g., spatial extent of operational, interim, and final closure covers), while also providing SWM the flexibility necessary for future facility operations. For some radionuclide species and DU locations, the revised conceptual model for STs and ETs has led to substantial differences in the SOFs. Therefore, to ensure that the discrepancy between PA2022 and PA2008 is explainable and reasonable, relevant changes to the conceptual models and the key impacts on SOFs are summarized as follows:

- In some PA2022 cases, placement of operational covers occurs later based on the 2008 SA by Collard and Hamm (2008). This SA explored placement of operational covers at 5, 10, and 15 years after operational closure. In most PA2022 cases, operational covers are placed over STs four years after the last projected waste package and over ETs that closed before 2065.
- A more specific operational timeline is used for each DU in PA2022 versus PA2008.
- Intact infiltration rates in PA2022 are lower during interim closure and the initial period of final closure.
- In PA2008, 10% subsidence was applied uniformly over all DUs. In PA2022, subsidence potentials no greater than 2% are allowed.
- The blending scheme for subsidence also differs between the two PAs. The PA2022 blending scheme is more representative because subsidence impacts only a small percentage of the waste zone and the scheme captures the geometric effects of hole placement in three locations. On the other hand, the PA2008 blending scheme impacted the entire waste zone, did not capture nonlinearities in the 2-D VZ models, and blended fluxes to the water table rather than blending the representative cases as is done in PA2022.
- Infiltration rates for Case11 in PA2008 differ from infiltration rates for Case11a, Case11b, and Case11c in PA2022 as shown in Figure 8-18.
    - The infiltration rate for the 0.54% subsidence scenario is four-times higher than in PA2008 in the worst-case hole location, and about 75% higher in the median-case hole location (i.e., subsidence region at the midpoint). However, the hole is spatially localized in the 3-D VZ model, which leaves the remainder of the waste zone effectively intact.
    - Infiltration rates for all other PA2022 percent-subsidence scenarios are comparable to PA2008 infiltration rates in the worst cases or lower than PA2008 infiltration rates in other cases.
- Depth to the water table in PA2008 is 55 ft bgs. PA2022 considers hydrostratigraphic groupings which increases depth to the water table in many locations. Longer travel

distances to the water table allow for more decay to occur and/or for the operational cover(s) to be installed.

- In the PA2008 VZ model , no clay layer is modeled beneath the waste zone. The PA2002 hydrostratigraphic groupings, on the other hand, include a clay layer beneath the waste zone. This increases travel time, thereby allowing more time for decay and/or installation of operational covers.

Overall, the net impact of the above modeling improvements is an increase in inventory limits. A summary of changes between PA2008 and PA2022 for individual trenches is given in Appendix H, Table H-105.

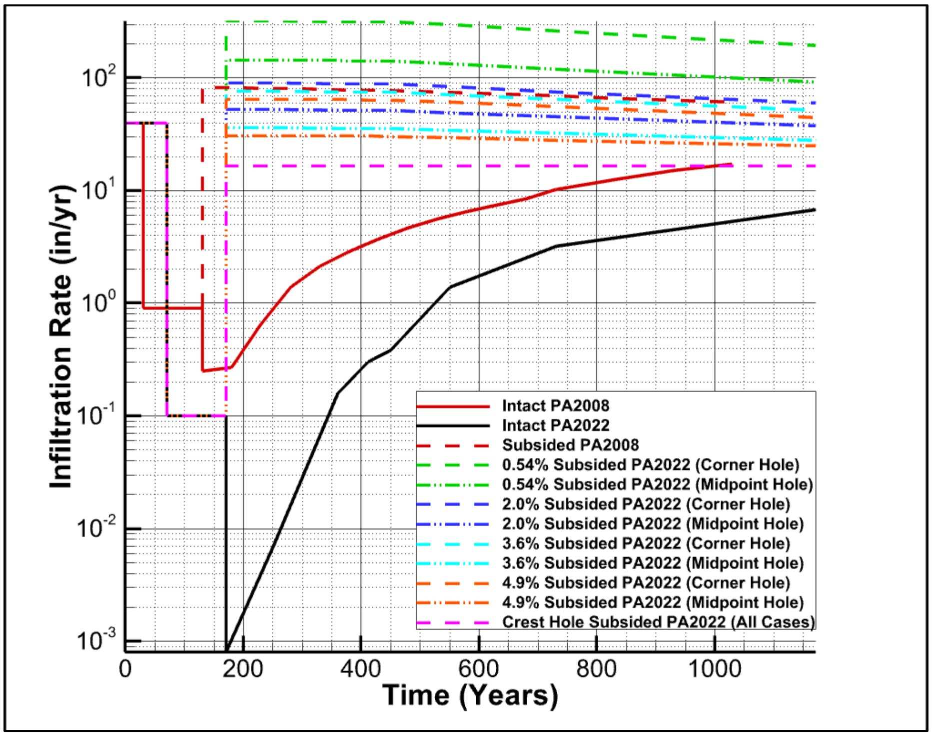


Figure 8-18. Comparison of Trench Infiltration Rates used in PA2008 and PA2022

8.3.8.2. Low-Activity Waste Vault and Intermediate-Level Vault

The LAWV and ILV PA2022 models utilize a different conceptual model of concrete cracking and degradation than in PA2008. Compared to PA2008, the PA2022 models result in lower inventory limits. Based on the additional testing and evaluation described below, there is no reason to modify the models or change the PA2022 conclusions.

Two significant reference values can be used to compare model performance: (1) maximum flux to the water table and (2) maximum concentration at the 100-meter POA. Flux to the water table depends on the VZ flow and transport model while the 100-meter POA concentration also includes the effects of aquifer flow and transport. For both vaults in PA2022, the I-129 GW beta-gamma inventory limit is the most-controlling disposal limit. Table 8-19 includes the two reference values above as well as the preliminary beta-gamma inventory limits for the LAWV and ILV in PA2008 and PA2022. For the ILV, the maximum flux to the water table occurs after the GW compliance period (Year 0 to Year 1,171). As shown later, the ILV peak flux during the compliance period for PA2008 is about 18% of the PA2022 peak flux. Peak concentrations at the 100-meter POA in Table 8-19 occur within the compliance period and were used to compute inventory limits. The results demonstrate consistent performance of the LAWV and ILV models with both resulting in PA2022 limits that are about half the PA2008 values.

Table 8-19. PA2008 and PA2022 Peak Flux to Water Table, Peak 100-meter POA Concentration, and Preliminary Inventory Limit for I-129 in Low-Activity Waste and Intermediate-Level Vaults

Metric	LAWV			ILV		
	PA2022	PA2008	Ratio	PA2022	PA2008	Ratio
Peak Flux to Water Table (Ci yr^{-1} Ci^{-1}) [VZ Model]	6.98E-03	2.74E-03	2.55	5.19E-03	4.46E-03	1.16
Relative Year	1,099	464	--	1,241	1,996	--
Peak 100-meter POA Concentration (pCi L^{-1} Ci^{-1}) [Aquifer Model]	4.37E+02	2.13E+02	2.05	9.62E+01	4.68E+01	2.05
Relative Year	1,171	451	--	1,171	658	--
I-129 mrem pCi^{-1}	5.48E-03		--	5.48E-03		--
I-129 mrem L^{-1} Ci^{-1}	2.39E+00	1.16E+00	2.05	5.27E-01	2.56E-01	2.05
Water Ingestion (L yr^{-1})	730.5		--	730.5		--
I-129 mrem yr^{-1} Ci^{-1} [Dose Model]	1.75E+03	8.51E+02	2.05	3.85E+02	1.87E+02	2.05
Preliminary Disposal Limit (Ci) [Limits Model] (4 mrem yr^{-1} maximum dose)	2.29E-03	4.70E-03	0.49	1.04E-02	2.14E-02	0.49

Notes:
Line shading is to distinguish rows common to individual metrics.
Ratio = PA2022/PA2008

Three potential sources of PA modeling differences are investigated for the LAWV and ILV: (1) K_d, (2) infiltration, and (3) treatment of vault concrete cracking and degradation. The results of these investigations are discussed in the three subsections below. Note that differences in aquifer modeling are not quantified as part of the additional model investigations.

Both PAs use similar 2-D VZ models, although the PA2022 calculation uses a finer mesh in both the VZ and aquifer models. Differences in flux to the water table between the two calculations are discussed in separate reports for the LAWV (Smith, 2021b) and ILV (Smith, 2021a).

8.3.8.2.1. K_d Values

Radionuclides modeled in the LAWV and ILV are nearly identical. Table 8-20 lists K_d values used in PA2008 (Kaplan, 2007a) for those radionuclides appearing in both PA2008 and PA2022. Table 8-21 lists the K_d values employed in PA2022 (Kaplan, 2016b) for the same radionuclides. K_d values for reducing cement are utilized in cementitious materials while oxidizing cement K_d values are selected for the ILV waste zone only. The majority of the K_d values have increased or remained the same since PA2008. K_d values for C-14 and Sr-90 in concrete have increased substantially. For I-129, K_d in soils increased while K_d in concrete decreased. Compared to the

PA2008 model, I-129 will undergo faster transport through vault concrete but slower transport through soil regions in the PA2022 model.

Table 8-20. PA2008 K_d Values

Element	K_d (mL g^{-1})						
	Sandy Soil	Clayey Soil	Reducing Cement Stage I	Reducing Cement Stage II	Reducing Cement Stage III	Oxidizing Cement Stage I	Oxidizing Cement Stage II
Ac	1,100	8,500	5,000	5,000	500	5,000	5,000
Am	1,100	8,500	5,000	5,000	500	5,000	5,000
C	0	0	20	10	0	20	10
Cf	1,100	8,500	5,000	5,000	500	5,000	5,000
Cl	0	0	0.8	2	0	0.8	2
Cm	1,100	8,500	5,000	5,000	500	5,000	5,000
Cs	50	250	2	4	2	2	4
H	0	0	0	0	0	0	0
I	0	0.6	8	20	0	8	20
K	50	250	2	4	2	2	4
Ni	7	30	1,000	1,000	500	1,000	1,000
Np	0.6	35	2,000	2,000	200	2,000	2,000
Pa	0.6	35	2,000	2,000	200	2,000	2,000
Pb	2,000	5,000	500	500	250	500	500
Pu	270	5,900	5,000	5,000	500	5,000	5,000
Ra	5	17	100	100	70	100	100
Sr	5	17	1	1	0.8	1	1
Tc	0.1	0.2	5,000	5,000	5,000	0	0
Th	900	2,000	5,000	5,000	500	5,000	5,000
U	200	300	5,000	5,000	5,000	1,000	1,000

The "CemLeach" (cement leachate) values in Table 8-21 are applied in the backfill immediately surrounding the below-ground portion of the ILV because the ILV is grouted with CLSM as cells are filled. As a result, the surrounding soil will be most susceptible to the effects from cement leaching. These enhanced $K_{d\ CemLeach}$ values were not used in PA2008 and are not utilized in any other LAWV or ILV soil region in the PA2022 models. The $K_{d\ CemLeach}$ values are typically greater than the K_d values for soil. However, for I-129, $K_{d\ CemLeach}$ values are only 10% of the soil values, which will enhance I-129 transport through the ILV backfill region.

Table 8-21. PA2022 K_d Values

Element	K_d (mL g^{-1})								
	Sandy Soil	Clayey Soil	Sandy Soil CemLeach	Clayey Soil CemLeach	Reducing Cement Stage I	Reducing Cement Stage II	Reducing Cement Stage III	Oxidizing Cement Stage I	Oxidizing Cement Stage II
Ac	1,100	8,500	1,650	12,750	7,000	7,000	1,000	6,000	6,000
Am	1,100	8,500	1,650	12,750	7,000	7,000	1,000	6,000	6,000
C	1	30	5.0	150	2,000	5,000	50	2,000	5,000
Cf	1,100	8,500	1,650	12,750	7,000	7,000	1,000	6,000	6,000
Cl	1	8	0.1	0.8	0	10	1	0	10
Cm	1,100	8,500	1,650	12,750	7,000	7,000	1,000	6,000	6,000
Cs	10	50	10.0	50.0	2	20	10	2	20
H	0	0	0	0	0	0	0	0	0
I	1	3	0.1	0.3	0	2	0	8	10
K	5	25	5.0	25.0	2	20	10	2	20
Ni	7	30	22.4	96.0	65	400	400	65	400
Np	3	9	4.5	13.5	10,000	10,000	5,000	10,000	10,000
Pa	3	9	4.5	13.5	10,000	10,000	5,000	10,000	10,000
Pb	2,000	5,000	6,400	16,000	5,000	5,000	1,000	300	300
Pu	650	6,000	1,300	12,000	10,000	10,000	2,000	10,000	10,000
Ra	25	180	75	540	6,000	6,000	600	200	100
Sr	5	17	15	51	1,000	1,000	100	90	15
Tc	0.6	1.8	0.06	0.18	1,000	1,000	1,000	0.8	0.8
Th	900	2,000	1,800	4,000	10,000	10,000	2,000	10,000	10,000
U	300	400	900	1,200	5,000	5,000	5,000	1,000	5,000

Notes:

CemLeach K_d values are shaded in gray.

K_d values that have increased and decreased relative to PA2008 are shaded in orange and green, respectively.

K_d values that are unchanged relative to PA2008 are unshaded.

8.3.8.2.2. Infiltration

Figure 8-19 displays HELP-model-calculated infiltration rates for the LAWV and ILV as they are implemented in the PA2008 and PA2022 PORFLOW models. Time zero in the plots represents the end of ELLWF operations and the start of IC. This alignment better represents the relative infiltration curves because the assumed operational life of the ELLWF was less in PA2008 (25 years) than in PA2022 (70 years).

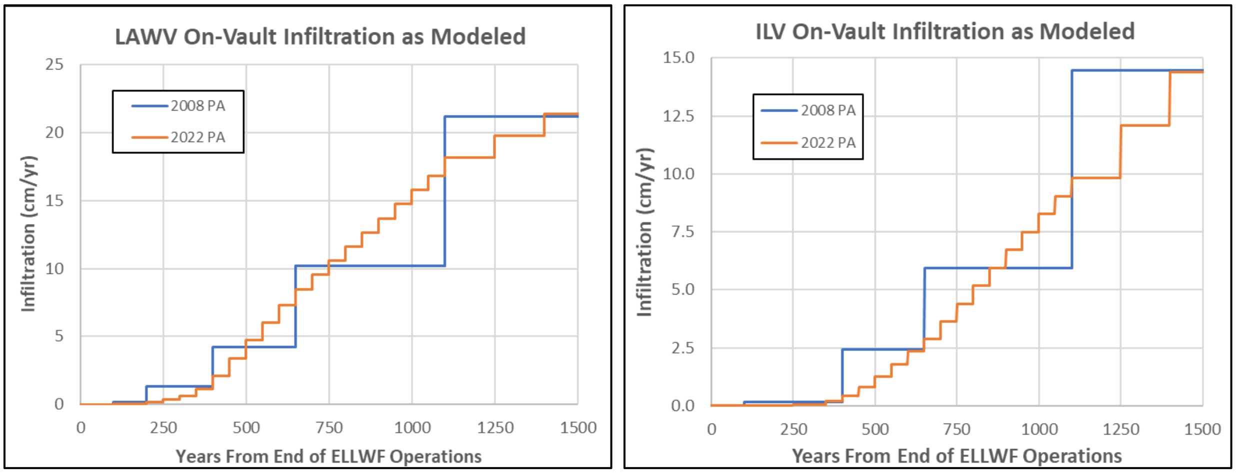


Figure 8-19. HELP Model Infiltration Rates for LAWV (left) and ILV (right) as Modeled in PA2008 and PA2022

In the PA2022 vault models, HELP model infiltration rates (Dyer, 2019b) are interpolated to intermediate time steps to better define infiltration flow as performance of the final closure cap degrades. The PA2022 closure cap design includes a coupled geomembrane-GCL barrier that will reduce infiltration over the waste disposal areas. For the LAWV, PA2022 infiltration rates are lower than the PA2008 rates for 500 years. For the ILV, PA2022 infiltration rates are lower than PA2008 rates for the first 900 years after operations cease. The all-pathways GW compliance period is Year 100 to Year 1,100 in the two graphs. For the LAWV, total infiltration over this 1,000-year period increased 23% from 6,025 cm in PA2008 to 7,440 cm in PA2022. For the ILV, total infiltration over this same increased 6% from 3,325 cm in PA2008 to 3,511 cm in PA2022. The net effect of changes in infiltration rate on the ILV appear to be relatively small. However, increased infiltration over the LAWV will potentially elute a greater mass of radionuclides from the waste zone, through the VZ, and to the water table during the compliance period.

8.3.8.2.3. Concrete Cracking and Degradation

In PA2022, the behavior of vault concrete is treated the same for both the LAWV and ILV. Concrete degradation is modeled as a gradual evolution of concrete properties from those of intact E-Area Vault Concrete to those of operational soil cover over a 500-year period beginning at the end of IC. When the final closure cap is placed over the vaults at the start of IC, non-through cracking in the vault roof and walls is modeled using a homogeneous blend of 10% gravel and 90% E-Area Vault Concrete. The vault floor is assumed to initially remain intact but then degrade to soil properties over the 500-year period. Table 8-22 shows saturated hydraulic conductivities used for the LAWV and ILV walls and floor in PA2022. Concrete regions in the vault are assumed to retain cementitious sorption properties until the vault roof collapses, at which point vault concrete hydraulic and sorption properties become those of operational soil cover. In contrast, modeling of the LAWV and ILV concrete in PA2008 was handled much differently as discussed in Sections 8.3.8.2.4 and 8.3.8.2.5 for the LAWV and ILV, respectively. Both sections compare the PA2008 model to the PA2022 model.

Table 8-22. PA2022 Vault Concrete Hydraulic Properties

Cells 1-7	Vault Roof and Walls				Vault Floor		
Time from Start of Operations	E-Area Vault Concrete (%)	Gravel (%)	Soil (%)	K_{sat} (cm s^{-1})	E-Area Vault Concrete (%)	Soil (%)	K_{sat} (cm s^{-1})
0 - 170	100	0	0	1.0E–12	100	0	1.0E–12
170 - 220	90	10	0	1.8E–11	100	0	1.0E–12
220 - 270	81	9	10	9.8E-11	90	10	7.6E-12
270 - 320	72	8	20	5.2E-10	80	20	5.6E-11
320 - 370	63	7	30	2.7E-09	70	30	4.0E-10
370 - 420	54	6	40	1.4E-08	60	40	2.7E-09
420 - 470	45	5	50	6.6E-08	50	50	1.8E-08
470 - 520	36	4	60	3.2E-07	40	60	1.1E-07
520 - 570	27	3	70	1.5E-06	30	70	6.8E-07
570 – 620	18	2	80	6.7E-06	20	80	4.1E-06
620 - 670	9	1	90	3.0E-05	10	90	2.3E-05
670 – 1,900	0	0	100	1.3E–04	0	100	1.3E–04

8.3.8.2.4. Concrete Modeling for Low-Activity Waste Vault

Various LAWV models, which differed in the degree of cement cracking and the use or non-use of CDP factors, were evaluated in PA2008. CDP factors are multipliers to K_d values intended to account for the effect of cellulosic material in the waste zone on K_d. The PA2008 LAWV model employed to set inventory limits was a narrow cracked-concrete model using CDP factors. CDP factors are no longer included in the latest geochemical properties database (Kaplan, 2016b).

As indicated in Table 8-19 for the LAWV, the PA2022 inventory limits are roughly a factor of two higher than the PA2008 values. The PA2008 conceptual model of the LAWV included separation between the vault floor and wall footers when the soil cover was placed at the start of IC. The structural analysis at the time predicted that separation would occur 50 to 100 years after the soil cover is placed at the start of IC. This separation is not included in the PA2022 model which may be the primary reason for the differing model predictions. Additionally, the PA2022 model uses a blend of 90% concrete and 10% gravel to account for initial concrete cracking when the closure cap is placed. As shown in Figure 8-20 and Figure 8-21, the PA2008 model assumes the hydraulic performance of the vault concrete is substantially degraded by the initial cracking and then further degrades in several steps. Conversely, degradation of concrete performance is more gradual in the PA2022 model.

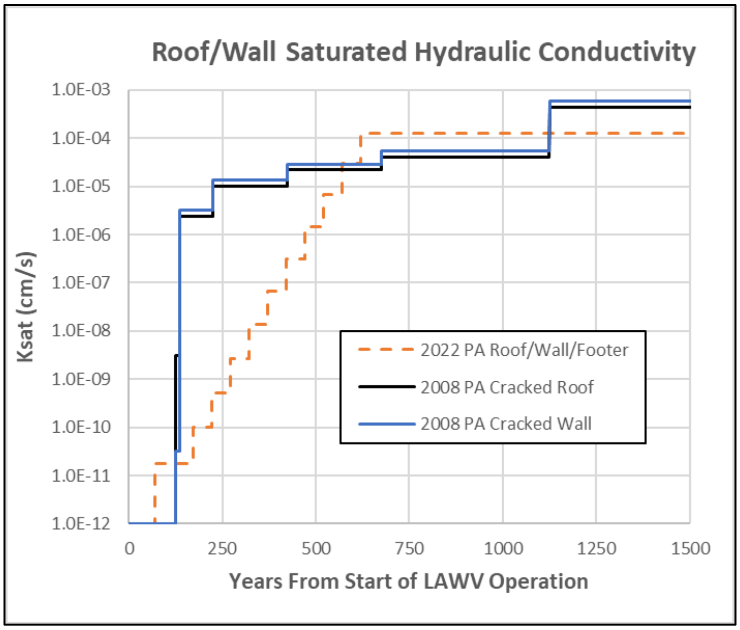


Figure 8-20. Comparison of LAWV Roof and Wall K_{sat} in PA2008 and PA2022

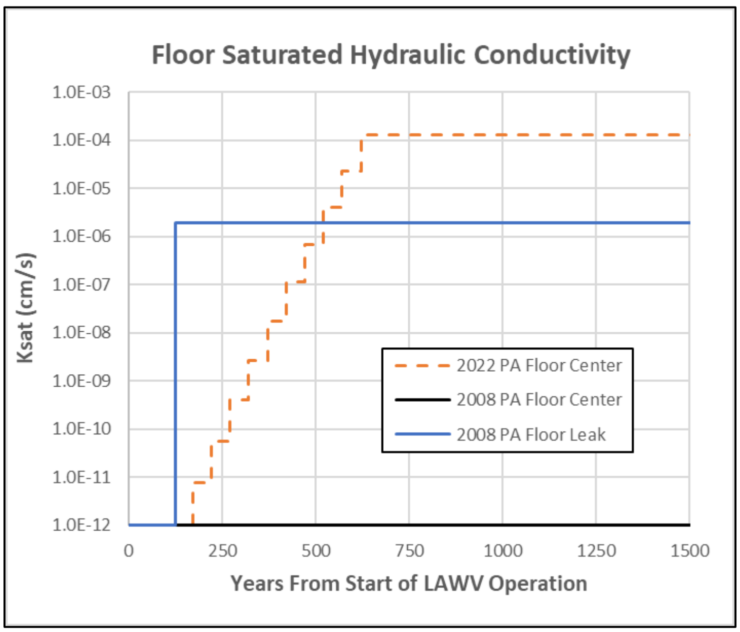


Figure 8-21. Comparison of LAWV Floor K_{sat} in PA2008 and PA2022

To evaluate the impact of separation between the LAWV floor and footers, the PA2022 model is modified to include 0.5-inch gaps in the footers where the floor is attached. Additional 0.5-inch gaps are also placed between the walls and footers. The location of these gaps is shown in Figure 8-22. As for PA2008, the gaps are assumed to have the physical and hydraulic properties of gravel and sorption properties (K_d values) of cement. The gaps create fast flow paths through the concrete.

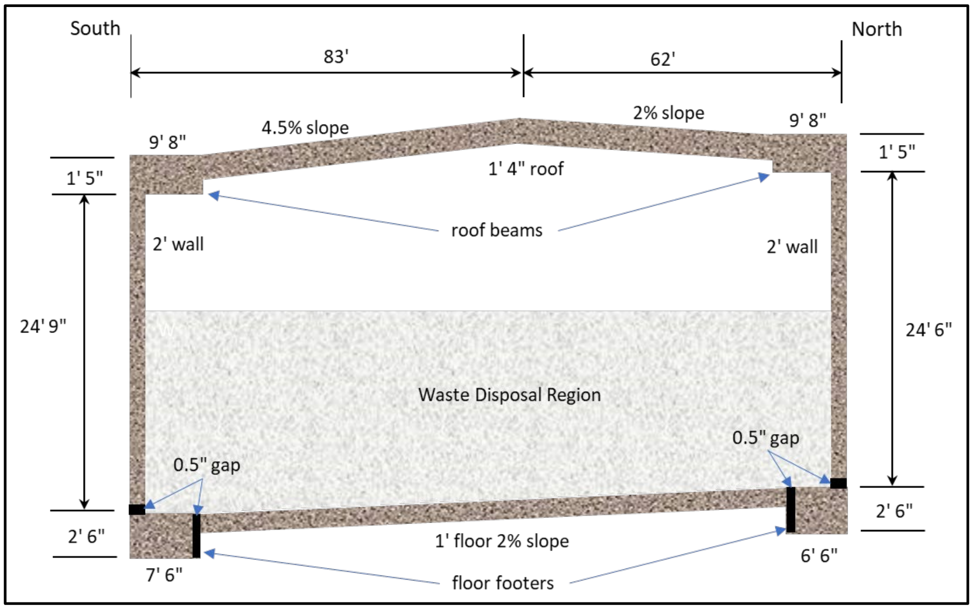


Figure 8-22. Schematic Diagram of Low-Activity Waste Vault Showing Locations of Concrete Gaps

Figure 8-23 displays I-129 flux to the water table for PA2022 with gaps (blue-dashed line labeled "cracked") and without (solid black line). Somewhat surprisingly, there is essentially no difference in transport with and without gaps. Similar results are obtained for C-14 and Cl-36 as reported in Appendix H, Section H.6.1.2. Tc-99 and U-235 are impacted by the fast flow paths, yet they both peak well beyond the compliance period (results not shown).

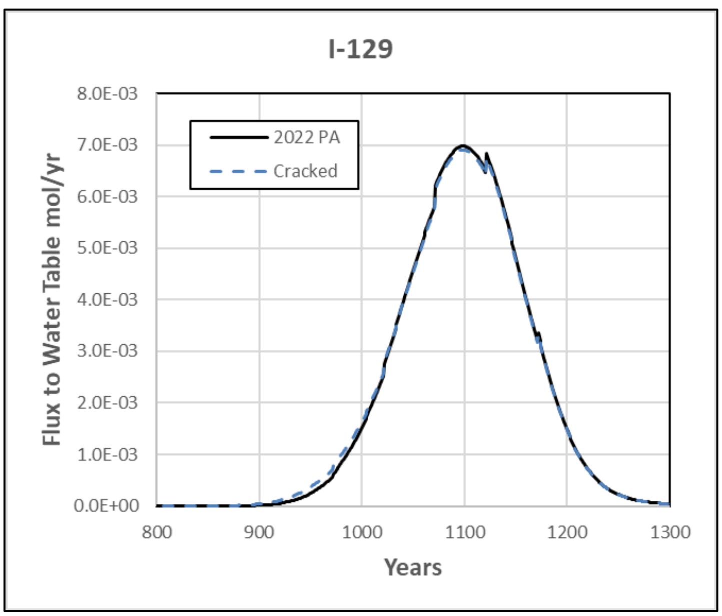


Figure 8-23. I-129 Flux to Water Table for LAWV with Floor and Wall Gaps

The LAWV VZ model with gaps is further modified to use PA2008 K_d values; I-129 results are shown in Figure 8-24. This change causes a significant difference in the flux profile with I-129 flux peaking much earlier. In a separate test not reported here, the same behavior for I-129 is observed in the ILV. Similar results for C-14 and Cl-36 are reported in Appendix H, Section H.6.1.2.

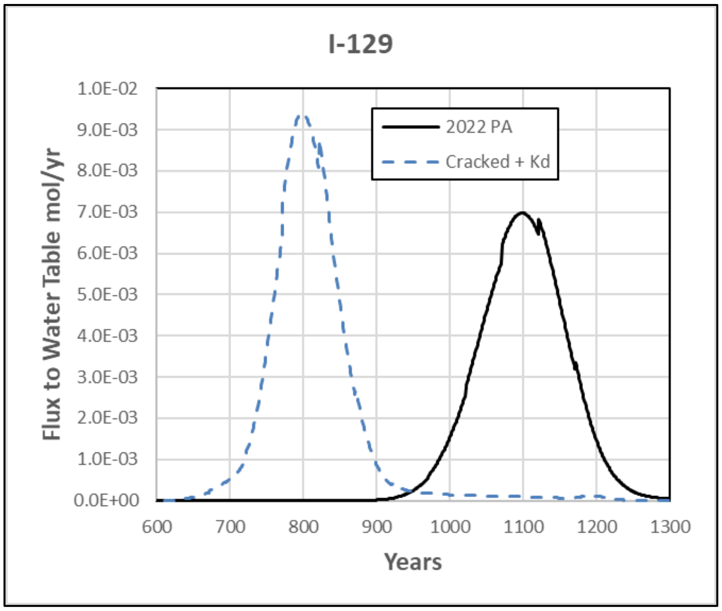


Figure 8-24. I-129 Flux to Water Table for LAWV with Floor and Wall Gaps and PA2008 K_d Values

As a final test for the LAWV, PA2008 infiltration rates are employed as the upper boundary condition together with the modified VZ model. Figure 8-25 displays the results for I-129 where the peak flux shifts approximately +50 years from Year ~800 (Figure 8-24) to Year ~850 (Figure 8-25). Results for C-14 and Cl-36, where there is little impact from the change in infiltration, are given in Appendix H, Section H.6.1.2.

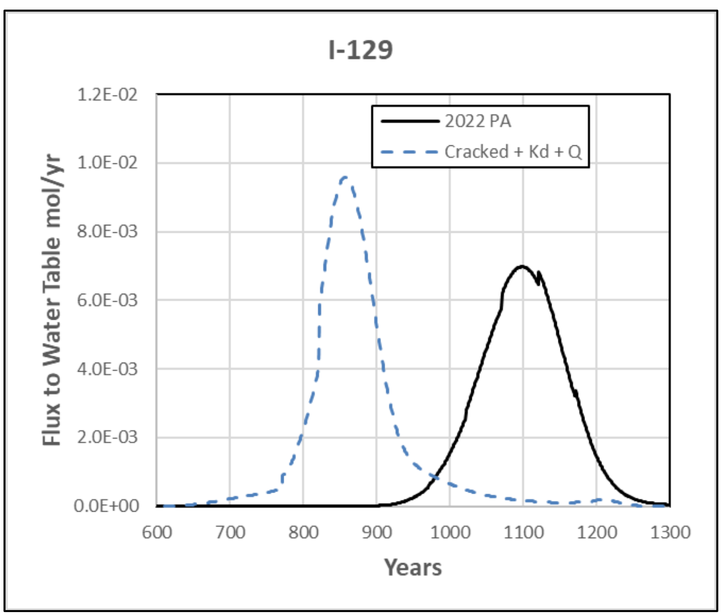


Figure 8-25. I-129 Flux to Water Table for LAWV with Floor and Wall Gaps, PA2008 K_d Values, and PA2008 Infiltration Rates (Years 600 to 1,300)

Figure 8-26 compares the I-129 flux profile from PA2008 (solid orange line) to the flux profile for the nominal PA2022 model (solid black line) and the flux profile calculated using the fully modified PA2022 model (dashed blue line). The modifications made to the PA2022 model do not entirely replicate the behavior of the PA2008 calculation. I-129 release in PA2008 begins sooner and is more gradual than in the PA2022 version (dashed blue line). The three peaks in the PA2008 flux profile coincide with the step changes in infiltration shown in Figure 8-19. Similar results comparing PA2022, modified PA2022, and PA2008 fluxes to the water table for C-14 and Cl-36 are shown in Appendix H, Section H.6.1.2. The contrasting results for the PA2008 and PA2022 models are potentially tied to the difference in concrete hydraulic conductivities displayed in Figure 8-20 and Figure 8-21, which can result in earlier release in the PA2008 model.

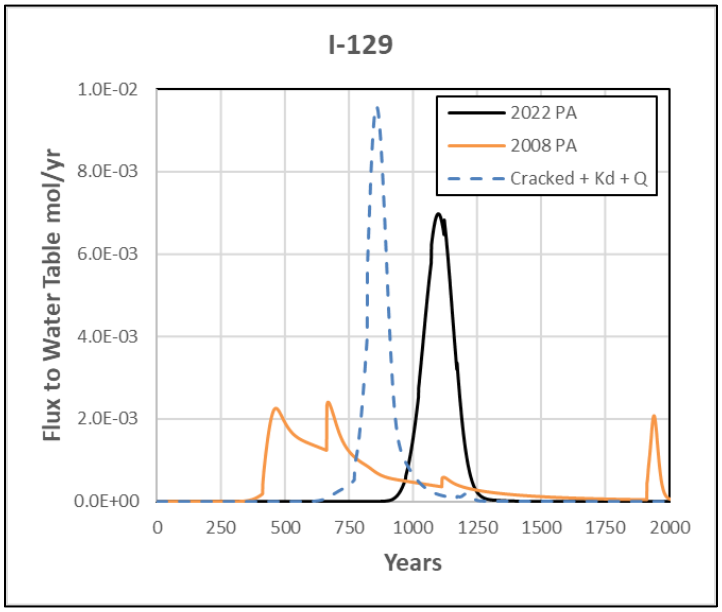


Figure 8-26. I-129 Flux to Water Table for LAWV with Floor and Wall Gaps, PA2008 K_d Values, and PA2008 Infiltration Rates (Years 0 to 2,000) Compared to PA2008 and Nominal PA2022 Model Results

8.3.8.2.5. Concrete Modeling for Intermediate-Level Vault

The wall and floor material compositions and saturated hydraulic conductivities used in PA2008 for the ILV are listed in Table 8-23. Cell 4 is the center cell of the ILNT segment of the ILV. This cell is structurally different from the other ILV cells with connection joints on both sides making it more susceptible to cracking from seismic events. The ILV structural analysis (Peregoy, 2006b) determined that the probability of Cell 4 experiencing a seismic event exceeding the design limit increased from 0 to 10% at 1,000 years. Based on this, in PA2008, concrete in Cell 4 was modeled as having gravel properties beginning 400 years after the start of IC. Because the PA2022 model degrades the concrete to soil 500 years after the end of IC, this change in concrete properties at 400 years after the start of IC is not included in the PA2022 model.

Table 8-23. PA2008 Concrete Hydraulic Properties for Intermediate-Level Vault Cells

Time from Start of IC	ILV Walls			ILV Floor		
	E-Area Vault Concrete (%)	Gravel (%)	K_{sat} (cm s^{-1})	E-Area Vault Concrete (%)	Gravel (%)	K_{sat} (cm s^{-1})
Cells 1,2,3,5, 6, and 7						
Years 0 – 1,900	100	0	1.0E–12	100	0	1.0E–12
Cell 4						
Years 0 – 400	100	0	1.0E–12	100	0	1.0E–12
Years 400 – 1,900	0	100	1.5E–01	0	100	1.5E–01

PA2008 disposal limits for the ILV were calculated by the following method:

1. Flux to the water table was calculated for deposition of 1.0 gmole in Cell 4.
2. Flux to the water table was calculated for deposition of 1.0 gmole in a typical ILV cell (one of the six cells not located in the center of the ILNT).
3. The fluxes were combined (summed) as follows: Cell 4 flux plus six times the non-center typical ILV cell flux.
4. The combined flux was input to the aquifer transport model to calculate a maximum concentration at the 100-meter POA and a preliminary inventory limit.
5. Because this preliminary limit represents burial of 7.0 gmoles of parent radionuclide, the limit was increased by a factor of seven to normalize it to a basis of 1.0 gmole disposed.

In Table 8-19, Figure 8-27, and Figure 8-28, the reported PA2008 flux and concentration have been divided by seven to place them on a basis of 1.0 gmole buried. Figure 8-27 displays I-129 flux to the water table as calculated in PA2008 for Cell 4, a typical ILV cell (Cell 1), and the combined flux from disposal of 1.0 curie. Flux from a typical ILV cell (Cell 1) peaks at about Year 2,000 but makes a negligible contribution to flux during the compliance period. Therefore, in PA2008, the flux to the water table used to determine limits was essentially 1/7 of the Cell 4 flux (solid red line in Figure 8-27). The sharp spike in PA2008 Cell 4 flux at Year 650 coincides with a change in infiltration as seen in Figure 8-19. The larger spike in flux at Year 1,900 (solid red line in Figure 8-27) occurred because the ILV roof was assumed to collapse after 1,900 years in PA2008. This is much earlier than the most probable roof collapse time of 5,770 years predicted by Peregoy (2006b) but was done to compress the timeframe for capturing slowly eluting radionuclides.

Figure 8-28 displays I-129 flux to the water table for PA2008 Cell 4, the PA2008 combined flux from a typical ILV cell plus Cell 4, and the nominal PA2022 flux. In PA2022, I-129 flux to the water table from a typical ILV cell peaks 1,241 years after the start of ILV operations, which falls between the peak flux times displayed in Figure 8-27 for PA2008 Cell 4 (Year 650; solid red line) and the PA2008 typical ILV cell (Year 1,996; solid blue line). The green vertical line in Figure 8-28 marks the end of the compliance period in Year 1,171 and demonstrates that the maximum PA2022 flux during the 1,000-year compliance period is close to 3.0E-03 gmol yr^{-1}, while the combined PA2008 flux is 18% lower at just over 5.0E-4 gmol yr^{-1} (refer to solid red line for PA2008 Cell 4 in Figure 8-28 for the reason given in the previous paragraph).

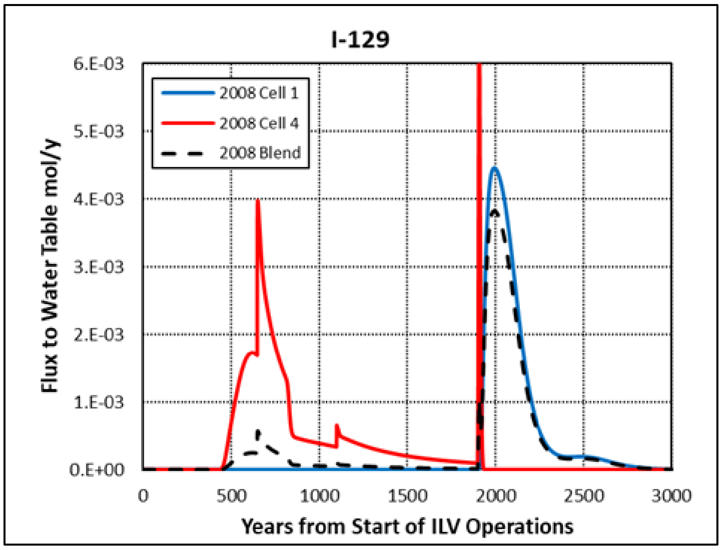


Figure 8-27. I-129 Flux to Water Table for PA2008 Typical Cell (Cell 1), Cell 4, and Combined Flux (2008 Blend) for Years 0 to 3,000 After Start of Intermediate-Level Vault Operations

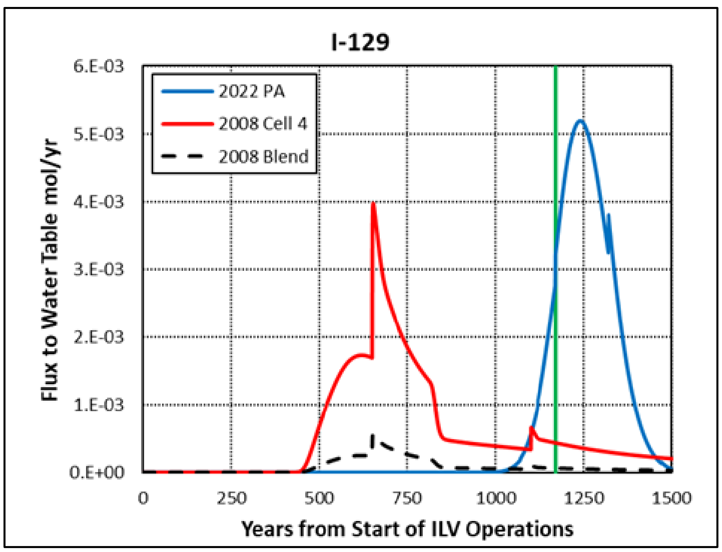


Figure 8-28. I-129 Flux to Water Table for PA2008 Cell 4, PA2008 Combined Flux (2008 Blend), and Nominal PA2022 Models for Years 0 to 1,500 After Start of Intermediate-Level Vault Operations

8.4. INADVERTENT HUMAN INTRUDER PATHWAYS

This section interprets results associated with the IHI pathways that are presented in detail in Chapter 7 and Appendix G (supporting information and key data). As indicated in Table 1-2, two specific IHI pathways are considered in this PA:

- **IHI Chronic Pathway (Chr):** Compliance period is Year 171 to Year 1,171
- **IHI Acute Pathway (Acu):** Compliance period is Year 171 to Year 1,171

Based on the IHI scenarios and exposure pathways considered, no mixing of solid waste from neighboring DUs is addressed. Inadvertent human intrusion into the ELLWF is assumed to not occur during the operational (Year 0 to Year 71) and IC (Year 71 to Year 171) periods because of the presence of facility security during these periods. Thus, inadvertent intrusion is not considered from Year 0 to Year 171.

Two key embedded conservatisms employed throughout all IHI transport analyses are as follows:

- All waste is buried at one specific point in time, which is the burial time of either the first or last package.
- GW leaching is zero throughout the entire period of performance, which implies that, once buried, no radionuclides leave or enter the waste zone other than through decay or ingrowth.

The second assumption above isolates the IHI analyses from the GW, air, and radon transport analyses.

8.4.1. Parent Radionuclides Requiring Inventory Limits

The list of parent radionuclides requiring inventory limits for the IHI pathways is based on the radionuclide screening process described in Section 2.3.7 as well as the list of SWFs in Table 8-2. A total of 111 unique parent radionuclides, which includes 29 generic waste form and 82 SWF radionuclides, are listed in Table 8-24.

Table 8-24. List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Inadvertent Human Intruder Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Generic Waste Form	29	4	2	0	0
Ag-108m	X				
Am-241	X				
Am-242m	X				
Am-243	X				
C-14	X				
Cf-249	X				
Cf-251	X				
Cm-247	X				
Cm-248	X				
Cs-137	X	X	X		
I-129	X				
K-40	X				
Nb-94	X	X			
Ni-59	X				
Ni-63	X				
Np-237	X				
Pu-239	X				
Pu-240	X				
Pu-241	X				
Ra-226	X	X	X		
Sn-126	X				
Sr-90	X	X			
Tc-99	X				
Th-229	X				
Th-230	X				
U-232	X				
U-233	X				
U-234	X				
U-236	X				
Special Waste Form	68	0	1	12	13
U-233D	X				
C-14N	X				
C-14X	X				
Cs-137T			X		
I-129C	X				
I-129D	X				
I-129E	X				
I-129F	X				
I-129G	X				
I-129H	X				
I-129I	X				
I-129J	X				
Ra-226T	X				
Th-230T	X				
C-14K	X				
I-129K	X				
Tc-99K	X				
I-129R	X				

Table 8-24 (cont'd). List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Inadvertent Human Intruder Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Special Waste Form (cont'd)					
Sr-90R	X				
Tc-99R	X				
U-234G	X				
U-236G	X				
Ag-108mH	X				
C-14H	X				
Nb-94H	X				
Ni-59H	X				
Ni-63H	X				
Tc-99H	X				
Am-241A	X				
Am-242mA	X				
Am-243A	X				
C-14A	X				
Cf-249A	X				
Cf-251A	X				
Cm-247A	X				
Cm-248A	X				
Cs-137A	X				
I-129A	X				
K-40A	X				
Nb-94A	X				
Ni-59A	X				
Ni-63A	X				
Np-237A	X				
Pu-239A	X				
Pu-240A	X				
Pu-241A	X				
Ra-226A	X				
Sn-126A	X				
Sr-90A	X				
Tc-99A	X				
U-232A	X				
U-233A	X				
U-233E (A)	X				
U-234A	X				
U-236A	X				
Am-241B	X				
C-14B	X				
Cs-137B	X				
I-129B	X				
Ni-59B	X				
Np-237B	X				
Pu-239B	X				
Pu-240B	X				
Pu-241B	X				
Sr-90B	X				
Tc-99B	X				

Table 8-24 (cont'd). List of Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Inadvertent Human Intruder Pathways for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Special Waste Form (cont'd)					
U-233B	X				
U-233E (B)	X				
U-234B	X				
Am-241S				X	X
Am-243S				X	X
Co-60S				X	X
Cs-137S				X	X
Mo-93S				X	X
Nb-93mS				X	X
Nb-94S				X	X
Ni-59S				X	X
Pu-241S				X	X
Sn-121mS					X
Sn-126S				X	X
Sr-90S				X	X
Zr-93S				X	X
Total Number Radionuclides	**97**	**4**	**3**	**12**	**13**

Notes:

[a] SWFs planned for future disposals are shaded in orange.

The list of generic waste form radionuclides in Table 8-24 for the trench reference DU-type is employed for every slit and engineered trench (15 STs and 8 ETs). However, for SWFs, Table 8-25 provides a breakdown of where the 68 SWF radionuclides disposed in trenches reside within the 23 total STs and ETs, along with the number of SWF radionuclides per DU. Note that ET06, ST17, and ST19 through ST22 are all future DUs that are not to be utilized under PA2022. Their inventory limits have been omitted from Table 8-25 and are instead listed in Appendix G because no plume interactions are required in their computations.

Table 8-25. Burial Locations of Special Waste Form Radionuclides Within Each Trench Disposal Unit Requiring an Inventory Limit for Inadvertent Human Intruder Pathways

SWF Radionuclide [a]	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST14	ST17[b]	ST18	ST19[b]	ST20[b]	ST21[b]	ST22[b]	ST23	ST24	ET01	ET02 thru ET09[b]
U-233D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C-14N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Ra-226T						X																
Th-230T						X																
C-14X									X													
U-234G		X																				
U-236G		X																				
I-129R					X																	
Sr-90R					X																	
Tc-99R					X																	
I-129C			X				X															
I-129D		X																			X	
I-129E																					X	
I-129F	X																					
I-129G		X																			X	
I-129H		X		X																	X	
I-129I		X	X	X																	X	
I-129J	X	X	X	X	X		X														X	
Am-241B								X	X	X												
C-14B								X	X	X												
Cs-137B								X	X	X												
I-129B								X	X	X												
Ni-59B								X	X	X												
Np-237B									X	X												
Pu-239B									X	X												
Pu-240B									X	X												
Pu-241B									X	X												
Sr-90B								X	X	X												
Tc-99B								X	X	X												
U-233B								X	X	X												
U-233E (B)									X	X												
U-234B									X	X												
Ag-108mH												X										
C-14H												X										
Nb-94H												X										
Ni-59H												X										
Ni-63H												X										
Tc-99H												X										
Am-241A																			X			
Am-242mA																			X			
Am-243A																			X			
C-14A																			X			
C-14K (A)																			X			
Cf-249A																			X			
Cf-251A																			X			
Cm-247A																			X			
Cm-248A																			X			
Cs-137A																			X			
I-129A																			X			
I-129K																			X			

Table 8-25 (cont'd). Burial Locations of Special Waste Form Radionuclides Within Each Trench Disposal Unit Requiring an Inventory Limit for Inadvertent Human Intruder Pathways

SWF Radionuclide [a]	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST14	ST17[b]	ST18	ST19 [b]	ST20 [b]	ST21 [b]	ST22 [b]	ST23	ST24	ET01	ET02 thru ET09 [b]
K-40A																			X			
Nb-94A																			X			
Ni-59A																			X			
Ni-63A																			X			
Np-237A																			X			
Pu-239A																			X			
Pu-240A																			X			
Pu-241A																			X			
Ra-226A																			X			
Sn-126A																			X			
Sr-90A																			X			
Tc-99A																			X			
Tc-99K																			X			
U-232A																			X			
U-233A																			X			
U-233E (A)																			X			
U-234A																			X			
U-236A																			X			
Total Number Radionuclides (68)	**4**	**9**	**5**	**5**	**6**	**4**	**4**	**10**	**17**	**16**	**2**	**8**	**2**	**2**	**2**	**2**	**2**	**2**	**31**	**1**	**7**	**1**

Notes:

[a] SWFs planned for future disposals are shaded in orange.

[b] ET06, ST17, and ST19 through ST22 are all future DUs that are not to be utilized under this PA.

8.4.2. Trigger Values

As discussed in Section 8.3.2 for the GW pathways, trigger-value radionuclides are typically radionuclides that do not have explicit CWTS inventory limits and are on a separate watch list. The DU-specific (final) trigger values associated with the IHI pathways are presented in this section.

As discussed in Section 2.3.7, radionuclides with no current inventory, but which are not eliminated during the IHI radionuclide screening process, are assigned preliminary trigger values. Because inventory limits for the IHI pathways are computed based on waste zone concentrations (i.e., buried inventory per unit volume of waste zone, μCi L^{-1}) and the waste zone volumes are DU-specific, final DU-specific trigger values for the IHI pathways must be computed using actual waste zone volumes versus the reference DU-type volumes employed in the radionuclide screening process.

The preliminary trigger values are specific to reference DU-type (see Table 2-28), and to account for DU waste volume size differences, final DU-specific trigger values are computed as follows:

$$L_{DU,i}^{trig-IHI} = \left[\frac{A_{DU}}{A_{DU-type}} \right] L_{DU-type,i}^{prelim-trig-IHI} \qquad \text{Eq. (8-9)}$$

where:

$L_{DU,i}^{trig-IHI}$	Final inventory trigger value for IHI pathway for i^{th} parent radionuclide in disposal unit *DU* (Ci)
$L_{DU\text{-}type,i}^{prelim\text{-}trig\text{-}IHI}$	Preliminary inventory trigger value for IHI pathway for i^{th} parent radionuclide in reference *DU-type* (Ci)
$A_{DU-type}$	Areal footprint for reference *DU-type* (ft^2 per 1,000)
A_{DU}	Areal footprint for disposal unit *DU* (ft^2 per 1,000)

The term in the square brackets represents the geometry factor, which is the waste zone volume ratio where the vertical height of the waste zone cancels out and only the areal footprint differences remain). The actual footprint area of each DU and its reference DU-type area are listed in Table 8-26.

The final trigger values for the IHI pathways for every DU are provided in Appendix H, Section H.5.2.

Table 8-26. Footprint Area of Waste Zone by Disposal Unit and Reference DU-Type

Reference DU-Type	DU	Waste Zone Footprint Area (ft²/1,000)
Trench (reference areal footprint = 73.6 ft²/1,000)	ST01	65.67
	ST02	65.61
	ST03	65.60
	ST04	65.60
	ST05	65.60
	ST06	65.59
	ST07	65.60
	ST08	65.60
	ST09	65.60
	ST10	59.60
	ST11	51.10
	ST14	65.60
	ST18	64.78
	ST23	65.60
	ST24	65.60
	ET01	96.84
	ET02	104.59
	ET03	80.85
	ET04	103.30
	ET05	101.70
	ET07	96.00
	ET08	96.00
	ET09	96.00
LAWV (reference areal footprint = 89.96 ft²/1,000)	LAWV	89.96
ILV (reference areal footprint = 10.48 ft²/1,000)	ILV	10.48
NRCDAG and NRCDAS (reference areal footprint = 5.88 ft²/1,000)	NR07E	5.88
	NR26E	47.69

8.4.3. Preliminary Inventory Limits and Worst-Case Preliminary Concentrations

For the IHI pathways, there is no explicit conversion from reference DU-type to preliminary inventory limits. Thus, the reference DU-type inventory limits represent the preliminary inventory limits for the IHI pathways.

As discussed in Sections 7.2 and 7.4 for each DU, the following two burial times are employed in the IHI dose calculations:

- All waste buried at the time of first package
- All waste buried at the time of last package

The worst-case brackets waste disposal within each DU as detailed in Chapter 7 and Appendix G.

8.4.3.1. Naval Reactor Component Disposal Areas

Table 8-27 highlights key differences between the PA2008 and PA2022 NRCDA analyses. The key differences between the two models are as follows:

- PA2008 did not have a VZ flow and transport model. Instead, waste was directly injected into the aquifer at the water table boundary.
- The PA2008 aquifer transport model was a simplified 1-D GoldSim® Pipe Pathway with a plume function.

Table 8-27. NRCDA Models in PA2022 and PA2008

Benchmark	PA2008	PA2022
Software	GoldSim®	PORFLOW
Vadose Zone	No explicit VZ model.	3-D flow and transport models including infiltration rates at the top boundaries that generate concentration fluxes at water table.
Aquifer Zone	1-D GoldSim® Pipe Pathway application with plume function to provide concentrations at the 100-meter POA. Velocity is chosen to represent the flow field from the GSA GW flow model.	Use refined 3-D GSA flow models and 3-D transport models that (1) employ VZ fluxes at the water table and (2) capture maximum concentrations at 100-meter POA.
Source Term	Placed in 1-D aquifer GoldSim® model.	Placed in waste zone of VZ model.
Release of Radionuclides	Generic waste form (crud): - Immediate release upon hydraulic failure (750 years after waste placement on pad). SWF (activated metal/alloy): - Release upon hydraulic failure (750 years after waste placement on pad) at the corrosion rate.	Generic waste form: - Early immediate release with placement of soil cover. - Late immediate release upon hydraulic failure (750 years after waste placement on pad). SWF (activated Zircaloy or Inconel): - Release upon hydraulic failure (750 years after waste placement on pad) at a fixed corrosion rate.

For demonstration purposes, Figure 8-29 displays PA2008 and PA2022 maximum aquifer concentrations at the 100-meter POA for the NR26E generic waste form (NRCDAG; Cases 1 and 2). For PA2022, peak concentrations within the compliance period (Year 0 to Year 1,171) are 578 pCi L^{-1} (Case 1) and 424 pCi L^{-1} (Case 2) at Year 184 and Year 1,146, respectively. Conversely, the peak concentration in PA2008 was 0.526 pCi L^{-1} at Year 780. That is, the PA2008 peak concentration is three orders of magnitude lower than the PA2022 peaks. Note that the concentrations shown in Figure 8-29 for Cases 1 and 2 are preliminary results because they do not account for plume interaction.

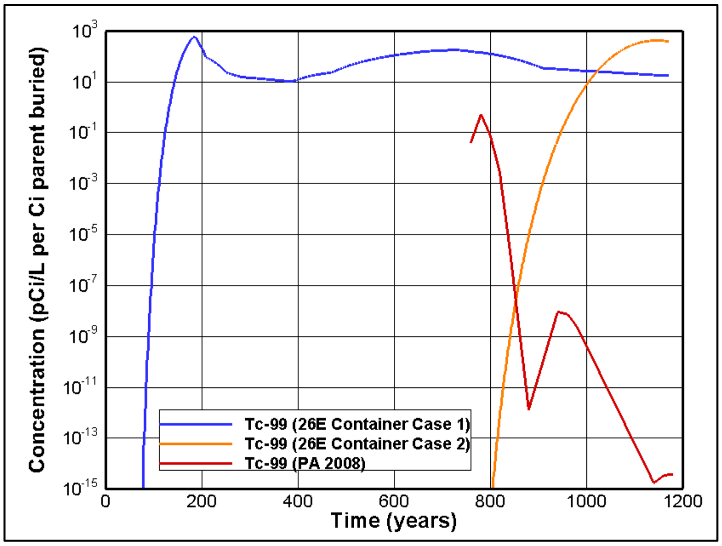


Figure 8-29. Maximum Aquifer Concentrations of Tc-99 at 100-meter POA

In summary, it is difficult to compare the current analysis results to those from PA2008 because of the vastly different modeling approaches used in the two sets of analyses.

8.4.4. Final Inventory Limits

For the IHI pathways, the conversion from preliminary to final for both inventory limits and trigger values is to account for DU footprint size only. Final inventory limits for the IHI pathways for all 33 DUs are provided in Appendix G, Section G.2. Six of the 33 DUs (ET06, ST17, ST19, ST20, ST21, and ST22) have been excluded based on activity-capacity reallocation requirements associated with GW plume interactions; however, their final inventory limits for the IHI pathways are still included in Section G.2.

8.4.5. Comparison to Prior Performance Assessment Results

For this PA, inventory limits for the IHI pathways are generally two orders of magnitude higher (i.e., lower doses) than those calculated in 2008 (WSRC, 2008). The primary reason inventory limits for the IHI pathways increased relates to how dynamic compaction of non-crushable containers is addressed. In PA2008, a no-compaction scenario was assumed. Conversely, the inventory limits presented in Chapter 7 and Appendix G in this PA assume that dynamic compaction occurs at the end of the IC period before placement of the final closure cap. The subsidence potential of the waste zone is greatly reduced by dynamic compaction at this point in time (i.e., 100 years after operational closure at the end of the IC period) and, as such, warrants consideration as the most likely scenario.

In addition, the ELLWF closure plan has been revised since 2008 and includes changes to the final closure cap design as detailed in Section 2.2.2. The IHI analysis in this PA follows the revised closure plan (Phifer et al., 2009). The key change to the final closure cap design that impacts IHI pathway modeling is the soil depth between the cover's erosion barrier and the top of the waste zone.

8.5. AIR PATHWAY

The results of the air pathway analyses are discussed in this section; the majority of which originate in Chapter 5. As listed in Table 1-2, one specific air pathway is considered but with two non-overlapping compliance periods:

- **Air Pathway (A):** Compliance period is Year 71 to Year 171; site boundary is the POA
- **Air Pathway (A):** Compliance period is Year 171 to Year 1,171; 100-meter POA applies

Both POAs involve downwind atmospheric concentrations where potential atmospheric plume mixing from neighboring DUs must be accounted for in the analyses. As discussed in Appendix H, a pessimistically leaning approach was chosen to address the atmospheric PIFs. Further details on the overall calculational strategy employed in computing the air pathway final inventory limits are provided in Appendix H, Section H.3.

Four of the key embedded pessimistically leaning conservatisms employed throughout all air transport analyses are the following modeling assumptions:

- All waste is buried at one specific point in time at the end of operations.
- No radionuclide decay occurs before burial, which is the time between radiological assessment by waste generators and actual time of burial.
- Radionuclide release from the waste zone as the result of GW transport or drilling is zero.
- Rn-222 and its daughters are addressed via the radon pathway per DOE M 435.1-1, Chg. 3 (U.S. DOE, 2021b).

The third and fourth assumptions above isolate the air pathway analyses from the GW, IHI, and radon transport analyses.

8.5.1. Parent Radionuclides Requiring Inventory Limits

The list of parent radionuclides requiring inventory limits for the air pathway is defined based upon the radionuclide screening results for the air pathway described in Section 2.3.8 and the SWFs listed in Table 8-2. A total of 18 unique parent radionuclides (three generic waste form and 15 SWF radionuclides) are included in Table 8-28.

Table 8-28. Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Air Pathway for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Generic Waste Form	2	2	3	0	1
C-14	X	X	X		X
H-3	X	X	X		
Kr-85			X		
Special Waste Form	11	0	4	2	2
C-14A	X				
C-14B	X				
C-14H	X				
C-14K	X		X		
C-14N	X				
C-14S				X	X
C-14T			X		
C-14X	X				
H-3A	X				
H-3B	X				
H-3C	X				
H-3F	X				
H-3R			X		
H-3S				X	X
H-3T			X		
H-3X	X				
Total Number Radionuclides	**13**	**2**	**7**	**2**	**3**

Notes:

[a] SWFs planned for future disposals are shaded in orange.

Radionuclides listed in Table 8-28 for the trench reference DU-type apply to each slit and engineered trench (15 STs and 8 ETs). However, for SWFs, Table 8-29 provides a breakdown of where the 15 SWF radionuclides disposed in trenches reside within the 23 total STs and ETs, along with the number of SWF radionuclides per DU.

Table 8-29. Burial Locations of Special Waste Form Radionuclides in Each Trench Disposal Unit Requiring an Inventory Limit for Air Pathway

SWF Radionuclide [a]	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST10	ST11	ST14	ST18	ST23	ST24	ET01	ET02 thru ET09
C-14A														X			
C-14B								X	X	X							
C-14H												X					
C-14K														X			
C-14N	X	X	X	X	X	X	X	X	X	X	X	X	X				
C-14X									X								
H-3A														X			
H-3B								X	X	X							
H-3C			X				X										
H-3F	X																
H-3X									X								
Total Number Radionuclides (11)	2	1	2	1	1	1	2	3	5	3	1	2	1	3	0	0	0

Notes:

[a] SWFs planned for future disposals are shaded in orange.

8.5.2. Trigger Values

Trigger-value radionuclides are typically radionuclides without explicit CWTS inventory limits and that reside on a separate watch list. A listing of DU-specific trigger values may exist for each GW, IHI, air, and radon pathway; those for the air pathway are presented in this section. If a trigger value is exceeded, then its radionuclide is considered for inclusion in CWTS, which generally requires an SA to generate final inventory limits.

Trigger values for the air pathway are based on DRFs and, therefore, are identical for a radionuclide across DUs. Based on pessimistically leaning plume overlap assumptions, the atmospheric PIF is independent of DU and radionuclide. The final trigger values for the air pathway for each DU are reported in Appendix H, Section H.5.3.

8.5.3. Preliminary Inventory Limits

Preliminary inventory limits for the air pathway are reference DU-type specific and are provided in Appendix H, Section H.3.1.

8.5.4. Atmospheric Plume Overlap

To account for downwind mixing of contaminant plumes emanating from multiple DUs, a simple and conservative (i.e., pessimistically leaning) modeling approach is taken. This model is discussed in Appendix H, Section H.3.2, where key assumptions made for a specific parent radionuclide are as follows:

- All DU source terms (i.e., plumes) migrating downwind are assumed to be completely aligned, which effectively assumes that every DU is sitting geometrically on top of each other.
- Peak-concentration separation along the 100-meter POA, associated with varying burial times and travel distances, is not explicitly accounted for because a single time window is employed to represent the entire compliance period.

Based on the conservative (i.e., pessimistically leaning) approach chosen as discussed in Appendix H, Section H.3.2, atmospheric PIFs are independent of DU and parent radionuclide. Given that a total of 27 DUs will have been in operation at the ELLWF's closure date, the atmospheric PIF, η^{Air}, is given by:

$$\eta^{Air} = 27.0 \qquad \text{Eq. (8-10)}$$

This atmospheric PIF is quite conservative (i.e., pessimistically leaning) for the following reasons:

- All preliminary inventory limits are computed based on a 100-meter travel distance from each DU to the 100-meter POA. Having complete plume alignment at the 100-meter boundary requires the majority of the DU travel distances to be significantly longer.
- All disposal times are set to the end of operations.

- The transport timing of each DU's peak concentrations will vary because of differences in burial timing and travel length.

8.5.5. Final Inventory Limits

Final DU-specific inventory limits are provided for every generic waste form and SWF parent radionuclide requiring an inventory limit for the air pathway. These inventory limits are based on nominal PA transport simulations as described in Sections 5.1.5, 5.2.3, 5.3.3, and 5.4.3 for STs and ETs, LAWV, ILV, and NRCDAs, respectively.

A final inventory limit for the air pathway is computed by applying a radionuclide-specific and time-group-specific atmospheric PIF as follows:

$$L_{DU,i}^{Air-final} = \frac{L_{DU,i}^{Air-prelim}}{\eta^{Air}} \qquad \text{Eq. (8-11)}$$

where:

$L_{DU,i}^{Air-final}$	Final inventory limit for air pathway for i^{th} parent radionuclide in a specific DU (Ci)
$L_{DU,i}^{Air-prelim}$	Preliminary inventory limit for air pathway for i^{th} parent radionuclide in a specific DU (Ci)

Final inventory limits are specific to reference DU-type and are provided in Appendix H, Section H.3.3. This includes assignment of limits for individual STs and ETs as well as SWF radionuclides.

8.5.6. Comparison to Prior Performance Assessment Results

Table 8-30 compares final inventory limits calculated in this PA for the air pathway to PA2008 limits (WSRC, 2008) and limits computed in a subsequent SA (Hiergesell and Taylor, 2011). In general, PA2022 inventory limits are higher than PA2008 limits but lower than those reported in the 2011 SA (SA2011). Material properties and Henry's Law constants (including the use of separate constants for cementitious materials) were updated between PA2008 and SA2011 which accounts for the increased limits. In addition, the PA2008 analysis excluded the concrete roofs for the LAWV and ILV during the first 25 simulation years, which drastically increased peak fluxes for these two DUs. Relative to SA2011, six major changes are incorporated into the PA2022 air pathway analysis:

1. C-14 solubility in cementitious material is included, which results in higher limits.
2. Plume overlap is accounted for in the analysis, which leads to lower limits.
3. Sorption to solids from the aqueous phase is included for C-14, which results in higher limits.
4. Material properties (negligible effect) and DRFs (higher limits) are updated.

5. Corrosive releases of radionuclides within NRCDAS welded casks are included, which results in higher limits.
6. Values for the material-specific, effective diffusion coefficients are higher, which leads to lower limits.

The change having the predominant influence on limits is the increase in effective diffusion coefficients. In SA2011, Equation 2 by Rogers and Nielson (1991) was used to calculate the effective diffusion coefficients, while Equation 9 by Rogers and Nielson (1991) is employed in PA2022 (see Section 6.3). Previous analyses also did not include the NRCDA generic waste form or the presence of Kr-85 in the ILV.

Table 8-30. Comparison of PA2022 Final Inventory Limits for Air Pathway to SA2011 and PA2008 Inventory Limits

Radionuclide	Inventory Limit (Ci)		
	PA2008	SA2011	PA2022
Trench			
C-14	2.90E+05	1.90E+05	7.74E+03
H-3	1.10E+07	2.80E+18	6.73E+13
CIG SWF			
C-14	2.90E+05	3.40E+09	4.32E+06
H-3	1.10E+07	---	7.68E+13
LAWV			
C-14	3.30E+03	3.50E+09	4.48E+12
H-3	4.50E+06 [a]	3.80E+13	1.25E+18
ILV			
C-14	2.20E+05	7.40E+08	2.54E+16
H-3	1.10E+08 [a]	6.40E+18	---
Kr-85	np	np	2.25E+09
NRCDAG [b]			
C-14	np	np	1.65E+04
NRCDAS [c]			
C-14 (26E)	2.60E+03	1.00E+04	2.69E+05
C-14 (7E)	5.30E+02	4.90E+03	2.69E+05
H-3	---	---	---

Notes:

A numerical value exceeding 1×10^{20} is represented by "---". The designation "np" means "not performed."

[a] Reported H-3 limit is maximum permissible total inventory over 25-yr operational period (DRF-based, minimal transport analysis performed).

[b] NRCDAG refers to large shear block boxes (bolted containers), stacked two high, and is treated as generic waste.

[c] NRCDAS refers to a welded KAPL CB/TS steel cask and is treated as a SWF.

8.6. RADON PATHWAY

This section interprets the results of the PA2022 radon flux analysis. As listed in Table 1-2, one specific radon pathway is considered:

- **Radon Pathway (R):** Compliance period is Year 71 to Year 1,171; flux is calculated at ground surface of waste footprint.

The PO for radon is a gas-phase, ground-surface flux directly above the buried waste.

Section H.4 in Appendix H gives further details on the overall computational strategy employed in determining the final inventory limits for the radon pathway.

Four of the key embedded pessimistically leaning conservatisms employed throughout all radon transport analyses are as follows:

- All waste is buried at one specific point in time at the beginning of facility operations.
- No radionuclide decay occurs before burial, which is the time between radiological assessment by waste generators and the actual time of burial.
- Release of radionuclides from the waste zone as the result of GW leaching or excavation processes is zero.
- Rn-222 and its daughter are excluded from air pathway analyses per DOE M 435.1-1, Chg. 3 (U.S. DOE, 2021b).

The third and fourth assumptions above isolate the radon flux analyses from the GW, IHI, and air transport analyses.

8.6.1. Parent Radionuclides Requiring Inventory Limits

The list of parent radionuclides requiring inventory limits for the radon pathway is defined by the radionuclide screening results described in Section 2.3.8 and the SWFs listed in Table 8-2. A total of 12 unique parent radionuclides (three generic waste form and nine SWF radionuclides) are listed in Table 8-31.

Table 8-31. Generic and Special Waste Form Parent Radionuclides Requiring Inventory Limits for Radon Pathway for Each Disposal Unit

Radionuclide [a]	STs and ETs	LAWV	ILV	NRCDAs	
				NR07E	NR26E
Generic Waste Form	3	1	1	0	0
Ra-226	X	X	X		
Th-230	X				
U-234	X				
Special Waste Form	5	0	0	0	0
Ra-226T	X				
Th-230T	X				
U-234A	X				
U-234B	X				
U-234G	X				
Total Number Radionuclides	**8**	**1**	**1**	**0**	**0**

The radionuclides listed in Table 8-31 for the trench reference DU-type apply to each slit and engineered trench (15 STs and 8 ETs). However, for SWFs, Table 8-32 provides a breakdown of where the nine SWF radionuclides disposed in trenches reside within the 23 total STs and ETs, along with the number of SWF radionuclides per DU.

Table 8-32. Burial Locations of Special Waste Form Radionuclides Within Each Trench Disposal Unit Requiring an Inventory Limit for Radon Pathway

SWF Radionuclide [a]	ST01	ST02	ST03 ST04 ST05	ST06	ST07 ST08	ST09 ST10	ST11 ST14 ST18	ST23	ST24	ET01 thru ET09
Ra-226T				X						
Th-230T				X						
U-234A								X		
U-234B						X				
U-234G		X								
Total Number Radionuclides (5)	**0**	**1**	**0**	**2**	**0**	**1**	**0**	**1**	**0**	**0**

Notes:

[a] No future disposals of SWFs containing these parent radionuclides are planned with the exception of U-234B.

8.6.2. Trigger Values

Preliminary trigger values presented in Section 2.3.8.2.3 on a unit area (1 m^2) basis are considered final after adjustment for footprint areal waste zone size differences because no subsurface plume interaction factors are applied. Trigger values are only required for the NRCDAS reference DU-type (SWF; welded steel casks) as provided in Appendix H, Section H.5.4.

8.6.3. Preliminary Inventory Limits

The PO for the radon pathway (20 pCi m^{-2} s^{-1}) is a ground-surface flux of Rn-222 as indicated in Table 1-2. Lateral migration of the gas-phase constituents by diffusion or advection is assumed to be negligible. Under this assumption, the GoldSim® analysis employs a 1-D vertical model of the VZ that includes the region containing the waste zone up to the ground surface. Essentially, this 1-D transport model becomes size independent in the areal extent, and the initial analyses are conducted using "reference" waste zone footprint sizes. However, vertical heights of the waste zone and depths from the ground surface to this waste zone are preserved as described in Sections 5.1.5, 5.2.3, 5.3.3, and 5.4.3 for STs and ETs, LAWV, ILV, and NRCDAs, respectively.

To calculate inventory limits for the radon pathway, the following three-step process is employed:

- A unit curie of a parent radionuclide is uniformly buried within a DU's waste zone (waste zone height provided in Chapter 5) where a DU-type-specific 1-D GoldSim®-based transport model is used to estimate the ground-surface flux of Rn-222.
- The peak Rn-222 flux during the compliance period (Year 71 to Year 1,171) is compared to the 20 pCi m^{-2} s^{-1} PO, and an inventory limit is computed for each reference DU-type.
- The DU-type-specific inventory limits for the radon pathway are then converted into DU-specific values based on the size of a DU's actual waste-zone footprint.

Preliminary inventory limits for the radon pathway for every DU are provided in Appendix H, Section H.4.2.

8.6.4. Plume Overlap

Gas-phase lateral diffusion occurs within the vadose zone to some limited extent. However, it is assumed that gas-phase lateral spreading within the vadose zone is marginal and the surface fluxes are computed using the areal footprint of each DU. Therefore, no subsurface plume interaction factors are applied. The preliminary inventory limits for the radon pathway become the final inventory limits once footprint areal size differences are accounted for.

8.6.5. Final Inventory Limits

Preliminary inventory limits for the radon pathway presented in Appendix H, Section H.4.2, are also considered the final inventory limits. These inventory limits are based on nominal transport runs as described in Sections 5.1.5, 5.2.3, 5.3.3, and 5.4.3 for STs and ETs, LAWV, ILV, and NRCDAs, respectively.

8.6.6. Comparison to Prior Performance Assessment Results

Table 8-33 compares the final inventory limits for the radon pathway calculated in this PA to the PA2008 limits (WSRC, 2008). In general, PA2022 inventory limits for trenches are lower than limits reported in PA2008. The change having the most influence on limits is the increase in the value of the diffusion coefficients from PA2008 to PA2022. PA2008 employed smaller material-specific diffusion coefficients than the current effective diffusion coefficients calculated using Equation 9 by Rogers and Nielson (1991) [see Section 6.3]. Material properties and Henry's Law constants for Rn-222 are also updated. For the LAWV and ILV, the PA2022 limits are higher than those in PA2008. The PA2008 analysis excluded the concrete roofs for the LAWV and ILV during the first 25 simulation years, which drastically increased peak fluxes for these two DUs.

Table 8-33. Comparison of PA2008 and PA2022 Final Inventory Limits for Radon Pathway

Radionuclide	PA2008		PA2022	
	Reference Area (m^2)	Inventory Limit (Ci)	Reference Area (m^2)	Inventory Limit (Ci)
Slit Trench [a]				
Ra-226	6,098	2.20E+04	7,459 [b]	6.81E+01
Th-230	6,098	4.20E+05	7,459 [b]	9.25E+02
U-234	6,098	7.20E+08	7,459 [b]	1.16E+06
Engineered Trench [a]				
Ra-226	9,063	3.30E+04	7,459 [b]	6.81E+01
Th-230	9,063	6.20E+05	7,459 [b]	9.25E+02
U-234	9,063	1.10E+09	7,459 [b]	1.16E+06
CIG Trench Segment				
U-234	6,042	4.30E+10	1,243	4.65E+04
LAWV				
Ra-226	8,666	2.40E+00	8,360	1.06E+05
ILV				
Ra-226	931	2.00E+01	974	1.83E+06

Notes:

a Separate inventory limits were assigned for STs and ETs in PA2008; the only difference was in the assumed reference area.

b For comparison purposes only in this table, a single reference area (7,459 m^2) is used to calculate PA2022 inventory limits for STs and ETs. See Section H.4.2 for the actual ST- and ET-specific final inventory limits.

8.7. PROJECTED CLOSURE INVENTORYS AND IMPORTANCE RANKING

This section provides upper-bound projected CWTS closure inventories and their corresponding importance ranking. The projected CWTS closure inventories represent upper-bound estimates for ELLWF closure in 2065, are best estimates with respect to the CWTS database, and are based upon the following two key aspects:

- **Best Estimate:** Use is made of all existing ELLWF CWTS inventories spanning more than 26 years of operation through March 2021. From this historical dataset, best-estimate DU compositions are established.
- **Upper Bound:** Each DU is assumed to close at its upper-bound inventory that is constrained by the administrative inventory limit on its maximum total SOF (i.e., activity limited versus volume limited).

The projected inventories are employed to compute (1) dose history files and (2) deterministic closure analyses. See Appendix H, Section H.7, for further details on the overall calculational strategy employed in computing projected inventories.

With each DU's projected closure, CWTS inventories, together with the CWTS final inventory limits discussed earlier in this chapter, a deterministic ranking of importance can be made based upon parent-radionuclide SOF contribution. This ranking process is performed where all exposure pathways are considered, which is consistent with how CWTS computes its maximum total SOF at a DU level.

To assess the relative importance to total SOF that various parent radionuclides have on a given DU, projected inventories are required. To assess the facility's overall performance during its entire lifecycle, closure analyses are required as discussed in Chapter 9. A closure analysis for the ELLWF requires projected inventories for all DUs at operational closure, which is estimated to be calendar year 2065. Based on the inventory limits by exposure pathway provided above and how the CWTS limits system imposes inventory constraints, projected 2065 CWTS inventories are provided below for all 27 DUs included in PA2022.

These best-estimate projected 2065 CWTS inventories are estimated using the waste generator's inventories in the CWTS system. Potential biases and uncertainties associated with the waste generator values are incorporated into these projections in Chapter 9 where the final closure analysis is presented. The deterministic closure analyses employ these projected CWTS inventories, where bias factors are then applied, resulting in "best estimate" projected inventories. See Chapter 9 and Section 2.3.5 for details on inventory biases and uncertainties.

8.7.1. Projected Closure Inventories

All inventory limits provided in prior sections of this chapter for each of the four exposure pathways (and their associated time windows, where employed) constitute a major portion of the CWTS limits system. Every DU's inventory is limited such that its total SOF does not exceed 1.0 (or 0.95 when an administrative limit is imposed). A total SOF is computed in CWTS for every time window within each independent exposure pathway. Specifically, up to 12 total SOFs are computed within CWTS for each DU of interest as follows:

1. **Beta-Gamma:** Three time windows for STs and ETs; two time windows for LAWV, ILV, and NR26E; one time window for NR07E
2. **Gross-Alpha:** One time window for all DUs
3. **Radium:** One time window for all DUs
4. **Uranium:** One time window for all DUs
5. **All-Pathways:** Two time windows for STs, ETs, LAWV, ILV, and NR26E; one time window for NR07E
6. **Acute IHI:** One time window for all DUs
7. **Chronic IHI:** One time window for all DUs
8. **Air:** One time window for all DUs
9. **Radon:** One time window for all DUs

ELLWF operations are limited at the DU level based on the maximum total SOF obtained from the above nine independent pathways, which includes up to 12 values when time windows are included. Note that no explicit compositional constraints are placed on a given DU. As discussed during the development of DU-dependent GW values, projected closure inventories are based on each DU reaching its upper administrative limit specifically as follows:

- Maximum total SOF = 1.00 for all DUs except those limited in the next bullet.
- Maximum total SOF = 0.95 for the closed DUs ST01 through ST05.

Impacts due to plume overlap between neighboring DUs are implicitly handled within the inventory limits provided above (specifically, air and aquifer plume overlapping potentials); therefore, for every exposure pathway, at no time throughout a compliance period will a total SOF exceed 1.0. The inventory limits and their application within the CWTS limits system are not compositionally dependent. Therefore, each DU at closure can have any composition (i.e., any mixture of parent radionuclides up to and including the pure component boundaries) that remains consistent with the constraints imposed by the CWTS limits system.

8.7.1.1. Projected Closure Inventory Composition Vectors

To compute the final (1) dose history time profiles and (2) deterministic closure analysis, a projected closure inventory (existing plus future) for each DU must be employed [refer to Eq. (8-7)]. The final inventory limits provided within this chapter impose a constraint on the closure inventories per DU. A “best estimate” of a DU’s closure inventory (and thus its closure composition) can be estimated using existing inventories, which represent a cumulation of burials over the past ~26 years of ELLWF operations, coupled with the application of a bias factor (i.e., actual versus CWTS value).

To estimate closure compositions on a DU basis, the existing CWTS inventories were collected. This estimated closure inventory is based on historical composition vectors available for all closed and open DUs as of March 31, 2021. These CWTS inventories are considered nominal PA values that can be projected to closure with reasonable confidence because they are based on ~26 years of historical operation; future operations (~44 years) are not expected to deviate significantly.

SWM issues a monthly ELLWF status report that provides current DU capacities in terms of volume filled and activity level (based on a maximum total SOF indicator). The following two key tables are of interest:

- Disposed volume status of EAV facilities (i.e., disposed volume capacities based on WITS/CWTS volume entries and measured areas used in the field).
- PA status of EAV facilities (i.e., WITS/CWTS computed maximum total SOFs per DU).

A condensed summary of the March 2021 monthly status report (Stewart, 2021) is provided in Table 8-34, where the table columns share the following data from left to right:

- PORFLOW aquifer model employed in generating inventory limits
- Updated DU naming convention as of this PA
- Status of a specific DU (closed, open, or future as of March 31, 2021)
- Total SOF computed within WITS/CWTS
- Percent of waste zone volume occupied by existing waste materials
- Ratio of percent activity (SOF) to percent volume occupied (referred to as a capacity ratio)
- Total existing inventory (Ci) for all generic waste form and SWF parent radionuclides requiring inventory limits

A total of 27 DUs represent the ELLWF (15 STs, 8 ETs, LAWV, ILV, NR07E, and NR26E). Seven DUs are closed, eleven are open, and nine are future units. Based on activity / volume ratio data in Table 8-34, average capacity ratios (expressed as %-activity / %-volume) are calculated as follows:

- Trench avg = 90%
- Vault avg = 28%
- NRCDA avg = 13%

Table 8-34. E-Area Low-Level Waste Facility Capacity Status as of March 31, 2021

PIF Aquifer Cutout	DU	DU Status	Total SOF (%) as of 3/31/2021	Volume Filled (%) as of 3/31/2021	Activity / Volume Ratio as of 3/31/2021	Existing Inventory Total [a] (Ci)
West	ET07	Future	--	--	--	--
	ET08	Future	--	--	--	--
	ET09	Future	--	--	--	--
	ET03	Open	74.3%	93.1%	0.80	114.35
	ET04	Future	--	--	--	--
	NR26E	Open	2.7%	11.7%	0.23	2.41E+05
	ST08	Open	88.6%	95.0%	0.93	45.79
	ST09	Open	84.7%	94.3%	0.90	271.97
	ST10	Future	--	--	--	--
	ILV	Open	9.1%	58.6%	0.16	2.27E+06
	ST11	Future	--	--	--	--
Center	ST01	Closed	85.4%	100.0%	0.85	17.12
	ST02	Closed	86.5%	100.0%	0.87	40.74
	ST03	Closed	89.4%	100.0%	0.89	63.46
	ST04	Closed	94.5%	100.0%	0.95	76.38
	ST23	Open	44.5%	28.2%	1.58	7451.10
	ST24	Future	--	--	--	--
	ST05	Closed	100.0%	100.0%	1.00	96.77
	ST06	Open	82.3%	90.6%	0.91	63.32
	ST07	Open	55.5%	66.4%	0.84	51.56
East1	ET02	Open	76.1%	79.0%	0.96	212.18
	ET01	Closed	86.7%	100.0%	0.87	102.46
	ST14	Open	89.6%	89.5%	1.00	3453.25
	ET05	Future	--	--	--	--
	LAWV	Open	13.3%	32.4%	0.41	4.28E+05
	ST18	Future	--	--	--	--
East2	NR07E	Closed	3.1%	100.0%	0.03	2.95E+05

Notes:

Open DUs are shaded in green; closed DUs are shaded in gray; future DUs are unshaded.

[a] The existing inventory total represents only those parent radionuclides (both generic waste form and SWF) that require inventory limits per this PA.

Where possible, SWM tries to manage the ELLWF so that all trench waste volumes are optimally utilized. However, for all exiting DUs thus far, the volume capacity is exhausted before reaching its activity capacity (total SOF = 1.0). In projecting future ELLWF inventory on a DU basis, the following four key assumptions are made:

- The assumed best-estimate composition vectors for future burials in both open and future DUs are fixed at their historical values.
- Future SWM plans remain intact for handling SWFs [i.e., some SWFs are one-time burials (e.g., HWCTR) while others are ongoing current and future burials (e.g., Naval Reactor Main Coolant Pump)]

- The potential capacity ratio constraint of reaching a DU's waste volume capacity, before reaching its activity constraint, remains the most likely scenario.
- When estimating future total inventories, it is conservatively (pessimistically leaning) assumed that operations will be activity limited, even though historical data indicate that the most likely scenario will be volume limited.

Each DU has a unique operational status (closed, open, or future) and, therefore, a unique status with respect to both generic waste form and SWF parent radionuclide inventories as follows:

- **Closed:** Inventory is fixed and set to the CWTS values as of March 31, 2021.
- **Open:** Both existing and future inventories are considered. The existing inventory is fixed at the CWTS inventory values as of March 31, 2021, while future inventory is added based on the DU's assumed future composition vector.
- **Future:** Only future inventory is considered and is added based on a DU's assumed future composition vector.

For the open DUs, composition vectors are estimated based on their existing inventories. For future DUs, composition vectors are estimated based on overall averaging of existing inventories for a given reference DU-type (e.g., future ET05 employed average values taken from ET01, ET02, and ET03 based on PA2022 SOF weighting). See Appendix H, Section H.7.1, for details.

Existing inventories are available for eleven open and seven closed DUs as indicated in Table 8-34; therefore, each of these 18 DUs has current composition vectors. As an example, the existing composition vectors for ST14 (open) and ILV (open) are shown in Table 8-35.

The shaded entries in Table 8-35 represent SWF radionuclides. Based on their waste form type, future burial plans, and preliminary inventory limits, Table 8-9 indicates how generic waste form and SWF radionuclides are addressed in the CWTS limits system. Note that certain SWFs are either one-time disposals or no longer expected in the future. For example, in ST14, the vessel and internals associated with HWCTR were disposed of in a one-time event (yellow-shaded SWF radionuclides under ST14). These two specific categories of SWFs (shaded in yellow and rose in Table 8-35) have zero composition vectors when used for future projections.

To compute a future composition vector ("ComVec"), available historical data is employed. For each DU status (closed, open, and future), the predicted future composition vectors are assumed to be consistent with the existing available composition vectors as shown in Table 8-36.

Based on these existing composition vectors and the PA2022 inventory limits, future composition vectors have been generated for all 27 DUs as discussed in Appendix H, Section H.7.2.

Table 8-35. Estimated Future Composition Vectors for Disposal Units ST14 and ILV

ST14			ILV		
Radionuclide	Existing (Ci)	ComVec [a] (unitless)	Radionuclide	Existing (Ci)	ComVec [a] (unitless)
Ag-108m	0.00E+00	0.00E+00	Ag-108m	4.02E-05	1.87E-11
Am-241	4.39E-01	2.81E-03	Am-241	6.78E-01	3.16E-07
Am-242m	2.73E-03	1.75E-05	Ar-39	0.00E+00	0.00E+00
Am-243	4.26E-03	2.73E-05	C-14	4.86E-01	2.26E-07
Be-10	1.17E-06	7.50E-09	Cf-249	1.58E-03	7.35E-10
C-14	5.96E-02	3.82E-04	Cl-36	7.47E-05	3.48E-11
Cf-249	3.60E-05	2.31E-07	Cm-245	2.48E-03	1.15E-09
Cf-251	1.20E-04	7.69E-07	Cs-137	3.71E+02	1.73E-04
Cl-36	3.39E-07	2.17E-09	H-3	1.38E+06	6.40E-01
Cm-245	1.03E-05	6.60E-08	I-129	5.73E-04	2.67E-10
Cm-247	5.54E-07	3.55E-09	K-40	5.57E-03	2.59E-09
Cm-248	3.24E-15	2.08E-17	Kr-85	2.03E+01	9.47E-06
Cs-135	6.09E-08	3.90E-10	Ni-59	9.50E-01	4.42E-07
Cs-137	1.07E+02	6.87E-01	Ni-63	1.16E+02	5.40E-05
H-3	2.54E-01	1.63E-03	Np-237	1.54E-02	7.17E-09
I-129	1.91E-05	1.23E-07	Pu-239	7.95E-01	3.70E-07
K-40	3.67E-06	2.35E-08	Pu-241	4.31E+00	2.00E-06
Nb-94	1.37E-03	8.81E-06	Ra-226	7.67E-01	3.57E-07
Ni-59	3.46E-02	2.22E-04	Sr-90	1.11E+02	5.18E-05
Ni-63	2.05E+00	1.31E-02	Tc-99	1.18E-01	5.47E-08
Np-237	5.62E-03	3.60E-05	U-235	2.50E-03	1.16E-09
Pa-231	2.93E-10	1.88E-12	U-235D	7.71E-03	3.59E-09
Pd-107	1.69E-08	1.09E-10	I-129C	1.40E-02	0.00E+00
Pu-239	5.22E-01	3.35E-03	C-14K	9.45E+02	0.00E+00
Pu-240	1.53E-01	9.78E-04	I-129K	2.34E-05	0.00E+00
Pu-241	4.38E+00	2.81E-02	Tc-99K	3.66E-02	0.00E+00
Ra-226	8.35E-05	5.35E-07	H-3R	1.23E+05	0.00E+00
Rb-87	1.30E-11	8.30E-14	Ar-39T	2.79E+01	1.30E-05
Sn-126	3.46E-04	2.22E-06	C-14T	6.60E+00	3.07E-06
Sr-90	4.05E+01	2.60E-01	Cs-137T	8.83E+02	4.11E-04
Tc-99	2.53E-02	1.62E-04	H-3T	7.71E+05	3.59E-01
Th-229	1.20E-04	7.69E-07	--	--	--
Th-230	2.36E-04	1.51E-06	--	--	--
Th-231	4.01E-03	2.57E-05	--	--	--
U-232	5.56E-04	3.56E-06	--	--	--
U-233	4.86E-02	3.11E-04	--	--	--
U-234	2.97E-01	1.90E-03	--	--	--
U-236	4.95E-04	3.17E-06	--	--	--
U-233D	5.80E-06	3.72E-08	--	--	--
C-14N	2.09E-02	1.34E-04	--	--	--
Ag-108mH	0.00E+00	0.00E+00	--	--	--
C-14H	5.18E+00	0.00E+00	--	--	--
Nb-94H	1.10E-01	0.00E+00	--	--	--
Ni-59H	3.68E+01	0.00E+00	--	--	--
Ni-63H	3.25E+03	0.00E+00	--	--	--
Tc-99H	3.19E-03	0.00E+00	--	--	--
	Sum =	***1.00E+00***		***Sum =***	***1.00E+00***

Notes:

All shaded entries are associated with SWFs where the specific highlighting color reflects how they are addressed (see Table 8-9).

[a] ComVec represents the composition vector, in terms of activity fraction of future waste, being buried in a DU.

Table 8-36. Disposal Unit Future Composition Vectors Estimated from Existing Composition Vectors where Needed

DU Status	DU Grouping	ComVec Based on Existing DU
Closed	ET01	None
	ST01, ST02, ST03, ST04, ST05	
	NR07E	
Open	ET02, ET03	Each DU
	ST06, ST07, ST08, ST09, ST14	
	ILV, LAWV	
	NR26E	
Future	ET04, ET05, ET07, ET08, ET09	ET avg
	ST10, ST11, ST18, ST23	ST avg
	ST24	ST avg2

8.7.1.2. Projected Total Inventories at Closure by Disposal Unit

A simple relationship is utilized to compute projected CWTS closure inventories on a DU-specific basis. The total DU inventory represents the existing plus future contributions:

$$I_{DU,i}^{Tot} \equiv I_{DU,i}^{Exist} + I_{DU,i}^{Fut} = I_{DU,i}^{Exist} + \left(\varepsilon_{DU} \times \lambda_{DU,i}\right) \qquad \text{Eq. (8-12)}$$

where:

$I_{DU,i}^{Tot}$ projected closure inventory of i^{th} parent radionuclide in a specific *DU* (Ci)

$I_{DU,i}^{Exist}$ Existing inventory of i^{th} parent radionuclide in a specific *DU* (Ci)

$I_{DU,i}^{Fut}$ Future inventory of i^{th} parent radionuclide in a specific *DU* (Ci)

$\lambda_{DU,i}$ Future composition fraction for i^{th} parent radionuclide in a specific *DU* (unitless)

ε_{DU} Total future inventory in a specific *DU* (unitless)

A total inventory of the i^{th} parent radionuclide within a *DU* is linearly related to the total future inventory as defined by Eq. (8-12) because the existing inventories and composition vectors are fixed quantities. To estimate the total future DU inventory, the maximum (max) total SOF constraint at the DU level is required. Section 8.7.2 describes this process.

Each DU has its own total future inventory; however, the total SOF along the 100-meter POA links these 27 quantities through their DU-specific PIFs that represent plume overlap and DU capacity considerations. Table 8-37 presents the estimated total future DU inventories for the set of air and GW pathways PIFs established earlier in this chapter. For each DU, the total future inventory value is computed based on the SOF constraint listed in the last column of Table 8-37. Note that for the six closed DUs (ET01, and ST01-ST05), the SOF constraint is reduced from 1.0 to 0.95 for ST01 through ST05. ET01 remains at a limit of 1.0 to assist in addressing plume overlap aspects due to upstream units in the Eastern section. SWM employs an administrative margin of 5% to help accommodate (and deal with) possible waste generator inventory errors discovered post burial.

NR07E is closed and has a significant transport path length to reach the northern portion of the 100-meter POA (North Curtain). Its PIF is set to a high value to help provide more activity capacity to the other DUs in the eastern portion of the ELLWF.

Table 8-37. Estimated Total Future Disposal Unit Inventories Based on Future Composition Vectors

PIF Aquifer Cutout	DU	DU Status	PIF (unitless)	Existing Inventory (Ci)	Future Inventory (Ci)	Total Inventory (Ci)	Maximum Total SOF (unitless)
West	ET07	Future	2.000		286.66	286.66	1.000
	ET08	Future	2.000		379.60	379.60	1.000
	ET09	Future	2.150		414.06	414.06	1.000
	ET03	Open	6.000	114.35	210.44	324.78	1.000
	ET04	Future	6.800		544.11	544.11	1.000
	NR26E	Open	6.000	2.41E+05	5.19E+07	5.22E+07	1.000
	ST08	Open	7.050	45.79	77.84	123.63	1.000
	ST09	Open	2.253	271.97	73.96	345.93	1.000
	ST10	Future	5.200		416.52	416.52	1.000
	ILV	Open	2.561	2.27E+06	1.19E+07	1.41E+07	1.000
	ST11	Future	4.000		399.82	399.82	1.000
Center	ST01	Closed	1.825	17.12		17.12	0.950
	ST02	Closed	18.985	40.74		40.74	0.950
	ST03	Closed	15.352	63.46		63.46	0.950
	ST04	Closed	16.270	76.38		76.38	0.950
	ST23	Open	1.800	7,451.10	654.26	8,105.36	1.000
	ST24	Future	1.550		362.82	362.82	1.000
	ST05	Closed	14.680	96.77		96.77	0.950
	ST06	Open	3.000	63.32	379.10	442.41	1.000
	ST07	Open	7.000	51.56	61.32	112.88	1.000
East1	ET02	Open	6.380	212.18	70.53	282.71	1.000
	ET01	Closed	4.684	102.46		102.46	1.000
	ST14	Open	13.040	3,453.25	82.55	3,535.81	1.000
	ET05	Future	14.000		48.88	48.88	1.000
	LAWV	Open	3.970	4.28E+05	9.62E+05	1.39E+06	1.000
	ST18	Future	8.354	0.0	89.58	89.58	1.000
East2	NR07E	Closed	20.000	2.95E+05		2.95E+05	0.138

Notes:
Open DUs are shaded in green; closed DUs are shaded in gray; future DUs are unshaded.
Maximum Total SOF = 0.950 (SWM administrative limit) are shaded in red.

As indicated in Table 8-37, a maximum total SOF constraint of 1.0 is employed for all existing and future DUs. Here, every DU is assumed to become activity limited but only ST01 through ST05 have the 95% reduced capacity.

The overall profile of the maximum total SOF along the North Curtain is computed using these total future inventories and is shown in Figure 8-30. The resulting maximum total SOF profiles for each DU are also shown in Figure 8-30. The black-dashed curve represents the maximum total SOF profile where it touches the SOF constraint of 1.0 at seven separate locations along the North Curtain. The maximum total SOF profile is the arithmetic sum of all 27 DU maximum SOF contributions. Note the long-range impact of plume overlap occurring in the eastern sector of the ELLWF, which results in reduced capacity available in the upstream DUs (ST19-ST22).

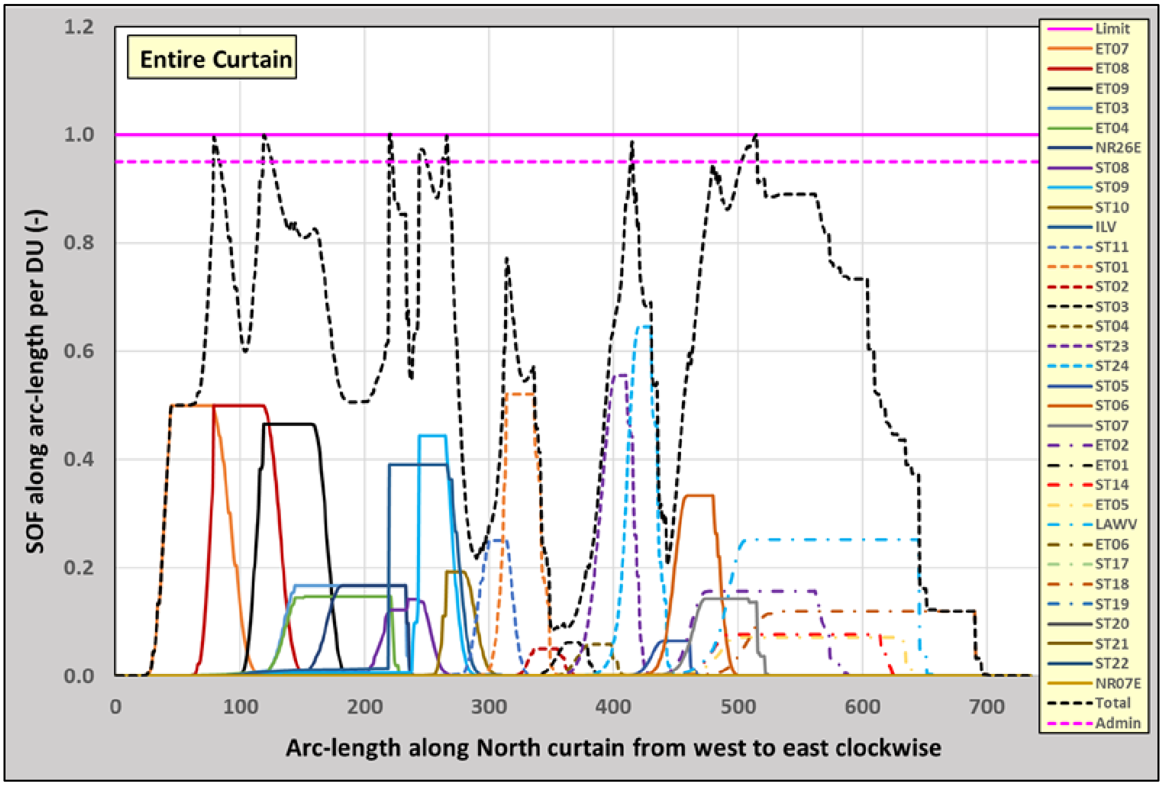


Figure 8-30. Maximum Total Sum-of-Fractions Along 100-meter POA (North Curtain) Based on Upper-Bound Estimate of Disposal Unit Inventories and Time-Windowing Inventory Limits

Each future inventory value listed in Table 8-37 is computed based on consideration of all inventory limits for the GW, IHI, air, and radon pathways and is contingent upon the SOF constraint provided. The total future inventories and the resulting total maximum SOF profile (Figure 8-30) are unique with respect to the composition vectors chosen. However, the GW PIF approach is generalized in that the total maximum SOF profile will not exceed 1.0 at any point along this North Curtain regardless of what composition vectors are chosen.

In generating the future inventories, the total SOF for each exposure pathway, as well as the associated time windows, are computed. A breakdown of the total SOF by exposure pathway is provided in Table 8-38. As the table indicates, beta-gamma and gross-alpha releases dominate.

The future inventories represent the projected 2065 CWTS closure inventories that are employed in the deterministic closure analysis, where CWTS inventory biases are also employed. The projected 2065 CWTS closure inventories are provided for all 27 DUs in Appendix H, Section H.7.2.

Table 8-38. Estimated Total Future Disposal Unit Inventories Based on Best-Estimate Composition Vectors

PIF Aquifer Cutout	DU	DU Status	Beta-Gamma SOF	Gross-Alpha SOF	Radium SOF	Uranium SOF	All-Pathways SOF
West	ET07	Future	0.426	1.000	0.001	0.000	0.122
	ET08	Future	0.516	1.000	0.001	0.000	0.122
	ET09	Future	0.550	1.000	0.001	0.000	0.122
	ET03	Open	0.316	1.000	0.000	0.000	0.123
	ET04	Future	1.000	0.092	0.000	0.000	0.061
	NR26E	Open	1.000	0.000	0.000	0.000	0.096
	ST08	Open	1.000	0.011	0.000	0.000	0.016
	ST09	Open	1.000	0.026	0.000	0.000	0.063
	ST10	Future	1.000	0.130	0.000	0.000	0.074
	ILV	Open	1.000	0.000	0.000	0.000	0.010
	ST11	Future	1.000	0.066	0.000	0.000	0.056
Center	ST01	Closed	0.950	0.000	0.000	0.000	0.001
	ST02	Closed	0.950	0.022	0.000	0.000	0.035
	ST03	Closed	0.950	0.441	0.000	0.000	0.102
	ST04	Closed	0.950	0.141	0.000	0.000	0.083
	ST23	Open	1.000	0.086	0.000	0.000	0.048
	ST24	Future	1.000	0.263	0.000	0.000	0.035
	ST05	Closed	0.950	0.410	0.000	0.000	0.058
	ST06	Open	1.000	0.752	0.000	0.000	0.094
	ST07	Open	1.000	0.474	0.000	0.000	0.059
East1	ET02	Open	0.972	1.000	0.000	0.000	0.122
	ET01	Closed	1.000	0.047	0.000	0.000	0.007
	ST14	Open	1.000	0.060	0.000	0.000	0.020
	ET05	Future	0.697	1.000	0.000	0.000	0.121
	LAWV	Open	1.000	0.000	0.000	0.000	0.009
	ST18	Future	1.000	0.070	0.000	0.000	0.012
East2	NR07E	Closed	0.138	0.000	0.000	0.000	0.015

Notes:

Open DUs are shaded in green; closed DUs are shaded in gray; future DUs are unshaded.

GW pathways with SOF = 1.0 (imposed limit) are shaded in orange.

GW pathways with SOF = 0.950 (SWM administrative limit) are shaded in red.

The projected closure inventories are based on the following:

- Historical inventories providing composition vectors
- Final inventory limits reported in this chapter based on the provided time windowing
- An assumption that each DU is operated up to its allowable inventory limit

To account for potential composition changes during future operations, a Monte Carlo stochastic analysis is employed in the closure analysis (Section 9.1.2). The stochastics are performed about the deterministic best-estimate conditions. This is also considered to be an upper-bound estimate for each DU because its total inventory is set to a value that yields a total SOF of 1.0 (or 0.95 for ST01 through ST05) along the 100-meter POA, which is consistent with the above composition vector constraint.

8.7.2. Importance Ranking

Once plume overlaps for the air and GW pathways are explicitly (and conservatively) accounted for in the total future inventories, each DU can operate independently from its neighbors. For each DU, a rank ordering of parent radionuclide SOF contributions is provided below. The rank ordering is limited to the best-estimate projected CWTS inventories discussed above; therefore, it represents a deterministic assessment only. Stochastic aspects are further addressed in the closure analysis in Section 9.1.2. Chapter 9 also discusses the shifting of results once bias factors are applied.

For each DU, the parent radionuclides can be rank ordered with respect to total SOF for any or all pathways. The rank ordering is performed where all exposure pathways are included; however, a GW pathway is the most limiting as expected.

The following rank ordering processing steps are employed for each DU:

- For all generic waste form and SWF parent radionuclides with inventory limits, total existing plus future disposal inventories are estimated based on reaching a final total SOF limit of 0.95 (SWM administrative limit) or 1.0. For each pathway and time window employed, SOF contributions are computed using the projected CWTS inventories and their associated CWTS inventory limits. For example, most ETs are limited by the gross-alpha GWP pathway, while the remaining DUs are limited by the beta-gamma GWP pathway.
- For the most limiting pathway (either beta-gamma or gross-alpha in the above example), its SOF contribution value per parent radionuclide is computed and sorted by magnitude.
- A normalized SOF ratio value is computed which is relative to the radionuclide with the largest contribution to total SOF.

In Chapter 2, the GW and IHI radionuclide screening processes (1) employed a 0.1% criterion on absolute SOF contributions when bounding transport analyses were employed (Section 2.3.7) and (2) applied a 10X factor to projected inventories to address uncertainties. For presentation purposes, the normalized listings are shortened so that only radionuclides whose contributions exceed 0.01% of the maximum SOF contribution are shown. To provide quick visual assessments, the rank-ordered lists are color coded as follows:

- **Red**: Normalized SOFs ranging from 10% to 100% because contributions above 10% represent a significant portion of the sum.
- **Yellow:** Normalized SOFs ranging from 1% to 10% because many prior PA analyses used 1% as a metric for screening out.
- **Blue:** Normalized SOFs ranging from 0.1% to 1% because 0.1% is employed in this PA as a screening out metric.
- **Orange:** Normalized SOFs ranging from 0.01% to 0.1% because 0.1% represents a contribution well within the noise of the analysis.

The DU-specific rank ordering lists are also composited to highlight the key overall parent radionuclides having the greatest impacts on POs. The composited list is provided in Table 8-39 for STs, ETs, LAWV, ILV, NR07E, and NR26E. In most situations, maximum normalized SOF contributions from lower-ranked radionuclides decline rapidly such that only a small subset of parent radionuclides requiring inventory limits contribute to the total SOF. The following parent radionuclides typically have the greatest impact on the total SOF: C-14, H-3, I-129, Np-237, Sr-90, and Tc-99.

These short-list parent radionuclides agree well with dominant contributors identified in other PAs across the DOE complex. They are typically more mobile than the overall set of radionuclides considered, while spanning a wide range in half-life. This short-list of parent radionuclides was also the focus in Chapter 6 where PORFLOW and GoldSim® model uncertainty quantification and sensitivity analysis are addressed.

Table 8-39. Composited Rank Ordering of Normalized Sum-of-Fractions Contributions Based on Disposal Unit

STs		ETs		LAWV and ILV		NR07E and NR26E	
Radionuclide (24total)	Max SOF	Radionuclide (8 total)	Max SOF	Radionuclide (5 total)	Max SOF	Radionuclide (9 total)	Max SOF
H-3F	100.00%	H-3	100.00%	I-129	100.00%	Tc-99S	100.00%
I-129J	100.00%	Np-237	100.00%	H-3	23.07%	Sr-90S	39.03%
Np-237	100.00%	I-129	66.46%	I-129C	8.57%	Sn-121mS	16.50%
H-3	100.00%	Tc-99	54.84%	Cs-137	4.15%	Am-241S	13.67%
Tc-99	100.00%	Sr-90	32.40%	H-3T	1.90%	I-129	11.58%
I-129	100.00%	Ni-63	8.80%	--	--	Tc-99	9.30%
H-3X	100.00%	I-129J	1.29%	--	--	C-14S	8.37%
H-3A	76.43%	C-14	1.03%	--	--	Am-243S	7.59%
C-14X	46.84%	--	--	--	--	Sn-126S	2.94%
I-129C	34.67%	--	--	--	--	--	--
Sr-90	17.34%	--	--	--	--	--	--
I-129G	16.88%	--	--	--	--	--	--
H-3B	15.61%	--	--	--	--	--	--
I-129D	12.15%	--	--	--	--	--	--
I-129A	9.20%	--	--	--	--	--	--
Tc-99A	7.48%	--	--	--	--	--	--
Cs-137A	6.52%	--	--	--	--	--	--
I-129H	5.76%	--	--	--	--	--	--
Tc-99B	5.18%	--	--	--	--	--	--
I-129B	4.90%	--	--	--	--	--	--
Ni-63	4.84%	--	--	--	--	--	--
I-129K	2.56%	--	--	--	--	--	--
Ni-59	1.72%	--	--	--	--	--	--
C-14K	1.71%	--	--	--	--	--	--

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: yellow (1% to 10%); red (10% to 100%).

Summaries of the rank ordering lists at the individual DU level are provided in Table 8-40 and Table 8-41 for STs; Table 8-42 for ETs; Table 8-43 for LAWV and ILV; and Table 8-44 for

NR07E and NR26E. At the individual DU level, the top contributors to the maximum total SOF are H-3, H-3F, H-3X, I-129, I-129J, Np-237, Tc-99, and Tc-99S.

Table 8-40. Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Slit Trench Disposal Unit (Set 1)

ST01		ST02		ST03		ST04		ST05		ST06		ST07		ST08	
Closed		Closed		Closed		Closed		Closed		Open		Open		Open	
Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF
H-3F	100.00%	I-129J	100.00%	Np-237	100.00%	H-3	100.00%	Tc-99	100.00%	I-129	100.00%	H-3	100.00%	H-3	100.00%
H-3	21.91%	Tc-99	62.49%	Tc-99	93.81%	Tc-99	88.18%	I-129	94.24%	Np-237	99.24%	Np-237	48.18%	I-129	93.00%
I-129	2.37%	I-129	45.56%	I-129	83.37%	I-129	46.16%	Np-237	84.02%	H-3	94.34%	I-129	21.70%	Tc-99	6.10%
I-129J	1.28%	H-3	17.70%	I-129C	34.67%	Np-237	20.46%	H-3	19.86%	Tc-99	31.61%	Tc-99	6.40%	Sr-90	2.65%
Tc-99	0.87%	I-129G	16.88%	H-3	15.54%	I-129J	1.27%	Ni-63	1.71%	Am-241	0.81%	Ni-59	1.72%	Ni-59	1.38%
Ra-226	0.01%	I-129D	12.15%	I-129J	8.00%	Ni-59	0.97%	Sr-90	0.95%	Ni-59	0.66%	I-129C	1.62%	Np-237	1.06%
--	--	I-129H	5.76%	Ni-59	1.44%	I-129H	0.96%	Am-241	0.92%	Sr-90	0.38%	Am-241	0.26%	Ni-63	0.53%
--	--	Np-237	4.93%	Ni-63	0.37%	Ni-63	0.74%	C-14	0.62%	Pu-241	0.21%	C-14	0.23%	C-14	0.14%
--	--	Ni-63	4.56%	C-14	0.34%	C-14	0.33%	Pu-241	0.38%	C-14	0.20%	Pu-241	0.18%	Ni-59B	0.06%
--	--	Ni-59	1.57%	Am-241	0.20%	C-14N	0.22%	I-129J	0.17%	Ra-226T	0.10%	Ni-63	0.11%	H-3B	0.06%
--	--	C-14N	0.53%	Pu-241	0.14%	Am-241	0.09%	Ni-59	0.13%	Cs-137	0.06%	C-14N	0.06%	Am-241	0.05%
--	--	C-14	0.32%	C-14N	0.11%	I-129I	0.07%	I-129R	0.11%	Ni-63	0.04%	I-129J	0.04%	Cs-137	0.02%
--	--	I-129I	0.16%	Sr-90	0.06%	Sr-90	0.07%	C-14N	0.07%	Th-230T	0.01%	Cs-137	0.02%	Pu-241	0.01%
--	--	Sr-90	0.03%	I-129I	0.06%	Pu-241	0.06%	Tc-99R	0.03%	--	--	Sr-90	0.01%	Tc-99B	0.01%
--	--	Am-241	0.03%	Cs-137	0.01%	Cs-137	0.01%	Cs-137	0.01%	--	--	--	--	--	--
--	--	Pu-241	0.01%	--	--	--	--	K-40	0.01%	--	--	--	--	--	--
--	--	Cs-137	0.01%	--	--	--	--	--	--	--	--	--	--	--	--
--	--	Cl-36	0.01%	--	--	--	--	--	--	--	--	--	--	--	--

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: orange (0.01% to 0.1%); blue (0.1% to 1%); yellow (1% to 10%); red (10% to 100%).

Table 8-41. Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Slit Trench Disposal Unit (Set 2)

ST09		ST10		ST11		ST14		ST18		ST23		ST24	
Open		Future		Future		Open		Future		Open		Open	
Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF
H-3X	100.00%	H-3	100.00%	I-129	100.00%	H-3	100.00%	H-3	100.00%	I-129	100.00%	H-3	100.00%
C-14X	46.84%	Tc-99	60.21%	Tc-99	51.00%	Tc-99	15.85%	I-129	14.97%	H-3A	76.43%	Np-237	25.99%
H-3	17.54%	I-129	37.04%	H-3	12.75%	I-129	9.07%	Tc-99	7.83%	Tc-99	50.34%	I-129	24.38%
Tc-99	9.77%	Sr-90	17.34%	Np-237	8.34%	Np-237	5.91%	Np-237	6.92%	H-3	41.11%	Tc-99	12.56%
I-129	6.55%	Np-237	16.75%	Sr-90	3.45%	Ni-63	0.63%	Ni-59	0.25%	Np-237	15.40%	Ni-59	0.38%
Np-237	3.83%	H-3B	15.61%	Ni-63	1.52%	Ni-59	0.29%	Ni-63	0.09%	I-129A	9.20%	Ni-63	0.33%
H-3B	2.80%	Tc-99B	5.18%	Ni-59	1.28%	Tc-99H	0.26%	Am-241	0.06%	Tc-99A	7.48%	Am-241	0.26%
Sr-90	2.63%	I-129B	4.90%	C-14	0.12%	Sr-90	0.08%	Pu-241	0.02%	Cs-137A	6.52%	Sr-90	0.18%
Tc-99B	0.95%	Ni-63	4.84%	Am-241	0.09%	C-14H	0.07%	Cs-137	0.02%	I-129K	2.56%	C-14	0.13%
Ni-63	0.87%	Ni-59	0.89%	Cs-137	0.08%	C-14	0.05%	C-14	0.02%	C-14K	1.71%	Pu-241	0.10%
I-129B	0.86%	Am-241	0.17%	C-14N	0.07%	Cs-137	0.04%	Sr-90	0.01%	Ni-59	1.30%	Cs-137	0.08%
Ni-59	0.18%	C-14	0.16%	Pu-241	0.04%	Am-241	0.03%	C-14N	0.01%	Ni-63	0.93%	K-40	0.01%
C-14	0.03%	Pu-241	0.09%	K-40	0.02%	Ag-108mH	0.02%	--	--	Sr-90	0.41%	--	--
Am-241	0.03%	Cs-137B	0.08%	--	--	C-14N	0.02%	--	--	Tc-99K	0.41%	--	--
Cs-137B	0.03%	Cs-137	0.07%	--	--	Pu-241	0.01%	--	--	Cs-137	0.34%	--	--
Cs-137	0.03%	Np-237B	0.02%	--	--	Ni-63H	0.01%	--	--	U-233E	0.26%	--	--
Pu-241	0.02%	Pa-231	0.02%	--	--	--	--	--	--	Ni-59A	0.17%	--	--
Np-237B	0.01%	Am-241B	0.01%	--	--	--	--	--	--	Am-241	0.16%	--	--
--	--	--	--	--	--	--	--	--	--	Np-237A	0.15%	--	--
--	--	--	--	--	--	--	--	--	--	C-14	0.14%	--	--
--	--	--	--	--	--	--	--	--	--	U-234A	0.13%	--	--
--	--	--	--	--	--	--	--	--	--	Nb-94	0.13%	--	--
--	--	--	--	--	--	--	--	--	--	Am-241A	0.10%	--	--
--	--	--	--	--	--	--	--	--	--	C-14A	0.09%	--	--
--	--	--	--	--	--	--	--	--	--	Cm-248A	0.07%	--	--
--	--	--	--	--	--	--	--	--	--	Pu-241	0.06%	--	--
--	--	--	--	--	--	--	--	--	--	Am-243	0.06%	--	--
--	--	--	--	--	--	--	--	--	--	Pu-239A	0.05%	--	--
--	--	--	--	--	--	--	--	--	--	Sn-126	0.05%	--	--
--	--	--	--	--	--	--	--	--	--	Pu-241A	0.05%	--	--
--	--	--	--	--	--	--	--	--	--	Ni-63A	0.03%	--	--
--	--	--	--	--	--	--	--	--	--	K-40	0.02%	--	--

Table 8-41 (cont'd). Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Slit Trench Disposal Unit (Set 2)

ST09		ST10		ST11		ST14		ST18		ST23		ST24	
Open		Future		Future		Open		Future		Open		Open	
Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF
--	--	--	--	--	--	--	--	--	--	Cm-247A	0.02%	--	--
--	--	--	--	--	--	--	--	--	--	U-233A	0.02%	--	--
--	--	--	--	--	--	--	--	--	--	Ra-226	0.01%	--	--
--	--	--	--	--	--	--	--	--	--	Pu-239	0.01%	--	--
--	--	--	--	--	--	--	--	--	--	U-234	0.01%	--	--
--	--	--	--	--	--	--	--	--	--	U-235	0.01%	--	--
--	--	--	--	--	--	--	--	--	--	Sr-90A	0.01%	--	--
--	--	--	--	--	--	--	--	--	--	U-232	0.01%	--	--

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: orange (0.01% to 0.1%); blue (0.1% to 1%); yellow (1% to 10%); red (10% to 100%).

Table 8-42. Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Engineered Trench Disposal Unit

ET01		ET02		ET03		ET04		ET05		ET07		ET08		ET09	
Closed		Open		Open		Future		Future		Future		Future		Future	
Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF	Radio-nuclide	Max SOF
H-3	100.00%	Np-237	100.00%	Np-237	100.00%	H-3	100.00%	Np-237	100.00%	Np-237	100.00%	Np-237	100.00%	Np-237	100.00%
I-129	7.25%	H-3	48.57%	H-3	31.16%	I-129	66.46%	H-3	57.87%	H-3	35.52%	H-3	34.40%	H-3	33.74%
Np-237	4.73%	Tc-99	48.26%	I-129	20.19%	Tc-99	54.84%	Tc-99	11.86%	Sr-90	18.58%	Sr-90	29.08%	Sr-90	32.40%
Tc-99	3.89%	I-129	11.07%	Tc-99	10.26%	Np-237	11.92%	I-129	7.00%	I-129	8.91%	I-129	8.49%	Ni-63	8.80%
I-129J	1.29%	Am-241	0.43%	C-14	1.03%	Ni-63	5.22%	Ni-63	0.48%	Tc-99	7.17%	Ni-63	8.16%	Tc-99	8.24%
I-129D	0.57%	Pu-241	0.20%	Am-241	0.22%	Sr-90	3.09%	Am-241	0.34%	Ni-63	6.75%	Tc-99	7.98%	I-129	8.17%
Ni-63	0.21%	Ni-59	0.18%	Pu-241	0.08%	Ni-59	0.69%	Sr-90	0.23%	C-14	0.76%	C-14	0.73%	C-14	0.74%
I-129E	0.17%	C-14	0.13%	Cs-137	0.05%	C-14	0.17%	Pu-241	0.14%	Ni-59	0.24%	Am-241	0.25%	Am-241	0.26%
Ni-59	0.11%	Sr-90	0.03%	Sr-90	0.01%	Am-241	0.07%	Ni-59	0.12%	Am-241	0.22%	Ni-59	0.23%	Ni-59	0.24%
I-129H	0.07%	Ni-63	0.02%	Pa-231	0.01%	Cs-137	0.06%	C-14	0.09%	Pu-241	0.09%	Pu-241	0.10%	Pu-241	0.11%
I-129G	0.06%	Pa-231	0.02%	--	--	Pu-241	0.03%	Pa-231	0.02%	Ra-226	0.03%	Cs-137	0.05%	Cs-137	0.06%
C-14	0.02%	Cs-137	0.01%	--	--	Cl-36	0.01%	Ra-226	0.01%	Cs-137	0.03%	Ra-226	0.03%	Ra-226	0.03%
Am-241	0.01%	U-232	0.01%	--	--	U-232	0.01%	Cs-137	0.01%	Th-230	0.02%	Th-230	0.02%	Th-230	0.02%
Cl-36	0.01%	U-233	0.01%	--	--	U-233	0.01%	--	--	Pa-231	0.02%	Pa-231	0.02%	Pa-231	0.02%
Cs-137	0.01%	--	--	--	--	Ra-226	0.01%	--	--	U-234	0.01%	U-234	0.01%	U-234	0.01%
--	--	--	--	--	--	--	--	--	--	U-232	0.01%	U-232	0.01%	U-232	0.01%

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: orange (0.01% to 0.1%); blue (0.1% to 1%); yellow (1% to 10%); red (10% to 100%).

Table 8-43. Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Vault

LAWV		ILV	
Open		Open	
Radionuclide	Max SOF	Radionuclide	Max SOF
I-129	100.00%	I-129	100.00%
Cs-137	4.15%	H-3	23.07%
Sr-90	0.74%	I-129C	8.57%
Nb-94	0.29%	H-3T	1.90%
Ra-226	0.17%	Ra-226	0.40%
H-3	0.08%	H-3R	0.32%
Tc-99	0.05%	Cs-137T	0.31%
--	--	Cs-137	0.13%
--	--	Ar-39T	0.02%

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: orange (0.01% to 0.1%); blue (0.1% to 1%); yellow (1% to 10%); red (10% to 100%).

Table 8-44. Rank Ordering of Normalized Sum-of-Fractions Contributions for Each Naval Reactor Component Disposal Area

NR07E		NR26E	
Closed		Open	
Radionuclide	Max SOF	Radionuclide	Max SOF
Tc-99S	100.00%	Tc-99S	100.00%
Am-241S	7.52%	Sr-90S	39.03%
Sr-90S	3.29%	Sn-121mS	16.50%
Am-243S	1.50%	Am-241S	13.67%
Mo-93S	0.49%	I-129	11.58%
Nb-93mS	0.39%	Tc-99	9.30%
C-14S	0.37%	C-14S	8.37%
I-129S	0.33%	Am-243S	7.59%
Sn-126S	0.07%	Sn-126S	2.94%
--	--	Mo-93S	0.93%
--	--	I-129S	0.26%
--	--	Nb-93mS	0.25%
--	--	C-14	0.15%
--	--	Nb-94S	0.13%
--	--	Co-60S	0.05%

Notes:

Normalized SOF contributions computed based on best-estimate CWTS 2065 projected closure inventories.

Ranges used in color coding: orange (0.01% to 0.1%); blue (0.1% to 1%); yellow (1% to 10%); red (10% to 100%).

8.7.3. Maximum Sum-of-Fractions by Exposure Pathway

Maximum SOFs can be computed for each pathway and time window using the inventory limits and CWTS projected inventories provided in this chapter. The CWTS inventories used here are unbiased values that are directly input into CWTS from waste generators. Calculation results are provided in Table 8-45.

Table 8-45. Maximum Sum-of-Fractions for Each Disposal Unit by Exposure Pathway Based on CWTS Projected 2065 Inventories

DU	DU Status	GW Pathways								IHI Pathways		Air Pathway	Radon Pathway
		Beta-Gamma			Gross-Alpha	Radium	Uranium	All-Pathways					
		BG1	BG2	BG3				AP1	AP2	Acute	Chronic		
ST01	Closed	9.50E-01	2.62E-02	3.07E-02	2.56E-05	0.00E+00	1.57E-15	8.97E-04	5.17E-04	8.60E-06	7.12E-06	7.90E-06	5.76E-05
ST02	Closed	7.74E-02	6.61E-01	9.50E-01	2.18E-02	3.48E-09	2.31E-11	3.54E-02	2.38E-02	2.93E-05	2.85E-05	1.58E-05	3.44E-06
ST03	Closed	6.84E-02	9.50E-01	6.32E-01	4.41E-01	1.69E-10	4.52E-10	1.02E-01	5.03E-02	3.04E-05	6.26E-05	3.14E-06	2.30E-06
ST04	Closed	6.82E-01	9.50E-01	4.27E-01	1.41E-01	2.50E-08	1.50E-10	8.30E-02	2.89E-02	5.51E-05	6.06E-05	7.93E-06	5.36E-06
ST05	Closed	9.63E-02	9.50E-01	4.37E-01	4.10E-01	1.24E-05	7.63E-11	5.74E-02	5.77E-02	5.04E-05	8.73E-05	5.34E-06	8.87E-06
ST06	Open	7.98E-01	1.00E+00	3.02E-01	7.52E-01	2.40E-05	2.03E-10	4.24E-02	9.44E-02	5.79E-04	6.03E-04	7.11E-06	7.81E-04
ST07	Open	1.00E+00	3.07E-01	1.42E-01	4.74E-01	5.38E-07	1.22E-10	1.46E-02	5.88E-02	1.74E-04	5.88E-05	9.91E-06	3.29E-07
ST08	Open	9.64E-01	1.00E+00	6.72E-01	1.09E-02	1.83E-05	7.60E-12	1.64E-02	7.98E-03	2.63E-04	6.68E-05	6.39E-06	5.41E-07
ST09	Open	1.00E+00	4.72E-01	3.58E-01	2.65E-02	1.14E-05	2.03E-11	6.27E-02	5.36E-02	4.08E-04	1.45E-04	1.15E-04	2.78E-06
ST10	Future	8.80E-01	1.00E+00	3.71E-01	1.30E-01	6.64E-05	1.23E-10	7.39E-02	2.07E-02	1.17E-03	4.13E-04	1.00E-05	7.95E-06
ST11	Future	9.90E-02	1.00E+00	9.67E-01	6.57E-02	2.56E-05	7.58E-11	5.57E-02	2.91E-02	7.43E-04	5.44E-04	2.61E-05	3.99E-05
ST14	Open	1.00E-00	2.63E-01	1.46E-01	5.96E-02	1.21E-06	3.03E-11	2.01E-02	1.32E-02	4.22E-04	5.03E-04	6.85E-04	3.25E-06
ST18	Future	1.00E+00	2.32E-01	1.69E-01	7.00E-02	1.68E-07	2.47E-11	1.09E-02	1.15E-02	2.22E-04	1.62E-04	5.84E-06	7.06E-06
ST23	Open	6.48E-01	1.00E+00	6.33E-01	8.61E-02	6.97E-07	6.29E-11	4.82E-02	2.16E-02	2.31E-03	4.67E-02	2.70E-05	5.17E-05
ST24	Future	1.00E+00	3.80E-01	2.06E-01	2.63E-01	1.00E-06	6.70E-11	1.90E-02	3.46E-02	8.89E-04	6.47E-04	1.50E-05	2.82E-05
ET01	Closed	1.00E+00	1.31E-01	8.08E-02	4.71E-02	1.22E-05	1.46E-11	5.60E-03	6.81E-03	6.42E-05	9.65E-05	1.69E-05	5.53E-05
ET02	Open	9.72E-01	2.26E-01	7.49E-02	1.00E+00	5.51E-05	4.72E-10	4.20E-02	1.22E-01	1.78E-04	4.75E-04	6.63E-06	5.76E-06
ET03	Open	3.16E-01	3.07E-01	1.02E-01	1.00E+00	0.00E+00	1.47E-10	1.62E-02	1.23E-01	4.96E-04	3.61E-04	9.60E-06	4.46E-06
ET04	Future	7.66E-01	1.00E+00	6.04E-01	9.20E-02	1.49E-05	1.20E-10	6.08E-02	2.18E-02	5.09E-04	6.84E-04	2.59E-05	4.86E-05
ET05	Future	6.97E-01	1.21E-01	6.91E-02	1.00E+00	1.10E-04	5.33E-10	3.30E-02	1.21E-01	7.79E-05	1.01E-04	2.33E-06	4.44E-06
ET07	Future	4.26E-01	4.03E-01	7.34E-02	1.00E+00	5.85E-04	2.20E-10	1.99E-02	1.22E-01	2.88E-04	3.88E-04	1.36E-05	2.75E-05
ET08	Future	4.22E-01	5.16E-01	7.41E-02	1.00E+00	6.12E-04	2.30E-10	2.31E-02	1.22E-01	3.82E-04	5.14E-04	1.81E-05	3.65E-05
ET09	Future	4.19E-01	5.50E-01	7.40E-02	1.00E+00	6.29E-04	2.34E-10	2.38E-02	1.22E-01	4.17E-04	5.60E-04	1.97E-05	3.98E-05
LAWV	Open	8.32E-04	1.00E+00	--	0.00E+00	0.00E+00	0.00E+00	4.63E-06	9.41E-03	7.39E-07	5.35E-02	1.25E-12	1.21E-06
ILV	Open	2.33E-01	1.00E+00	--	0.00E+00	0.00E+00	0.00E+00	1.94E-03	9.52E-03	2.85E-05	7.67E-03	5.90E-08	2.74E-06
NR07E	Closed	1.38E-01	--	--	4.70E-12	0.00E+00	3.02E-24	1.45E-02	--	1.99E-08	1.83E-02	5.15E-04	0.00E+00
NR26E	Open	8.38E-02	1.00E+00	--	1.16E-07	0.00E+00	1.20E-17	8.33E-03	9.60E-02	1.45E-06	6.83E-01	7.18E-02	0.00E+00

Notes:

Maximum SOFs are based on CWTS 2065 projected closure inventories where no bias or uncertainty is applied. Pathway and time windows (BG1, BG2, BG3, AP1, AP2) containing the maximum SOF are shaded in red. Time windows not used are marked by "--." DU status shading: open (green), closed (gray), future (unshaded).

For each DU, the pathway (and its time window) where the imposed limit (SOF = 1.0) or administrative limit (SOF = 0.95) is reached is highlighted in red. As indicated in Table 8-45, beta-gamma and gross-alpha represent the most limiting GW pathways across the entire ELLWF. The SOFs allow for a comparison of differing pathways because the SOFs represent normalized margins to their appropriate POs. To compare other pathways (PW) to the most limiting pathway (GW in this case), a relative SOF ratio is computed as follows:

$$\varepsilon_{DU} \equiv \frac{SOF_{DU}^{PW-max}}{SOF_{DU}^{GW-max}} \quad \text{Eq. (8-13)}$$

where:

SOF_{DU}^{PW-max}	DU's maximum SOF for specific PW pathway (unitless)
SOF_{DU}^{GW-max}	DU's maximum SOF for the GW pathways (unitless)
ε_{DU}	Relative SOF ratio (unitless)

Ratios less than 1.0 reflect the degree to which a GW pathway is limiting relative to other exposure pathways, which is the relative margin.

Results for this PA are provided in Table 8-46 where the GW and IHI pathways are collapsed to single values representing the maximum SOFs across time windows and sub-pathways. For each non-GW exposure pathway (IHI, air, and radon), the DU with the maximum SOF is highlighted in red. The three righthand columns in Table 8-46 list the relative margins (SOF ratios) by pathway and DU. The DU with the maximum SOF ratio for each non-GW pathway is highlighted in orange.

Figure 8-31 presents a graphical, rank-ordered comparison of margins for the IHI, air, and radon pathways relative to the limiting GW pathway using the SOF ratios from Table 8-46. The air pathway SOF ratio for the LAWV is less than 10^{-11} and is omitted from Figure 8-31.

Average SOF ratios by exposure pathway are as follows:

- **GW:** 1.0 or 0.95 (most limiting pathway for all ELLWF DUs)
- **IHI:** 4.66×10^{-3} (all 27 DUs included except NRCDAs)
- **Air:** 4.43×10^{-5} (all 27 DUs included except LAWV and NRCDAs)
- **Radon:** 4.92×10^{-5} (all 27 DUs included except NRCDAs)

Table 8-46. Sum-of-Fraction Margin Comparison for Each Disposal Unit by Exposure Pathway

DU	GW (SOF max)	IHI (SOF max)	Air (SOF)	Radon (SOF)	IHI (ratio)	Air (ratio)	Radon (ratio)
ST01	9.50E-01	8.60E-06	7.90E-06	5.76E-05	9.06E-06	8.31E-06	6.06E-05
ST02	9.50E-01	2.93E-05	1.58E-05	3.44E-06	3.09E-05	1.67E-05	3.62E-06
ST03	9.50E-01	6.26E-05	3.14E-06	2.30E-06	6.59E-05	3.31E-06	2.43E-06
ST04	9.50E-01	6.06E-05	7.93E-06	5.36E-06	6.38E-05	8.35E-06	5.64E-06
ST05	9.50E-01	8.73E-05	5.34E-06	8.87E-06	9.19E-05	5.62E-06	9.34E-06
ST06	1.00E+00	6.03E-04	7.11E-06	7.81E-04	6.03E-04	7.11E-06	7.81E-04
ST07	1.00E+00	1.74E-04	9.91E-06	3.29E-07	1.74E-04	9.91E-06	3.29E-07
ST08	1.00E+00	2.63E-04	6.39E-06	5.41E-07	2.63E-04	6.39E-06	5.41E-07
ST09	1.00E+00	4.08E-04	1.15E-04	2.78E-06	4.08E-04	1.15E-04	2.78E-06
ST10	1.00E+00	1.17E-03	1.00E-05	7.95E-06	1.17E-03	1.00E-05	7.95E-06
ST11	1.00E+00	7.43E-04	2.61E-05	3.99E-05	7.43E-04	2.61E-05	3.99E-05
ST14	1.00E+00	5.03E-04	6.85E-04	3.25E-06	5.03E-04	6.85E-04	3.25E-06
ST18	1.00E+00	2.22E-04	5.84E-06	7.06E-06	2.22E-04	5.84E-06	7.06E-06
ST23	1.00E+00	4.67E-02	2.70E-05	5.17E-05	4.67E-02	2.70E-05	5.17E-05
ST24	1.00E+00	8.89E-04	1.50E-05	2.82E-05	8.89E-04	1.50E-05	2.82E-05
ET01	1.00E+00	9.65E-05	1.69E-05	5.53E-05	9.65E-05	1.69E-05	5.53E-05
ET02	1.00E+00	4.75E-04	6.63E-06	5.76E-06	4.75E-04	6.63E-06	5.76E-06
ET03	1.00E+00	4.96E-04	9.60E-06	4.46E-06	4.96E-04	9.60E-06	4.46E-06
ET04	1.00E+00	6.84E-04	2.59E-05	4.86E-05	6.84E-04	2.59E-05	4.86E-05
ET05	1.00E+00	1.01E-04	2.33E-06	4.44E-06	1.01E-04	2.33E-06	4.44E-06
ET07	1.00E+00	3.88E-04	1.36E-05	2.75E-05	3.88E-04	1.36E-05	2.75E-05
ET08	1.00E+00	5.14E-04	1.81E-05	3.65E-05	5.14E-04	1.81E-05	3.65E-05
ET09	1.00E+00	5.60E-04	1.97E-05	3.98E-05	5.60E-04	1.97E-05	3.98E-05
ILV	1.00E+00	7.67E-03	5.90E-08	2.74E-06	7.67E-03	5.90E-08	2.74E-06
LAWV	1.00E+00	5.35E-02	1.25E-12	1.21E-06	5.35E-02	1.25E-12	1.21E-06
NR07E	1.38E-01	1.83E-02	5.15E-04	0.00E+00	1.32E-01	3.73E-03	NA
NR26E	1.00E+00	6.83E-01	7.18E-02	0.00E+00	6.83E-01	7.18E-02	NA

Notes:

NA = not applicable

The DU where the maximum SOF occurs for the non-limiting IHI, air, and radon pathways is shaded in red.

The DU where the maximum SOF ratio occurs for the non-limiting IHI, air, and radon pathways is shaded in orange.

A GW pathway is generally limiting by significant margins as evidenced by the average SOF ratios above. However, following are four cases where the margins are less than two orders of magnitude (above red-dashed line in Figure 8-31):

- **NR26E:** IHI SOF ratio = 0.683 IHI Chronic > Acute
- **NR07E:** IHI SOF ratio = 0.132 IHI Chronic > Acute
- **LAWV:** IHI SOF ratio = 0.0535 IHI Chronic > Acute
- **ST23:** IHI SOF ratio = 0.0467 IHI Chronic > Acute

In all four cases, the IHI chronic SOF exceeds the IHI acute, air, and radon pathways values. For NR07E and NR26E, only parent radionuclides contained within the NRCDAS SWF (welded casks) contribute to the total SOF for the IHI pathways.

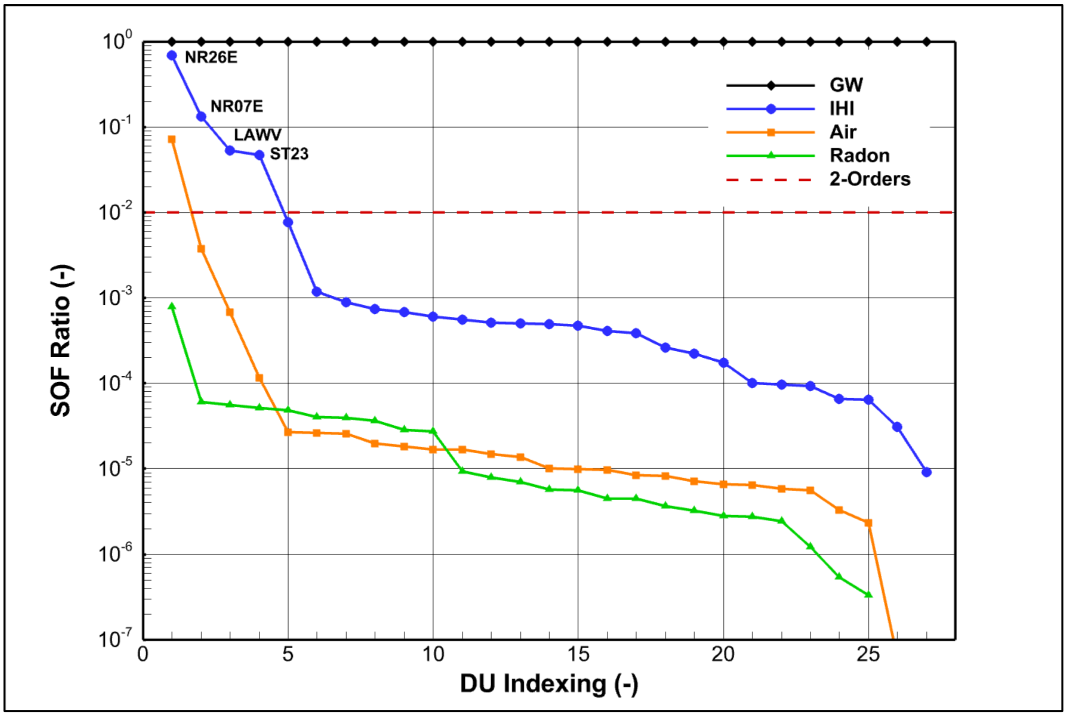


Figure 8-31. Rank-Ordered Sum-of-Fraction Ratios Elucidating Degree of Margin Between Groundwater-Limiting SOFs and Other Pathways

NR07E is a closed DU with a total SOF equal to 0.138 (Table 8-46, second column). Conversely, the projected total SOF for NR26E is 1.0 assuming this open NR pad hits its activity capacity. The largest SOF contributor for both NRCDAs is Tc-99S. As discussed in Section 7.4.5, the IHI SOF ratio values for NR07E and NR26E can be lowered substantially if explicit gamma-ray analyses are implemented that address actual cask materials.

For the LAWV, the main contributor to the IHI chronic pathway is Cs-137, accounting for 78% of the total SOF. Because Cs-137 is a strong gamma-ray emitter, its contribution can also be significantly reduced if explicit gamma-ray analyses are incorporated into the LAWV IHI model by assuming actual LAWV construction materials for shielding instead of soil properties.

Cs-137A is also the main contributor to the IHI chronic pathway for ST23, accounting for 77% of the total SOF. As for the LAWV, explicit gamma-ray analyses could substantially reduce Cs-137's SOF contribution by employing actual construction materials for the CIG grout.

8.8. REFERENCES

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