Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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E-Area Low-Level Waste Facility Multitiered Groundwater and Intruder Radionuclide Screening

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January 2021

SRNL-STI-2020-00566, Revision 0

SRNL.DOE.GOV

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Prepared for
U.S. Department of Energy

Keywords: *Performance Assessment, Groundwater screening, Intruder screening, ELLWF*

Retention: *Permanent*

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EXECUTIVE SUMMARY

Solid Waste Management (SWM) operates the E-Area Low-Level Waste Facility (ELLWF) where low level on-site and off-site solid waste streams are buried. The facility has been in operation since late 1994 and is currently projected to remain in operation until 2065. This facility can accommodate a broad range of waste forms resulting from the six different types of disposal unit (DU) options (i.e., varying degrees of engineered barriers → trenches to concrete vaults). This facility is currently operating under a Performance Assessment (PA) issued back in 2008, along with several subsequent supporting Special Analyses (SA). The Savannah River National Laboratory (SRNL) developed the prior PAs and SAs and was tasked to update the facility's upcoming PA, mostly likely to be issued during FY2022. For operating the E-Area facility, a Waste Inventory Tracking System (e.g., WITS) is actively employed by waste generators where every radionuclide entering the facility (to be buried in one of its many DUs[1]) must be either directly or indirectly accounted for. Since there is a large number of radionuclides in existence (>3,000), the International Commission on Radiological Protection (ICRP), specially ICRP Publication 107) has provided guidance on the subset of radionuclides requiring further assessment in landfills such as the E-Area LLWF. The ICRP-107 publication provides critical radiological information on 1,252 radionuclides consisting of 97 elements. This database, along with the current dose coefficients that have been developed for these radionuclides in DOE-STD-1196-2011 (DOE 2011), is the critical starting point for developing a consistent inventory limit system.

An earlier screening effort was performed (i.e., Aleman and Hamm 2020) where it was deemed appropriate/necessary to add an additional screening tier (i.e., Tier-2) to further reduce those parent radionuclides that would require explicit inventory tracking within the E-Area LLWF. This report accomplishes this along with other additional upgrades made to the Tier-1 analyses, including the option to have trigger-value radionuclides[2]. The parent radionuclide listings presented in this report supersede all prior screening efforts associated with the ELLWF and will be employed directly in the upcoming PA.

The explicit measurement and tracking of all 1,252 ICRP-107 radionuclides can be reduced when process knowledge, burial history, and radiological aspects are factored into conservative groundwater and intruder screening processes. Across the DOE complex these screening processes have been historically performed using the methodology suggested by the National Council on Radiation Protection and Measurements (NCRP) as presented in their original report (NCRP 1984) and then refined in a later report (NCRP 1996). In the recommended screening models employed within this report the traditional NCRP models are updated to better handle progeny and better reflect the known characteristics of E-Area. This improved screening process is referred to as the "NCRP-like" method. Various upgrades to the traditional NCRP methodology have been used by others (e.g., NRC funded effort by Kennedy and Strenge 1992). The more detailed models by Kennedy and Strenge (1992) were considered in this effort and are compared to the results from the more traditional NCRP-like models.

[1] The phrase "disposal unit" or the acronym "DU" used throughout this report is a PA term referring to a single disposal location, e.g., Slit Trench 1 (ST01).

[2] Trigger-value radionuclides are typically radionuclides that do not have explicit WITS inventory limits and are on a separate watch list. If a trigger value is exceeded, then its radionuclide is considered for inclusion it into WITS.

The groundwater and inadvertent intruder screening analyses presented in this report begin with this 1,252 radionuclide list and reduces it down to more manageable lists that are applicable to the various DU types contained within E-Area. In order to reduce this starting list, some level of exposure risk must be considered acceptable. Historically, a dose (or concentration level) has been compared to a screening criterion set to 1% of a performance measure (e.g., a beta-gamma dose not to exceed the 4 mrem/yr beta-gamma performance measure x 0.01 = 0.04 mrem/yr). Thus, if a radionuclide produced a bounding or screening-level dose (or concentrations) less than the screening criterion, it could be safely removed from further consideration. Several tiers of screening and bounding level analyses have been considered in this report.

In this screening effort, the performance measure has been tightened up by:

- Consistently looking at every exposure pathway regardless of the tier level; and
- Requiring that a pathway's maximum exposure not exceed 0.1% of the applicable performance measure (e.g., 0.1% of the 4 mrem/yr performance measure x 0.001 = 0.004 mrem/yr) over the entire period of performance. Post-assessments indicate that this 0.1% criterion yields acceptable residual Sum-of-Fraction (SOF) values for the screened-out radionuclides.

Bullet one ensures that no inconsistencies exist in between varying tiers such that a radionuclide passed on to the PA-level analysis would not have been first screened out at a higher level. Bullet two provides additional risk reduction in the very unlikely scenario that a set of radionuclides screened out from further consideration in a pathway would produce a cumulative dose impact approaching the applicable performance measure. The upper bound estimate on that risk is <0.18% increase in a disposal unit's sum-of-fractions.

In addition, in this updated screening effort, the "upper bound" inventory estimates for screening purposes (i.e., the projected closure inventories) have been scaled up by a factor of ten. This scaling factor is being applied to address various uncertainty aspects in estimating E-Area closure inventories.

In developing an overall inventory limits system, a tiered approach is most efficient with respect to its acceptance and maintenance. For example, if the tracking of a significant number of radionuclides can be omitted through relatively simple, and acceptable, arguments/models the overall costs are greatly reduced (i.e., both up front and maintenance costs). The overall structure of the E-Area tiered inventory limit system is:

- **Tier-0** - Initial screening list based on radiological and process knowledge aspects
- **Tier-1** - "NCRP-like" groundwater and intruder screening (very conservative)
- **Tier-2** - Simple, but bounding, 1D "Hybrid" fate and transport modeling (conservative)
- **Tier-3** - Generic waste (multi-D, no credit taken for any possible waste form barriers)
- **Tier-4** - Special waste form (multi-D, credit taken for certain waste form barriers)

The first three tiers constitute the groundwater and inadvertent intruder screening steps. The key outputs from this screening process is a significantly reduced set of radionuclides requiring more complex multi-dimensional fate and transport analyses in either Tier-3 or Tier-4. Within this updated screening report only Tier-0, Tier-1, and Tier-2 results are presented. Tier-3 and Tier-4 results are developed in detailed PA calculations where the Tier-1 and Tier-2 radionuclide lists generated here are used for inadvertent intruder and groundwater analyses, respectively.

In the groundwater and intruder screening described in this report, the list of radionuclides that failed the Tier-0, -1 and -2 screening (i.e., passed through requiring detailed PA analysis) included some that have never been reported by low-level waste (LLW) generators nor identified by SWM in their E-Area closure inventory estimates (Sink 2016, Simmons 2020). Ignoring these low-probability radionuclides presents a risk of an unanalyzed disposal condition in the future. Within the current E-Area limits system, radionuclides not found nor projected to be disposed in E-Area have been tracked using "trigger values" as a means of limiting the number of radionuclides managed/tracked inside WITS, thus reducing the level of effort for detailed PA calculations. The trigger value represents the number of curies of a radionuclide that would result in 0.1% of the limiting performance objective (PO) when employing the conservative GW or Intruder screening model (e.g., 4 mrem/yr beta-gamma PO x 0.001 = 0.004 mrem/yr screening criterion). The GW trigger values provided in this report are "preliminary" values where the impacts associated with plume overlap (i.e., the co-mingling of aquifer contaminant plumes emanating out from neighboring DUs) have not been included. In a follow up report addressing plume interaction factors (PIF), these preliminary trigger values will be adjusted downward to account for plume overlap. Since all inadvertent intruder exposure scenarios do not involve either the aquifer or the atmosphere, the inadvertent intruder trigger values are final values.

This "Trigger Value" list of radionuclides and associated curies are tracked outside of WITS. If a radionuclide inventory is received in the future, whose trigger value is exceeded, then SWM Engineering makes the decision whether, or at what point, to perform a Special Analysis to add the new radionuclide and disposal limit to WITS. With the implementation of a new multitiered disposal limits system, SWM will need to make the decision on whether to continue employing trigger values in managing LLW disposal inventory.

In the multitiered approach undertaken in this report, supplemental tracking of these low-probability radionuclides is optional. This multitiered approach never screened out a radionuclide based on its absence from E-Area. All 1,252 radionuclides contained within the original ICRP-107 lists were processed. However, the trigger-value option is provided and, in some cases, may be deemed appropriate and recommended. The methodology and results of trigger value calculations are described in Chapter 5.

In the 2022 PA revision there will be a total of 33 DUs (closed, active, and future units) contained within the E-Area footprint:

- **Engineered Trenches (ETs)** - (9 ET units) [ET01, ET02, ET03, ET04, ET05, ET06, ET07, ET08, ET09];
- **Slit Trenches (STs)** - (20 ST units) [ST01, ST02, ST03, ST04, ST05, ST06, ST07, ST08, ST09, ST10, ST11, ST14, ST17, ST18, ST19, ST20, ST21, ST22, ST23, ST24];
- **Low Activity Waste Vault (LAWV)** - (1 LAWV unit);
- **Intermediate Level Vault (ILV)** - (1 ILV unit); and
- **Naval Reactor Component Disposal Areas (NRCDAs)** - (2 NRCDA units) [NRCDA-7E, NRCDA-26E].

Note that Component-in-Grout (CIG) trenches, CIG01 and CIG02, are being repurposed as Slit Trenches, ST23 and ST24, respectively, in the next PA. The existing CIG segments in CIG01 (ST23) will be treated as special wasteforms.

For groundwater and inadvertent intruder screening purposes these five types of DUs were represented by the following five screening models:

- **Trench** [represents all ETs, STs, and former CIG trenches];
- **LAWV;**
- **ILV; and**
- **NRCDAG** [represents a **NRCDA** model for generic Naval Reactor waste]; and
- **NRCDAS** [represents a **NRCDA** model for special waste forms].

Table ES-1 provides the number of radionuclides remaining (i.e., not screened out) at each tier. Starting with the ICRP-107 list of 1,252 radionuclides, Tier-0 significantly reduces this number by more than 75% by considering radionuclide decay and process knowledge. Employing conservative screening models, Tier-1 and Tier-2 further reduce this number for each pathway and DU type. The resulting numbers of groundwater and inadvertent intruder radionuclides remaining at each tier for each DU type is based on a union of the various unique pathways considered, specifically:

- **Groundwater** – Beta-Gamma, Gross Alpha, Radium, Uranium, and All-Pathways; and
- **Inadvertent Intruder** – Acute Intruder and Chronic Intruder.

In Table ES-1 the number of Tier-1 "parent" radionuclides remaining (highlighted in light green and orange for groundwater and inadvertent intruder, respectively) after the "NCRP-like" groundwater and intruder screening are shown for each DU model (i.e., parent implies the first member in a decay chain with the total dose from that decay chain consisting of the rolled-up contributions from that parent and its progeny). The list of Tier-1 groundwater radionuclides for each DU type were then employed as input into a groundwater-only Tier-2 process. The results of the groundwater Tier-2 screening are also shown in Table ES-1 (highlighted in middle green). The Tier-2 screening is based on a 1D "Hybrid" model where the Waste and Vadose zones aspect of the NCRP-like model are replaced with a detailed 1D PORFLOW fate and transport model.

Finally, the number of radionuclides failing the Tier-1 (inadvertent intruder) and Tier-2 (groundwater) screening processes by pathway (i.e., who's maximum SOF exceeds the 0.1% screening criterion) are divided into: (1) a "Trigger Values" list (i.e., those radionuclides not found nor projected to be disposed in E-Area) and (2) a "Minimum Requiring Limits" list (i.e., those radionuclides with estimated inventories at E-Area closure). Thus, application of this multitiered inventory limits system explicitly addresses all 1,252 radionuclides from the original ICRP-107 list through screening where those radionuclides that are not screened out have either trigger values or disposal limits.

Based on the recommended (i.e., Tier-1 "NCRP-like" and Tier-2 1D "Hybrid" models for screening) groundwater and intruder screening methodologies, the list of parent nuclides that fail the screening criterion (i.e., 0.1% SOF) are summarized in the Summary and Conclusion Section (Chapter 4.0) for each of the DU screening models.

Further reductions in the Trigger Values list shown in Table ES-1 (i.e., reduced numbers as provided in parentheses for trigger value listings) were made where process knowledge associated with the expected abundances of very "heavy" elements during reactor core irradiation was considered and discussed in Appendix L. Further reductions can be considered in future efforts when additional process knowledge becomes available (e.g., noble gases, additional heavy elements, fission products, or neutron activated products as discussed in Appendix L) to refine the screening process.

The starting point for subsequent inadvertent intruder and groundwater detailed PA calculations (i.e., Tier-3 and Tier-4) are the Tier-1 and Tier-2 listings, respectively. These specific listings are provided in Chapter 4.0 and Chapter 5.0 and can be located based on the table references listed in Table ES-2 or in Table ES-3 depending on whether or not trigger-values are to be employed by SWM.

Table ES-1. Number of radionuclides remaining after screening.[h]

Tier Level	Pathway	Trench	ILV	LAWV	NRCDAG	NRCDAS
ICRP-107[a]	na	1,252	1,252	1,252	1,252	1,252
Tier-0[b]	na	271	272	271	295	295
Tier-1[c]	Beta-Gamma	131	110	102	129	91
	Gross Alpha	83	80	75	75	67
	Radium	12	11	12	8	10
	Uranium	19	27	18	24	19
	All-Pathways	129	138	128	128	118
	Groundwater[d]	163	141	134	157	122
	Acute Intruder	56	24	7	26	30
	Chronic Intruder	88	29	20	29	75
	Inadvertent Intruder[e]	88	29	20	29	75
Tier-2[f]	Beta-Gamma	37	39	36	32	27
	Gross Alpha	21	20	16	15	14
	Radium	3	2	1	1	0
	Uranium	1	1	1	1	1
	All-Pathways	40	44	37	35	30
	Groundwater[g]	43	45	39	38	31
Trigger Values[i]	Groundwater	16 (12)	25 (21)	20 (16)	25 (21)	20 (17)
	Inadvertent Intruder	56 (50)	27 (27)	20 (20)	28 (28)	62 (57)
Minimum Requiring Limits[j]	Groundwater	27	20	19	13	11
	Inadvertent Intruder	32	2	0	1	13

[a] The initial number of parent radionuclides being considered consistent with ICRP-107.
[b] The initially reduced number of parent radionuclides considered where radionuclides were screened out based on radiological and process knowledge aspects for SRS and Naval Reactor operations.
[c] The number of parent radionuclides remaining after Tier-1 screening on a pathway basis.
[d] The Tier-1 number of parent radionuclides remaining (highlighted in light green) for groundwater. This represents the union of the five groundwater pathway sets of radionuclides failing the Tier-1 screening.
[e] The Tier-1 number of parent radionuclides remaining (highlighted in orange) for inadvertent intruder. This represents the union of the two intruder pathway sets of radionuclides passing the Tier-1 screening.
[f] The number of parent radionuclides remaining after Tier-2 screening on a pathway basis. Tier-2 screening only performed for groundwater pathways.

[g] The Tier-2 number of parent radionuclides remaining (highlighted in medium green) for groundwater. This represents the union of the five groundwater pathway sets of radionuclides passing the Tier-2 screening.
[h] The number of parent radionuclides listed represents the total non-screened out radionuclides. These listings can be further broken into two groups: (1) those having trigger values, and (2) those requiring inventory limits.
[i] The number of radionuclides which can have trigger values (i.e., all radionuclides not screened out that have no WITS inventories nor estimated closure inventories). The reduced numbers within the parentheses present the elimination of heavy elements consistent with the recommendations provided in Appendix L.
[j] The minimum number of radionuclides that will require subsequent Tier-3 and Tier-4 analyses (i.e., the case where all available trigger-value radionuclides are employed).

Table ES-2. List of parent radionuclides requiring subsequent Tier-3 or Tier-4 Analyses including all potential trigger-value radionuclides.

Tier Level	Pathway	Trench	ILV	LAWV	NRCDAG	NRCDAS
Tier-1	Inadvertent Intruder[a]	Table 4-10	Table 4-2	Table 4-4	Table 4-6	Table 4-8
Tier-2	Groundwater[b]	Table 4-16	Table 4-12	Table 4-13	Table 4-14	Table 4-15

[a] List of parent radionuclides, provided in Chapter 4.0 (Section 4.3), requiring subsequent analyses for inadvertent intruder.
[b] List of parent radionuclides, provided in Chapter 4.0 (Section 4.4), requiring subsequent analyses for groundwater.

Table ES-3. List of parent radionuclides requiring subsequent Tier-3 or Tier-4 Analyses excluding all potential trigger-value radionuclides.

Tier Level	Pathway	Trench	ILV	LAWV	NRCDAG	NRCDAS
Tier-1	Inadvertent Intruder[a]	Table 5-16	Table 5-12	Table 5-13	Table 5-14	Table 5-15
Tier-2	Groundwater[b]	Table 5-21	Table 5-17	Table 5-18	Table 5-19	Table 5-20

[a] List of parent radionuclides, provided in Chapter 5.0 (Section 5.2.1), requiring subsequent analyses for inadvertent intruder minus trigger-value radionuclides.
[b] List of parent radionuclides, provided in Chapter 5.0 (Section 5.2.2), requiring subsequent analyses for groundwater minus trigger-value radionuclides.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMU	Atomic Mass Units
AP	All-Pathways
ASCII	American Standard Code for Information Interchange
CA	Composite Analysis
CIG	Components-In-Grout
CP	Compliance Period
CSV	Comma-Separated-Values
DF	Dilution Factor
DOE	Department of Energy
DU	Disposal Unit
EDE	Effective Dose Equivalent
EIC	End of Institutional Control
ELLWF	E-Area Low-Level Waste Facility
EM	Evaluation Model
EPA	Environmental Protection Agency
ET	Engineered Trench
FTF	F-Area Tank Farm
GW	Groundwater
HFIR	High-Flux Isotope Reactor
HLW	High-Level Waste
ICRP	International Commission on Radiation Protection
IC	Institutional Control
II	Inadvertent Intruder
ILNT	Intermediate Level Non-Tritium
ILT	Intermediate Level Tritium
ILV	Intermediate Level (Waste) Vault
LAWV	Low Activity Waste Vault
MCL	Maximum Contaminant Level
ME	Matrix Exponentiation
MS	Microsoft
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
NRCDA	Naval Reactor Components Disposal Area
NRCDWSM	Nuclear Regulatory Commission Drinking Water Scenario Model

ODEs	Ordinary Differential Equations
ORNL	Oak Ridge National Laboratory
PA	Performance Assessment
PA2000	Performance Assessment issued in the year 2000
PA2008	Performance Assessment issued in the year 2008
PA2022	Performance Assessment to be issued in the year 2022
PIF	Plume Interaction Factors
PM	Performance Measure
PO	Performance Objective
POA	Point of Assessment
POP	Period of Performance
RHS	Right Hand Side
SA	Special Analysis
SIC	Start of Institutional Control
SOF	Sum-of-Fraction
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
ST	Slit Trench
SWM	Solid Waste Management
TPBAR	Tritium Producing Burnable Absorber Rod
UDQ	Unreviewed Disposal Question
US	United States
VZ	Vadose Zone
WAC	Waste Acceptance Criteria
WITS	Waste Information Tracking System
WT	Watertable
WZ	Waste Zone

1.0 Introduction

Solid Waste Management (SWM) operates the E-Area Low-Level Waste Facility (ELLWF) where several onsite waste generators (and some offsite customers) have ongoing waste streams being accepted and buried in active disposal units (DU). The facility has been in operation since late 1994 and is anticipated to remain open until 2065 based on the current site ten-year plan (SRNS 2015). Several DU types are available to handle a broad range of waste streams, specifically;

- 29 Trenches – Engineered Trenches (ETs), Slit Trenches (STs), and Component-in-Grout (CIG) Trenches;
- 1 Low Activity Waste Vault (LAWV);
- 1 Intermediate Level Vault (ILV); and
- 2 Nuclear Reactor Component Disposal Areas (NRCDAs).

Regardless of their waste form, inventory limits (or trigger values) are imposed on all radionuclides being buried in E-Area who contribute to dose beyond a given dose criterion. A Waste Information Tracking System (WITS) was created and is maintained by SWM (Bair 2018). WITS provides waste generators guidance on how waste can be handled within the E-Area DUs.

There are over 3,000 known radionuclides and only a subset of these are of any potential concern to E-Area operations. Screening criteria are established based on regulatory Performance Objectives (PO) and a suite of bounding analyses is performed to reduce this large list of radionuclides down to a more manageable set of radionuclides that are tracked within WITS and are subjected to inventory limits that are unique to:

- each radionuclide;
- waste form; and
- disposal unit.

This reduction in the number of radionuclides that require tracking is accomplished by performing both Groundwater (GW) and Inadvertent Intruder (II) screening analyses where appropriate. The radionuclides that require inventory limits are to be tracked separately from those having trigger values.

This report describes these screening analyses, the basis behind the screening analysis approach, the trigger-value listings, and the resulting lists of radionuclides requiring further detailed performance assessment (PA) analyses.

1.1 Key Motivations to Update Screening Analyses

For the upcoming 2022 PA (referred to as PA2022) a new complete set of GW and II screening efforts were initiated. Deficiencies and new data sources (e.g., radiological) warranted a complete set of new screening lists. During our first pass at updating the GW and II screening, we implemented many new concepts and aspects into the analysis effort. The results of that screening effort are given in Aleman and Hamm (2020).

As discussed in Aleman and Hamm (2020), the application of a Tier-2 reduction in the radionuclide lists was not considered but became a contingency plan if the outcomes from the Tier-1 were viewed to contain too large a set of radionuclides for WITS application (i.e., after consultation with SWM). Based on the Tier-1 results provided in Aleman and Hamm (2020) a Tier-2 was deemed warranted and represents the primary reason for this follow-on report, along with the implementation of trigger values. In all aspects, the results contained within this report supersede the earlier screening report by Aleman and Hamm (2020).

A variety of other aspects have been incorporated into this report and the most relevant items are listed below:

- Incorporated additional inventory projections and logic for Tier-1 analyses (i.e., extended the 2040 projections by Sink (2016a) to cover operations out to 2065);
- Added Ar-37 to the ILV Tier-0 list (went from 271 radionuclides to 272);
- Updated all Tier-1 results where no aquifer dilution was applied (i.e., dilution factors set to 1);
- Added Tier-2 models and analyses (aquifer dilution was deferred to this tier level);
- Post-screening out of unusual radionuclides (e.g., very heavy elements); and
- Incorporated the trigger-value concept to further reduce radionuclides requiring complex fate and transport analyses.

1.2 Basic Screening Concept

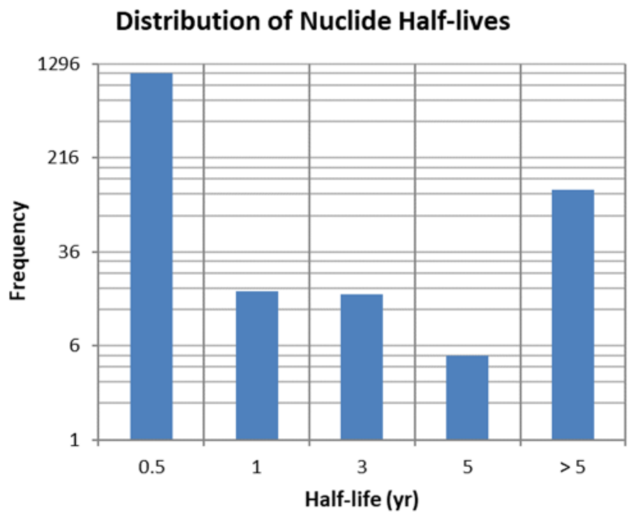
For a specific DU type, screening a large list of potential radionuclides down to a more manageable number relies on the following methodology:

1. Establishing an upper bound estimate on each radionuclide's potential inventory (i.e., a parent radionuclide's inventory estimate in units of Ci);
2. Computing what typically is referred to as "screening factors" for each radionuclide (i.e., in units of mrem/Ci of parent buried for all dose pathways of interest); and
3. Comparing the computed doses (i.e., product of the upper bound inventory estimate and the various screening factors) to appropriate performance measures at some chosen human receptor location (i.e., some downstream point of assessment).

In Step 2 above a trade-off exists between the degree of modeling conservatism (i.e., level of complexity in the fate and transport mechanisms considered) versus the number of tracked radionuclides within WITS, that promotes the notion of making use of a multitier screening approach. In this report details regarding each of these three steps are provided.

1.3 Foundation for a Tiered Disposal Limit System

The starting point for the GW and II screening effort is the recommended list of 1,252 radionuclides provided by ICRP (2008) in their publication 107. ICRP (2008) provides this list in their Annex A and refers to it as the ICRP-07 collection. This list is considered to be the appropriate set of radionuclides to be addressed when operating a solid waste landfill. This new list has grown from the earlier list of 826 radionuclides (NCRP 1996) employed in the 2008 PA (referred to as PA2008) screening process. To a very large extent, the 826 list is a subset of the larger 1,252 listing. The 1,252 list has a very broad range of radionuclides as evidenced by the spread in half-lives: 9.5×10^{-15} yr to 1.5×10^{17} yr. A simple histogram plot highlighting the half-life distribution is shown in Figure 1-1.



(yr)	*Half-life Bin*	*Frequency*
$t_{1/2} < 0.5$	0.5	1097
$0.5 < t_{1/2} < 1$	1	17
$1 < t_{1/2} < 3$	3	16
$3 < t_{1/2} < 5$	5	5
$5 < t_{1/2}$	>5	117

Figure 1-1. Half-life distribution (Years) among the 1,252 radionuclides listed in ICRP (2008).

As seen in Figure 1-1 ~88% of the radionuclides have half-life's less than 0.5 yr. As discussed within this report the radiological aspects of these 1,252 radionuclides are taken into account to help significantly reduce the number of parent nuclides required for follow-on detailed transport analyses. The creation/existence of many of these 1,252 radionuclides can be attributed to: fission fragments or products, neutron activation products, decay products, actinide members, or naturally occurring. The primary source of these radionuclides being buried within E-Area is from SRS production reactor and canyon reprocessing operations. Other sources are: US Naval Reactor components due to decommissioning of naval vessels or repatriated foreign fuel elements.

In developing an overall inventory limits system a tiered approach is most efficient with respect to its acceptance and maintenance. For example, if the tracking of a significant number of radionuclides can be omitted through relatively simple, but accepted, arguments the overall costs are greatly reduced.

The use of the term "conservative" when describing screening models in this report generally refers to the initial phases of a graded approach to the analysis consistent with DOE Technical Standard guidance (DOE 2017). The use of the term "conservative" when referring to data inputs in this report is described in the DOE Technical Standard as resulting in a "greater dose than best estimate input data." The conservative nature of screening models and inputs lead to concentration results and dose impacts that should be bounding in nature. With that in mind, some of the key aspects that were considered in arriving at an effective tiered system were:

- **Evaluation Model (EM)**
  - Easily defendable model that is typically quite conservative
  - Bounding in nature
  - Low cost of development and its application
- **Best Estimate plus Quantified Uncertainty (BE)**
  - More physically representative of actual behavior
  - Provides indication of operating margins
  - Higher costs of development and its application

- **Basic Tiered Inventory Limit Approach**
  - Tier-0 – Initial screening list based on radiological and process knowledge aspects
  - Tier-1 - "NCRP like" ground water screening (very conservative)
  - Tier-2 – Simple, but bounding, transport modeling (conservative)
  - Tier-3 - Generic waste (no credit taken for any possible waste form barriers)
  - Tier-4 - Special waste form (varying levels of credit taken into account)
  - Stochastic versus deterministic (not explicitly part of tiered system; addressing post-buried configurations of concern, closure analyses, and performance margins)

In the last bullet, the first three tiers encompass the overall GW and II screening efforts. Tier 2 incorporates the EM approach (first bullet) into the tiered inventory limit system. The BE approach in establishing deterministic limits was ruled out from consideration because 1) acceptable limits can be achieved at a lower cost using the basic tiered inventory limit approach, and 2) development of a tiered limits system is consistent with the graded approach promoted by the DOE technical standard.

Except as noted, the discussion that follows primarily focuses on the GW screening process. Section 3.3 provides a description of the II screening process. Those radionuclides whose estimated doses exceed a screening criterion (as laid out in subsequent sections of this report) for either Tier-1 or Tier-2, are considered to have failed the screening process and thus require the more detailed multi-dimensional fate and transport analyses of the PA as highlighted in Figure 1-2. Figure 1-2 represents a high-level flowsheet of the deterministic approach used to generate specific WITS inventory limits for every parent nuclide that fails the above screening process [Note that the basic logic flow as shown in Figure 1-2 is consistent with current plans; however, some of the various algorithms to be employed in the future are being updated.] These deterministic analyses referred to as Tier-3 and Tier-4 processes, will handle generic and special waste forms, respectively.

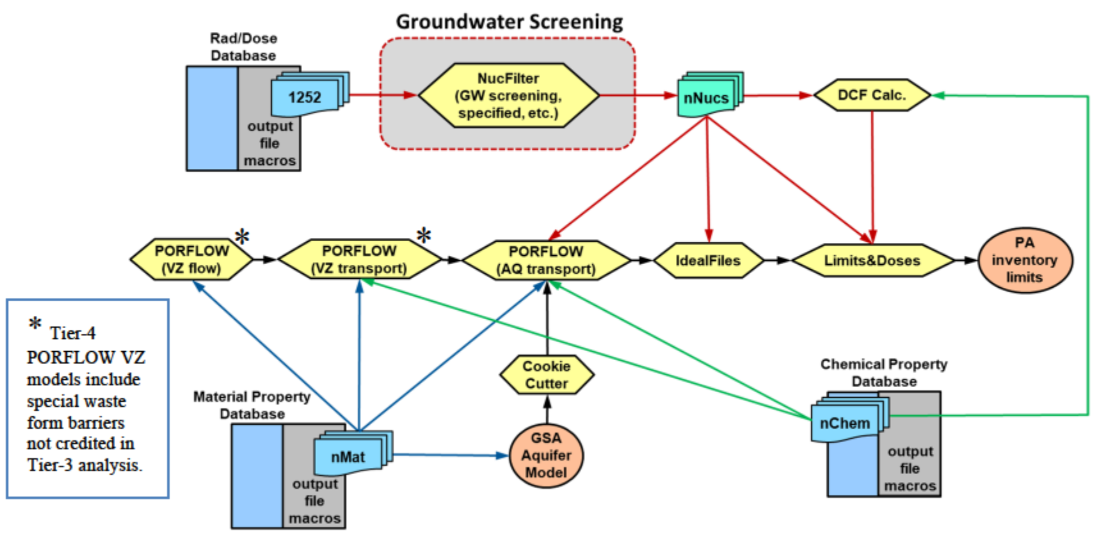


Figure 1-2. Tier-3 and Tier-4 candidate flowchart for 2021 PA analyses (deterministic aspects only).

A high-level overview of the multitiered GW inventory limit system for E-Area is shown in Figure 1-3. As indicated by Figure 1-3, the Tier-0, Tier-1, and Tier-2 steps constitute the GW screening process, while those processes below them constitute the limits system. The ultimate result from this GW screening process is a significant reduction in the number of parent radionuclides that must be considered in multi-dimensional fate and transport analyses, along with a reduced list of radionuclides requiring tracking within WITS explicitly.

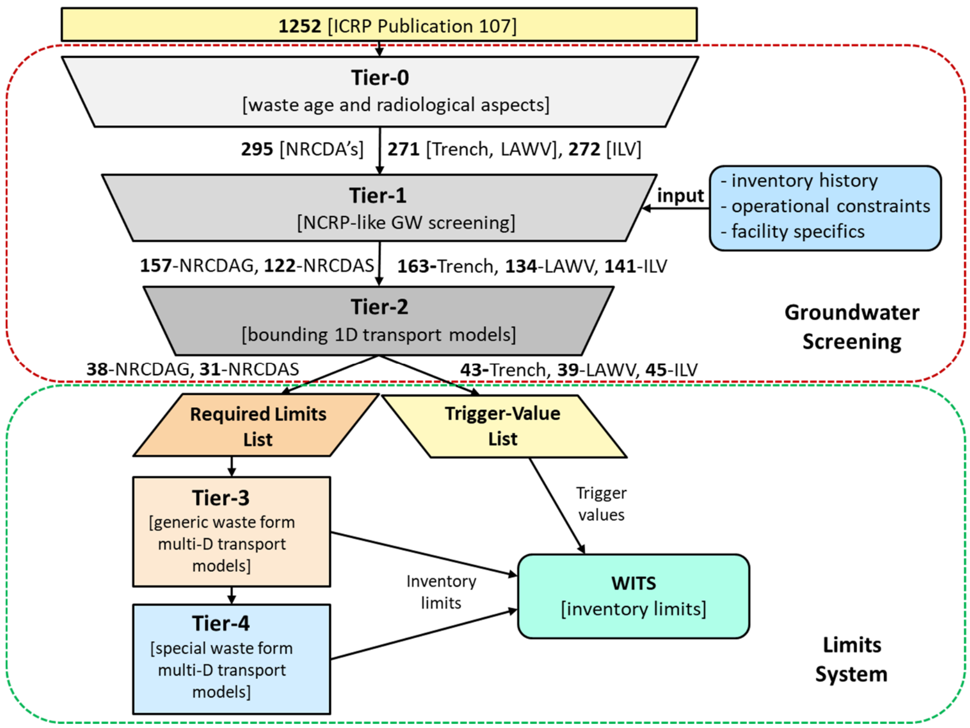


Figure 1-3. Schematic overview of the multitiered approach to establishing E-Area inventory limits.

In Figure 1-3 the recommended number of GW radionuclides to be considered are provided for each of the DU types for Tier-0, Tier-1, and Tier-2. The numbers of GW and II radionuclides by DU type that are not screened out for subsequent analyses are provided in Table 1-1. The Tier-1 analyses for both GW and II used the same initial list referred to as Tier-0. For sensitivity studies the initial list referred to as ICRP-107 was employed to estimate the Tier-1 results. No explicit Tier-2 analyses were performed for the II screening category.

Table 1-1. Number of radionuclides remaining after Groundwater and Inadvertent Intruder screening.

Category	Tier	Trench	ILV	LAWV	NRCDAG	NRCDAS
Initial Lists	**ICRP-107**	1,252	1,252	1,252	1,252	1,252
	Tier-0	271	272	271	295	295
Groundwater	**Tier-1**	163	141	134	157	122
	Tier-2	43	45	39	38	31
Inadvertent Intruder	**Tier-1**	88	29	20	29	75

As Table 1-1 indicates a significant number of radionuclides can be screened out from requiring the more complex multi-dimensional fate and transport analyses. No explicit inventory limits are required for the screened-out radionuclides since its extremely unlikely that their inventories will ever exceed the bounding inventories employed in their screening process.

As shown in Figure 1-3 the radionuclides that are not screened out (i.e., the totals per DU type and category as listed in Table 1-1) are segregated into one of the two following groups:

- Radionuclides requiring more detailed multidimensional fate and transport analyses (i.e., Tier-3 or Tier-4); or
- Radionuclides that are given conservative trigger values (i.e., based on Tier-1 results for II and Tier-2 results for GW screening factors).

Both of these radionuclide groups are tracked within WITS as separate identities.

To provide a brief overview of a GW screening process, the Tier-1 results obtained for generic trenches are discussed below (see Chapters 2 and 3 for more details). For GW there are five pathways that are considered:

1. Beta-Gamma (4 mrem/yr limit);
2. Gross Alpha (15 pCi/L limit);
3. Radium (Ra-226 + Ra-228) (5 pCi/L limit);
4. Uranium (30 μg/L limit); and
5. All-Pathways (25 mrem/yr limit)

where EPA Drinking Water Standards (pathways 1-4) and the DOE Order 435.1 Performance Objective (pathway 5) have been provided. Consistent with guidance for preparing the PA (DOE 1999), the requirement of DOE Order 435.1 to assess impacts to water resources has been interpreted as meaning that concentrations of radioactive contaminants should not exceed standards for public drinking water supplies established by the EPA. This interpretation is consistent with the SRS GW protection program. These POs are applied at the 100-m Point of Assessment (POA) over a range of Compliance Periods (CPs) within the DOE 435.1 Period of Performance (POP). For E-Area, the CPs of interest include a 171-year Operational plus Institutional Control period followed by a 1,000-year Post-Closure period for a 1,171-year POP. The 71-year Operational period starts when E-Area opened in 1994 and ends at the beginning of the 100-year Institutional Control period in year 2065. Sum-of-Fraction (SOF) values for all five pathways are computed and the maximum SOF over all five pathways and time is determined. For every parent nuclide considered (i.e., list obtained from Tier-0 results), if its maximum SOF contribution is less than a specified screening criterion, then that radionuclide is screened out from any future analyses. The screening criterion was set to 0.1% of the PO for each pathway giving a max allowable SOF contribution of 0.001. This value for the SOF criterion is believed to be a reasonably conservative choice given the various assumptions being made in (1) the projected closure inventories and (2) the embedded conservatism within the calculation of screening factors. For example, in the unlikely event that all 271 radionuclides taken from the Tier-0 process each attain a SOF just below the 0.1% screening criterion, this would combine to a SOF of less than 0.271, below a SOF of 1. A more realistic value of this combined SOF would be <0.004 (0.4%) as discussed in Section 2.5.1.

In determining a SOF contribution, the product of a screening factor for a particular pathway (e.g., mrem/yr-Ci for beta-gamma) multiplied by a "bounding" inventory (based on consideration of gamma dose, projected closure, weight, etc.) for a parent radionuclide (i.e., maximum estimated Ci buried in a DU) results in a dose value. The SOF value is then computed by dividing this dose or concentration by its appropriate PO value. In Figure 1-4 a distribution of max SOF values is shown for the GW Trench screening effort. As shown in Figure 1-4 the initial 271 parent nuclides taken from the Tier-0 process are reduced to 163 radionuclides requiring additional analyses in the Tier-2 effort (i.e., 108 were screened out).

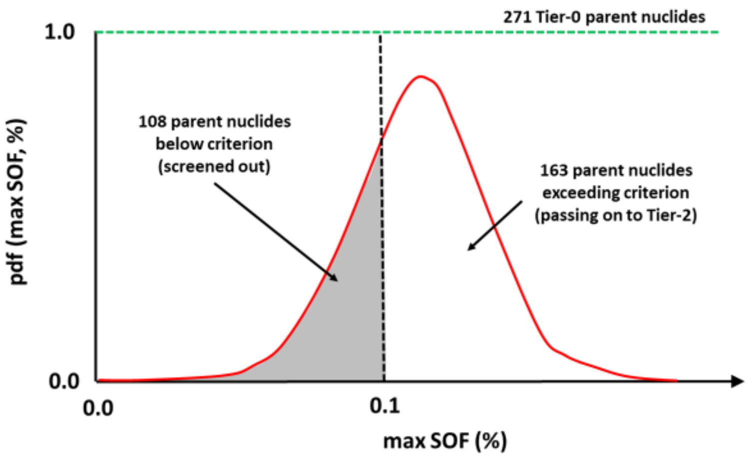


Figure 1-4. Example of a screening out of parent nuclides for a trench DU.

Thus, for the Trench example we also see in Table 1-1 that the initial 163 radionuclides from Tier-1 can be further reduced to 43 parent nuclides that will require either: (1) some level of multi-dimensional fate and transport analyses, or (2) a trigger value. Explicit inventory limits or trigger values are required, and these final 43 radionuclides then become part of WITS.

1.4 Disposal Unit Models for Screening Purposes

For the PA2022 there will be a total of 33 DUs contained within E-Area. The footprints for all 33 DUs are shown in Figure 1-5 and have been color-coded by disposal type (i.e., showing the new naming conventions here):

- **Engineered Trenches** - (9 ET units) [ET01, ET02, ET03, ET04, ET05, ET06, ET07, ET08, ET09]
- **Slit Trenches** - (20 ST units) [ST01, ST02, ST03, ST04, ST05, ST06, ST07, ST08, ST09, ST10, ST11, ST14, ST17, ST18, ST19, ST20, ST21, ST22, ST23, ST24]
- **Low Level Activity Vault** - (1 LAWV unit)
- **Intermediate Level Vault** - (1 ILV unit)
- **Naval Reactor Component Disposal Areas** - (2 NRCDA units) [NRCDA-7E, NRCDA-26E]

There are 4 additional DUs in the PA2022 that were not in the PA2008 (i.e., 3 ET units in Plot-8 and 1 more ST in the eastern portion of E-Area). The naming convention has changed for some of these DUs based on current SWM planning. For example, the two original Component-in-Grout (CIG) DUs are now going to be operated as STs. Only a section of these DUs will contain CIG components.

The 100-m POA surrounding the E-Area DUs is also shown in Figure 1-5 as a black dashed curve.

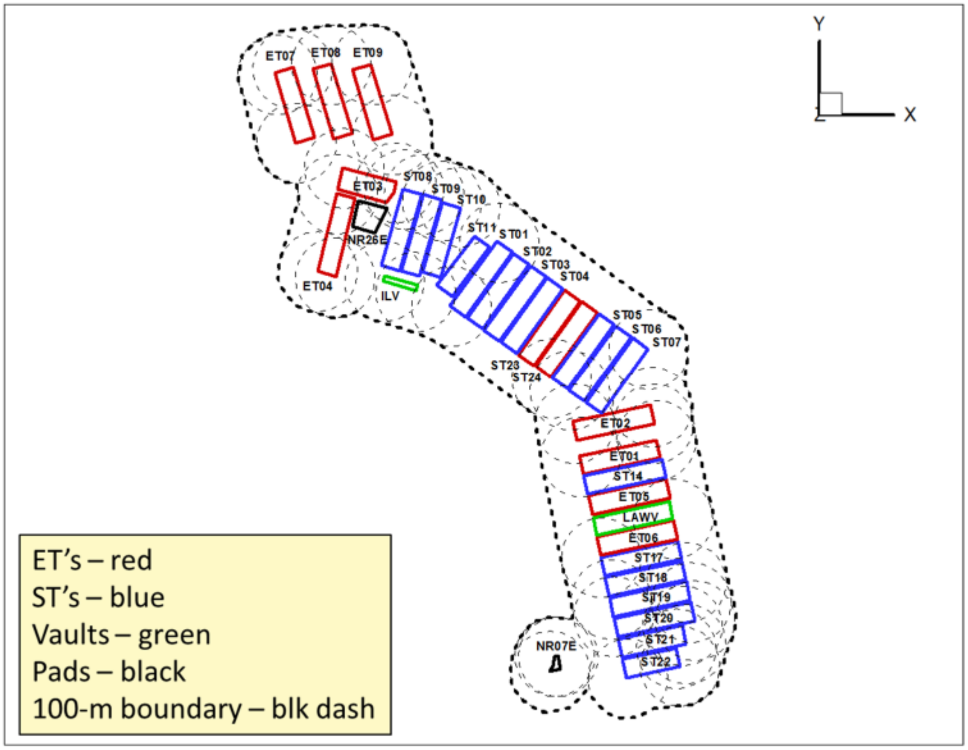


Figure 1-5. New E-Area footprints (33 DU's) and 100-m boundary.

For GW and II screening purposes five Tier-1 DU models are considered to be representative of these DU types:

- **Trench** (represents all ETs, STs, and former Component-in-Grout (CIG) trenches);
- **LAWV;**
- **ILV; and**
- **NRCDA** (represented by two models: a model for generic Naval Reactor waste (NRCDAG) and a model for special waste forms (NRCDAS). Note that NRCDA inventories are further broken apart for generic versus special waste form in Appendix H).

For DU types consisting of multiple units a decision is needed to employ either maximum or average inventory values. For screening purposes (i.e., for Tier-1 Tier-2 purposes) maximum inventory values were deemed more appropriate. In most cases, modeling parameters are set in a bounding manner with respect to the population of DUs being represented by each screening model.

1.5 Strategic Planning Team Recommendations

In 2015 a strategic planning team (Butcher and Phifer 2016) was created (with SRNL, SWM, and DOE members) to provide initial guidance on how the upcoming PA should be performed. The following GW radionuclide screening criteria recommendations were proposed in the 2016 PA Strategic Planning Team report:

- Employ a cost-effective graded approach in the next PA analysis to produce an internally consistent tiered GW inventory limit system. Consistency implies higher inventory limits are achieved in each subsequent tier.

- Consider a four-tiered system of GW analysis (i.e. screening, bounding, generic and special waste form). Each subsequent tier would analyze a correspondingly reduced set of radionuclides and evoke more detailed analysis. Screening and bounding models are considered evaluation models implying no (or very limited) sensitivity or uncertainty analyses required (cost savings). A bounding model would determine a set of limits for those radionuclides requiring no further refinement (in consultation with SWM). The expectation/objective was to get a dozen or so parent nuclides going into the detailed PORFLOW flow and transport analysis (however, as shown in Table 1-1 the final lists are similar to the PA2008 lists in total numbers).
- Ensure consistency in the GW analysis by employing the following strategy:
    - For all tiers consider the same set of dose pathways;
    - Employ the same data for all tiers of the GW analysis except where conservatively biased values of parameters are selected for evaluation models (e.g. bounding distribution coefficients); and
    - Obtain inputs to the models from a single set of controlled sources; the current Radionuclide, Geochemical and Material Properties data packages.
- Update the existing automated GW screening model (Taylor and Collard, 2005) with the current approved dose screening factors, decay chain upgrades, and site-specific properties. Run the model for the list of 1,252 radionuclides provided in the Radionuclide Data Package. Consider half-life and availability of dose coefficients in setting up the NCRP-like screening step. Utilize Sink's 2012 study (Sink 2012) as a method validation for the updated GW screening analysis. Any radionuclide that has been screened out will be eliminated from further analysis including both the generic and special waste form of the radionuclide. The reduced set of radionuclides passing this screening step to the next tier will help define the scope and starting point of the next PA revision effort.
- Update the anticipated inventory at ELLWF closure as input to the new screening model. For those radionuclides found in WITS, select bounding inventories based on a multiple of total ELLWF estimated inventories at closure (i.e., 10x). For those radionuclides not found in WITS, select and employ other criteria for obtaining a bounding inventory estimate.

This GW and Intruder Screening report addresses the "screening" and "bounding" tiers of the four-tiered system described above, alone with designated trigger values where appropriate. The screening tier consists of Tier-0, Tier-1, and Tier-2 steps. The bounding tier, a subset of screening, is designated as Tier-2. Tier-0 is an initial screening step which eliminates those parent radionuclides, which have no on-going sources of formation (precursors) and by investigation of the full-chain parent (and its progeny) half-lives and activities. The parent radionuclides not screened by Tier-0 are then analyzed using the Tier-1 GW leaching models and intruder screening. The Tier-1 screening step utilizes the NRCP screening methodology (NCRP 1996), while the Nuclear Regulatory Commission Drinking Water Screening Model (NRCDWSM) (Kennedy and Strenge 1992) was employed for sensitivity studies. These models are described later in this report. The parent radionuclides not screened by Tier-1 are then analyzed using the Tier-2 analyses which employ a hybrid approach as described later in this report.

Tier-2 is a PORFLOW-based approach that remains bounding and can be considered part of the overall screening efforts. It's based on 1D vadose zone fate and transport models coupled to a single-cell aquifer model that take into account, to some degree, both decay and transport aspects (excluding physical dispersive aspects). The ultimate radionuclide lists resulting from these multitiered computational processes are:

- a trigger-value list of radionuclides (i.e., a watch list of radionuclides whose inventories are recorded and monitored. If one of these radionuclide's inventories exceed a stated trigger value, then a Special Analysis (SA) would be required and the parent nuclide of interest would be added to the current WITS list); and
- a WITS-specified inventory list of radionuclides based on detailed PA analyses (i.e., a relatively smaller list of radionuclides, associated with either generic or special waste forms, requiring specific inventory limits at a disposal DU level).

During initial planning of the GW screening effort, the need for a Tier-2 process step was uncertain and was scheduled on a contingency basis. The first screening effort (i.e., as provided in Aleman and Hamm 2020) only pertained to Tier-0 and Tier-1 results. Those results strongly indicated that a Tier-2 step would be beneficial, and within this report the results of this Tier-2 effort were included, along with other upgrades to the prior screening effort (i.e., details provided later in this report). Following the Tier-2 screening, trigger values were calculated as an additional step further reducing the list of radionuclides requiring detailed PA calculations.

Note that the potential need for a trigger-value list will also be assessed during the Tier-2 effort.

1.6 History of Groundwater Screening Efforts

GW screening activities have been traditionally performed for numerous facilities across the United States (especially for DOE and NRC landfills). Below a list of screening efforts that were performed prior to this new effort documented within this report:

- **Kennedy and Strenge (1992)**
    - NRC drinking water scenario models the dose to persons whose sole exposure is from drinking GW that contains radionuclides leached from surface soil, as determined by a generic water-use model;
    - This scenario is included to permit a comparison with the drinking water standards of the EPA;
    - Conceptual model utilizes a three-box model: surface-soil layer leaching to an unsaturated-soil layer, unsaturated-soil layer leaching to a GW aquifer; and
    - The DandD software package embodies the NRC's screening methodology to allow licensees to convert residual radioactivity contamination levels at their site to annual doses.
- **NCRP (1996)**
    - Standard approach used throughout US to reduce nuclide list to manageable levels;
    - Outdated in terms of dose conversion factors;
    - Weakness in addressing parent nuclides with significant progeny;
    - No site-specific parameters considered; and
    - Limited number of dose pathways addressed.
- **Cook and Wilhite (1998)**
    - Early on screening analysis for the E-Area LLWF;
    - Based on the 826 radionuclide list provided in the NRCP screening methodology (NCRP 1996) and their screening factors; and
    - Many of the parameter settings employed in subsequent screening efforts based on this study.

- **McDowell-Boyer, Yu, Cook, Kocher, Wilhite, Holmes-Burns, and Young (2000)**
  - Performance Assessment (PA2000) for the E-Area LLWF; and
  - First PA started in 1994 and issued in January of 2000.
- **Cook and Wilhite (2004)**
  - Special Analysis (SA) in response to finding of disposed nuclides not covered in existing PA2000;
  - Updated model parameters of site-specific values (K_d's); and
  - Created new concept of "Trigger Values."
- **Taylor and Collard (2005)**
  - Automated "Cook and Wilhite (2004)" approach in Visual Basic for GW screening;
  - Improved methods to handle progeny;
  - Employed in PA2008; and
  - Recommended abandoning Trigger Values in lieu of direct use of inventory limits.
- **Hamm (2006)**
  - First-level screening process which identified 159 radionuclides for further evaluation in the Saltstone and Tank Farm Performance Assessments;
  - Application of 14 radionuclide screening steps for SRS High-Level Waste Tank Farm Closure with a starting list of 849 radionuclides;
  - Screening process uses information about the physical properties of each radionuclide such as half-life and decay mechanism;
  - Information about the source and handling of the waste is used in the decisions based on creation mechanisms and time since the radionuclide was created; and
  - NCRP methodology used in the screening process.
- **Taylor et al. (2008)**
  - A GW screening GoldSim based automated tool for use in the Composite Analysis (CA);
  - Progeny addressed based directly on available decay chain information; and
  - Dose computed based on use of dose calculations and inputs employed F-Area Tank Farm (FTF) PA.
- **INL (2010)**
  - A four-phase evaluation approach was used to screen out and assess potential GW impacts;
  - The first two phases use very simple and conservative site-independent screening methods to eliminate inconsequential radionuclides from further consideration. Phase 1: Radionuclide Half-Life Screening. Phase 2: NCRP Screening;
  - The third phase use a conservative model to simulate the release and transport of radionuclides through the subsurface to a hypothetical receptor; and
  - The fourth phase incorporates release of radionuclides from specific waste forms, sorption within the waste zone, site-specific sorption parameters for sedimentary interbeds, vadose zone and aquifer dispersion, and the influence of an engineered infiltration reducing cover.
- **Smith (2016)**
  - A GoldSim screening model that is more comprehensive than the NCRP123 model and includes the same exposure pathways used to determine a PA dose in detailed PA calculations;

- The GoldSim model includes leaching of the full-chain progeny from the waste zone for each parent radionuclide into an aquifer mixing zone;
- A calculation model using the equations and parameters described in the report by Smith et al. (2016) and listed in the "SRNL Radionuclide and Element Data Package" has been developed using the GoldSim software (Smith 2016a);
- The model runs a single GW water scenario (infiltration rate, waste zone bake time, aquifer dilution volume);
- The model is restricted to a set of parent radionuclides with no common daughters; and
- GoldSim screening of 1,252 parent radionuclides requires 126 executions of the GoldSim model with 10 difference parent radionuclides per execution. (hours of execution per single GW scenario).

2.0 New Screening Methodology

A GW and intruder radionuclide screening process and associated models were developed to provide a methodology to screen an extensive list of ICRP-07 radionuclides (1,252) into a manageable list of radionuclides to be analyzed in the next E-Area PA (PA2022). The screening methodology employs a multitiered approach by initially using logical steps to eliminate those radionuclides that would never be present for assaying by waste generators and thereby be screened out prior to analyses using self-evident radionuclide decay history and sources of formation. This step is known as Tier-0 screening. No explicit fate and transport aspects are considered during this screening step.

The list of radionuclides remaining after Tier-0 screening, are then analyzed and further screened using conservative GW leaching models. Two modeling options were investigated, one developed by the NCRP and the other one by the NRC. This step is known as Tier-1 screening. The results from the NCRP model were chosen to be employed in the subsequent screening efforts. The Inadvertent Intruder Tier-1 results are not further reduced by a subsequent Tier-2 step.

The list of radionuclides remaining after GW Tier-1 screening (i.e., based on the NCRP model), are then analyzed and screened using a hybrid model where the waste and vadose zones are represented by PORFLOW 1D flow and transport models. This step is known as the GW Tier-2 or bounding screening approach.

The final list of radionuclides generated from Intruder Tier-1 and GW Tier-2 screenings are used in the next PA of ELLWF. These listings are further reduced by applying trigger values to appropriately chosen radionuclides (see Chapter 5.0 for details), while the remaining radionuclides require additional analyses:

- **for Inadvertent Intruder Tier-1** – DU specific parameters are employed using the same basic logic that was used in the creation of the Tier-1 results; and
- **for Groundwater Tier-2** - subsequent multidimensional fate and transport analyses (beyond the scope of this screening effort) are employed (i.e., Tier-3 (generic waste forms) and Tier-4 (special waste forms) processing efforts).

The above follow on analyses result in inventory limits that are directly inputted in the WITS.

For GW screening purposes three different modeling approaches with varying degrees of incorporating fate and transport aspects were considered. A high-level comparison of these three modeling approaches is provided in Figure 2-1. Briefly, these three modeling approaches are:

- **NCRP123 Model** – a two box model (i.e., two separate computational cells) where leaching is addressed in the first box (waste zone) and connects directly to the second box (aquifer zone);
- **NRCDWSM Model** – a three box model (i.e., three separate computational cells) where the vadose zone is explicitly modeled in box-2; and
- **PorflowPS Model** – a hybrid model where the backfill, waste zone, and lower vadose zone are explicitly modeled using a PORFLOW 1D flow and transport model that connects directly (through flux to the WT files) to a single cell aquifer zone.

Details associated with each of these models are provided within the main body of this report, along with certain appendices. How these models were ultimately employed can be summarized as:

- **NCRP123 Model** – the Tier-1 parent radionuclide listings for all DU types were based on this model;
- **NRCDWSM Model** – Tier-1 analyses were computed and compared to the results obtained using the NCRP123-based model for sensitivity study purposes; and
- **PorflowPS Model** – the NCRP123-based Tier-1 results were employed as input where the final Tier-2 parent radionuclide listings for all DU types were generated.

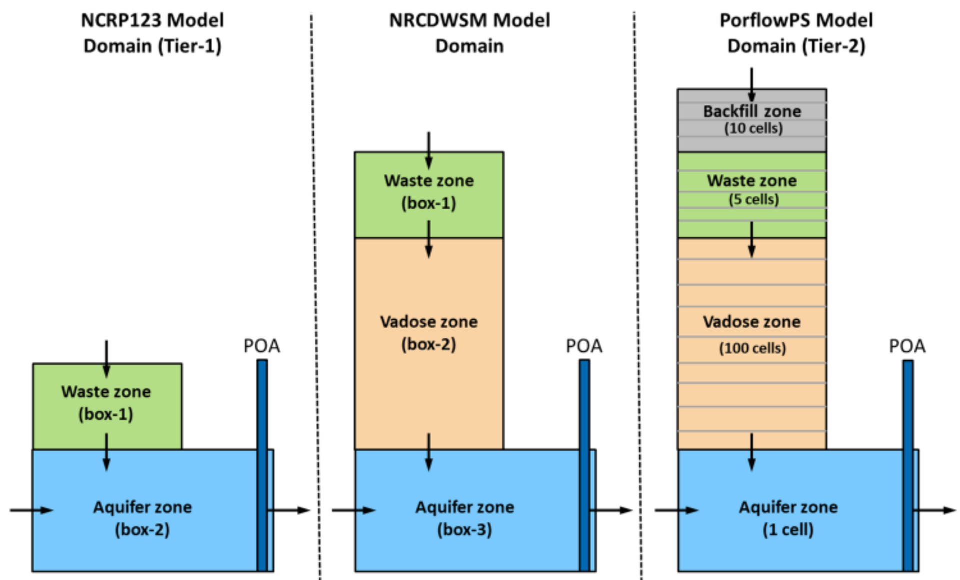


Figure 2-1. A high-level comparison of the three groundwater screening models considered.

Radionuclide inventories used for screening purposes are based on estimated ELLWF closure inventories for all radionuclides listed within WITS. Upper bound estimates of closure inventories for every DU within E-Area were obtained based on the following sources of information or constraints:

- WITS inventories for closed DUs (March 2020 WITS database query);
- Projected inventories by 2040 for all active and future DUs (Sink 2016a);
- Projected inventories by 2065 for all active and future DUs where the projection method employed assumes a constant DU composition until administrative SOF limits are reached (see Simmons (2020a) for an example of the method);
- Maximum estimated inventories derived from worker gamma-ray factor exposure limits for B-25 boxes (WAC procedures, SRNS 2014);
- Maximum estimated inventories derived from historical B-25 box weight measurements (Phifer and Wilhite 2001) and bounding radionuclide assumptions;
- Inventory estimates from Naval Reactor forecasting of future shipments (KAPL information); and
- Without available information the closure inventory of a specific nuclide was set to 10^7 Ci (except for H-3 which can exceed this value within the two vault DUs). The historical default screening inventory of 10^7 curies has been used in all prior E-Area PA revisions (1994, 2000 and 2008). It represented an approximate total number of curies that had been

disposed at SRS since operations started at the site (McDowell-Boyer 2000) providing a basis for an upper bound estimate.

Note that the projected closure inventories as highlighted in bullets 2 and 3 are based on: (1) snapshots of the WITS inventories, (2) limited process knowledge, (3) current WITS inventory limits, and (4) constant DU compositions. Thus, uncertainties exist in these projections and to bound these uncertainties these closure projections were increased by a factor of 10.

Details regarding the above closure inventory aspects are discussed in Appendix C and Appendix H.

The last bullet indicates that an upper bound DU inventory of 10^7 Ci was initially applied across every radionuclide (except for H-3) and was only reduced from that value it one of the previous bullets had lower values. This upper bound value of 10^7 Ci is considered to be very conservative and for many of the radionuclides significantly lower values are more realistic, however, no additional knowledge was available to reduce their values. As such, where appropriate trigger values were determined.

Numerous engineering calculations were performed during screening process. Both FORTRAN-based algorithms (i.e., created specifically for the screening efforts) and Excel spreadsheets were utilized. These algorithms are technically reviewed as one-time calculations and are not under software QA control. A listing of the FORTRAN-based algorithms employed is provided in Appendix M indicating their specific purpose and where they are archived.

2.1 Tier-0: Initial Screening of Radionuclides

The initial list of 1,252 radionuclides for Tier-0 screening is provided in Appendix A of ICRP (2008) and the detailed nuclear decay data is populated in SRNL (2019). The Decay-Chain and InitScreen computer algorithms were developed to support and perform the Tier-0 screening of radionuclides, respectively.

The Decay-Chain program automates the creation of PORFLOW input files with full chain (or short) chain progeny of each of the 1,252 radionuclides. This program computes the time history of radioactive decay and in-growth of daughter radionuclides over a 1250-year time period (exceeding the compliance period). The initial atom number of each parent radionuclide is set to 1.0E+12 pCi (1 Ci) divided by its decay constant (1/y). The 1,252 PORFLOW input files are executed in the HPC Linux cluster queuing system using the latest 64-bit version of PORFLOW. The time histories for each of the parent radionuclides are then post-processed by the backend of the Decay-Chain program. The resulting time histories of full (or short) chain atom numbers are converted to activities using each radionuclide's decay constant and are then written to MS Excel CSV and TecPlot ASCII files. The time histories of the full chain radionuclide activities for each parent nuclide are used by the InitScreen program for screening in Tier-0.

The InitScreen computer algorithm is designed to perform screening in careful, precise steps to ensure that each radionuclide is thoroughly evaluated, and that no radionuclide is screened out by an overly aggressive screening process. The screening process invokes process knowledge where available such as waste stream characterization and screening steps as described in the SRS HLW tank farm closure radionuclide screening report (Hamm 2006). An obvious first level of screening is to focus on radionuclides that have no on-going source of formation (e.g., many activation products) and their progeny. The initial attempt at Tier-0 screening utilizes the following steps:

1. Identify radionuclides that are part of any of the four decay-series (Ac, Np, Th, U) and retain for further analysis in Tier-1 because SRS high-level waste is known to contain the first member of each of these series.
2. Identify radionuclides for which there is high-level waste sludge characterization information (from which secondary solid low-level waste is generated) and retain for further analysis since these have been determined to likely be present in the waste and of importance to some aspect of the program. Note that this step may identify radionuclides for inclusion that could have been screened out at some later step if they had not been so designated.
3. Identify radionuclides with no precursors that would not be in the waste due to their physical properties (e.g., present as a gas and released in the reactor or during reprocessing [canyon dissolution phase]). We assume that the liquid-phase solubilities of noble gases are very low and that during the SRS canyon dissolution process all of these gases (present during reactor core irradiation) outgas from the aqueous phase. For non-SRS sources (e.g., TPBARs) these gases are considered on an individual basis.
4. Identify short-lived radionuclides which have no ongoing sources of formation. Employ information about the age of the waste (average of 23 years for SRS waste in 1995) to identify those nuclides that would not be expected to be in the waste at the time of closure due to their short half-lives. Restrict this analysis to those radionuclides that have no precursors and decay below a threshold activity ratio.
5. Identify fission fragment radionuclides which are members of isobaric decay chains. Short-lived fission fragment radionuclides with no precursors are screened out in Step 4. Employ information about the age of the waste (average of 23 years for SRS waste in 1995) to identify those nuclides that would not be expected to have ingrowth as progeny during the Tier-1 screening period. Screen out those fission fragment radionuclides with decay or ingrowth below a threshold activity ratio as a parent and daughter nuclide from 23 to 1194 years.
6. Identify radionuclides which are formed only by radioactive decay. Employ information about the age of the waste (average of 23 years for SRS waste in 1995) to identify those nuclides that would not be expected to have ingrowth as progeny during the Tier 1 screening period. Screen out those radionuclides with ingrowth below a threshold activity ratio as a daughter nuclide during the Tier 1 screening period.

The Tier-0 screening process addresses all of the 1,252 radionuclides and either keeps them for further evaluation in Tier-1 or screens them out for no further evaluation.

The average age of SRS created waste has been set to ~23 years. This is based on reactor operations starting in 1953 and running into 1988 (i.e., a 16 to 17-year average age assuming uniform production rates per year per reactor), plus an additional ~7 years until E-Area operations started in late 1994 to early 1995. The overwhelming majority of low-level waste received within E-Area has been generated at SRS and ends up in the Trench, LAWV, or ILV DUs.

The average age of Naval Reactor waste is discussed in Appendix H. All but a small fraction of surface-contaminated Naval Reactor waste streams (i.e., Naval Reactor pumps) end up on the Naval Reactor component pads (NRCDA-7E and NRCDA-26E).

The Tier-0 filtering process does not incorporate any fate and transport aspects and therefore represents a very conservative listing of parent radionuclides to be considered. As such, varying degrees of inclusion of fate and transport aspects are considered in the subsequent tiering process (i.e., Tier-1 and then Tier-2).

2.2 Tier-1: Groundwater and Intruder Radionuclide Screening

The first level of incorporating fate and transport aspects into the tiering process is referred to as the Tier-1 step. Two modeling options, as shown in Figure 2-1, have been considered and are discussed below.

The RadScreen computer algorithm implements the Tier-1 level of GW and intruder radionuclide screening. The Tier-1 screening process involves three levels of execution [Steps 1 and 3 are "PreScreening" and "Screening" models, respectively within RadScreen, Step 2 is external generation of screening factors using the SRNL Dose Tool Kit (Aleman 2019)]. Below are descriptions of each step in the Tier-1 screening process:

1. This is the "PreScreen" step where the intruder and GW scenarios (various infiltration rates and release times) are processed for the ICRP-07 and Tier-0 list of radionuclides. The GW scenarios are processed through each of the NCRP123 or the NRC Drinking Water Scenario models. The waste zone represents the areal footprint with the nominal or compacted/collapsed waste height of each disposal unit model for the intruder and GW scenarios, respectively. The initial inventory of the parent nuclide is initialized to the atom number equivalent of 10^{12} pCi divided by the decay constant of the parent nuclide. For each of the radionuclides, transient atom numbers are computed for a 1-year half-life cutoff short chain every year for an 1171-year period for each GW scenario (release time and infiltration rate). The short chain activities in the waste and aquifer zone are converted to concentrations for the intruder and GW pathways dose calculations using the waste zone soil volume and the volume of infiltration in a year, respectively. Aquifer dilution, mixing with regional GW, at the 100-m compliance well are further applied when using the NRCDWSM. The short chain concentrations (pCi/m^3 per Ci of parent) in the waste and aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (i.e., secular equilibrium). The **maximum full chain waste and aquifer zone concentrations** are determined every year from the intruder and the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit.
2. This step is external to RadScreen where the transient full chain activities for each parent nuclide computed in Step 1 are processed through the SRNL Dose Tool Kit for the calculation of **maximum screening factors** (concentration or dose per Ci of parent) for the GW and the inadvertent intruder pathways. The five GW pathways include the four EPA drinking water standards (Gross Alpha, Beta-Gamma, Radium and Uranium) and the DOE All-Pathways (AP). The inadvertent intruder includes the acute and chronic intruder dose pathways. Thus, there are five sets of screening factors for GW screening and two for intruder screening. The screening factor for each parent nuclide is the sum of doses from each member in the full chain that contributes dose to the pathway. Since the dose response is linear in concentration and parent inventory (there are no solubility limits in the screening models), the screening factors can be rolled up to the parent radionuclide. These

screening factors are now available to the "Screening" step to complete the Tier-1 screening process.

3. This final step is the "Screening" step within the RadScreen computer program. Absolute values of radionuclide inventories must be specified along with the screening criteria in order to screen out or retain radionuclides. Several methods or sources for estimating inventories were used to obtain a set of **limiting radionuclide disposal inventories** for each of the five Tier-1 DU models for use in this screening step. These included projected closure inventories, inventories derived from gamma-ray dose limits in WAC procedures for handling of B-25 boxes, weight-based inventories in B-25 boxes, and the historical screening inventory of 10^7 Ci. The **screening criteria** is set to 0.1% of the performance measure of each GW and intruder pathway. Each radionuclide's inventory is multiplied by each of the GW and intruder screening factors and then compared to the corresponding screening criteria. If any of the GW or intruder screening criteria are exceeded, then the nuclide is not screened out and is added to the appropriate list. A separate list of radionuclides remaining after Tier-1 screening is generated for GW and intruder screening. After Tier-1 screening is completed, the two lists of remaining radionuclides will be discussed with Solid Waste Engineering to determine if the bounding Tier-2 screening is warranted to reduce the list of Tier-1 radionuclides to numbers that are more practical for PA Tier 3-and Tier-4 analyses.

2.2.1 NCRP123 Screening Model

The screening calculations performed in this model are based on the method outlined in NCRP Report No. 123, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground*, (NCRP 1996) but do not use the exact equations or parameters provided in that document (i.e., this is the "NCRP-like" model referred to within this report). The radionuclide balance equations in this screening model are derived in Appendix A and solved using numerical techniques in Appendix B. An abbreviated chain of the ICRP-07 and Tier 0 radionuclides with progeny half-lives greater than 1 year are analyzed in the screening model. NCRP123 calculates a conservative dose to an individual from ingestion of contaminated GW and from agricultural activity in a garden using contaminated soil. The NCRP123 method for determining the radionuclide concentration in the GW is to elute radionuclides from the disposed waste directly into the GW which, with some dilution, is then ingested by the dose recipient. The method evaluates the dose assuming elution starts at a series of times following burial to allow for daughter ingrowth (i.e., bake times). The agricultural dose pathway includes ingestion of vegetables grown in a garden and exposure to garden soil where the soil is contaminated by exhumed waste. The NCRP123 model used in Tier-1 screening has been improved over the classical implementation in (NCRP 1996) and is discussed in Section 3.4.

The NCRP123 model consists of first-order removal (leaching) of radionuclides from the waste zone to the aquifer zone. The radionuclide screening model approach utilizes a series of bake times (no leaching) followed by leaching at a constant infiltration of water through the waste zone (i.e., a matrix of bake times versus infiltration rates). During the bake period in the waste zone, the radionuclide balance equations are solved for atom numbers of the short chain with radioactive decay and branching. Once leaching has started, the radioactive decay of the short chain takes into account the leach rate of each radionuclide in arriving at GW concentrations at the 100-m POA.

A schematic illustration of the dose pathways included in the screening model is shown in Figure 2-2 (extracted from Smith 2016).

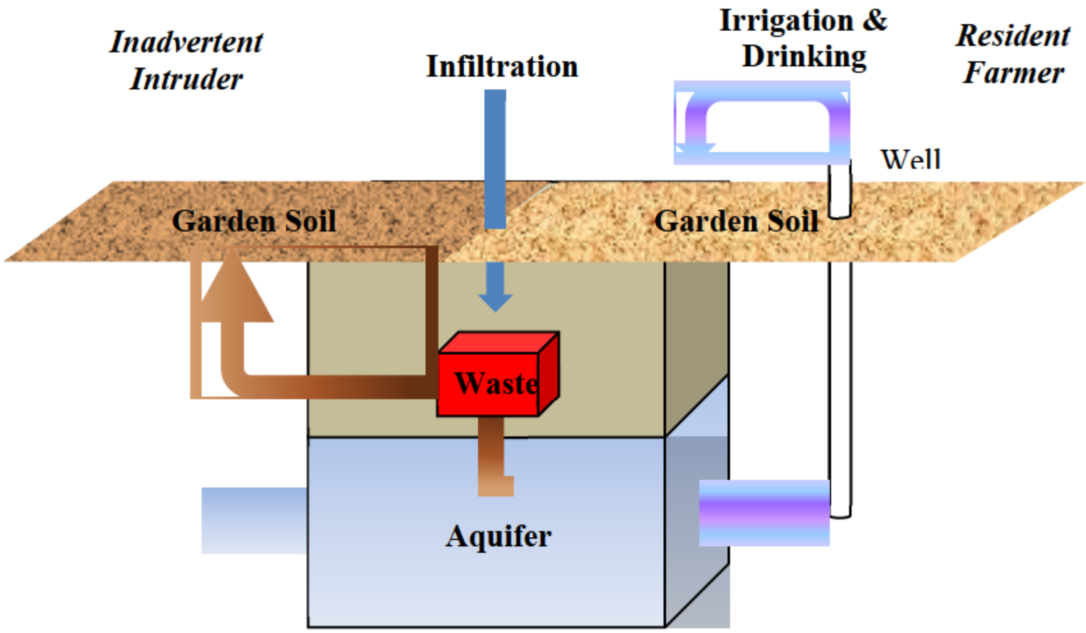


Figure 2-2. Illustration of RadScreen NCRP123 screening dose model.

The radionuclide balance equations for the NCRP123 model are derived in Appendix A and solved numerically using the matrix exponential method applied to solutions in Appendix B.

The radionuclide balance equation for the waste zone has the following form, accounting for regeneration, radioactive decay, and the rate of leaching:

(box-1) (2-1)

where

N_{1j} .... atom count of short chain in waste zone

N_{1i} .... atom count of precursor radionuclide i in waste zone

λ_j .... radioactive decay constant for j^{th} radionuclide (1/y)

b_{ji} .... effective branching or regeneration fractions (• 1)

i .... index of radionuclide precursors in the decay chain

j .... index of decay chain radionuclide (j=1 is the parent)

L_{12j} .... leach rate of radionuclide j from waste zone to aquifer (1/y)

For the aquifer zone, the radionuclide balance equation accounts for not only original quantities, regeneration and radioactive decay, but also for quantities entering from the waste zone:

(box-2) $$\frac{dN_{1j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1i} - \lambda_j N_{1j} - L_{12j}N_{1j} \quad \frac{dN_{2j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{2i} + L_{12j}N_{1j} - \lambda_j N_{2j} \qquad (2\text{-}2)$$

where

N_{2j} .... atom count of short chain in aquifer zone

N_{2i} .... atom count of precursor radionuclide i in aquifer zone

while the other terms are defined above. The summation term in each of the above equations is evaluated for only those terms for which a transition occurs.

The rate constant for movement between the waste and aquifer zones is evaluated as follows. The leach rate from the waste zone is

$$L_{12j} = \frac{I}{\theta_1 R_{1j} H_1} \tag{2-3}$$

where

I .... infiltration rate of clean water (m/y)

H_1 .... the assumed thickness of the waste zone containing the residual radioactive material (m)

θ_1 .... volumetric water content of the waste zone (-)

R_{1j} .... the retardation factor for movement of radionuclide j from the waste zone to the aquifer zone (-)

The retardation factor is calculated from the partition coefficient for the radionuclide in the waste zone as follows:

$$R_{1j} = 1 + \frac{\rho_1 k_{d,1j}}{\theta_1} \tag{2-4}$$

where

ρ_1 .... the bulk density of the waste zone(g/ml)

$k_{d,1j}$ .... the partition coefficient for radionuclide j in the waste zone (ml/g)

Unit conversion factors are employed in the above equations where appropriate. The atom counts, N_{2j}, computed above are converted into aquifer concentrations as shown in Appendix B.

2.2.2 NRC Drinking Water Scenario Model

The following description of the NRC Drinking Water Scenario Model (NRCDWSM) is from Kennedy and Strenge (1992).

For the soil scenarios, a conservative method of estimating the concentration of radionuclides in a GW aquifer is to use a simple leach-rate model for total water use. Leach rates are dependent on the chemical properties of the radionuclides in soil and on the rate of local moisture movement. For this water-use model, it is assumed that radionuclides migrate to the GW due to infiltration of water through the waste. To account for saturated and unsaturated soil conditions, a three-box compartmental model is used for this study to estimate the transfer of radionuclide atoms from the surface to the GW aquifer over time.

A conceptual representation of the three-box water-use model for the drinking water scenario is shown in Figure 2-3 (extracted from Kennedy and Strenge 1992). The figure shows the three boxes and indicates the flow of water through the system with infiltration being the driving force for transfer from the surface soil to the GW aquifer. The following assumptions are implied by the model:

- Initial radioactivity is contained within the top layer (box 1);
- The unsaturated-soil layer (box 2) and the GW aquifer (box 3) are initially free of contamination;
- The vertical saturated hydraulic conductivity is greater than the infiltration rate (i.e., no ponding or perched water is allowed);
- There is no retardation within the aquifer;
- The activity in the aquifer is diluted by the volume of water in the aquifer;
- The volume of water in the aquifer volume is considered to be the greater of the following: 1) the volume of infiltrating water or 2) the volume of water used for domestic purposes;
- The infiltration volume is the product of the infiltration rate and the area of land contaminated; and
- Water is removed from the aquifer at a constant rate during all years of interest in the analysis.

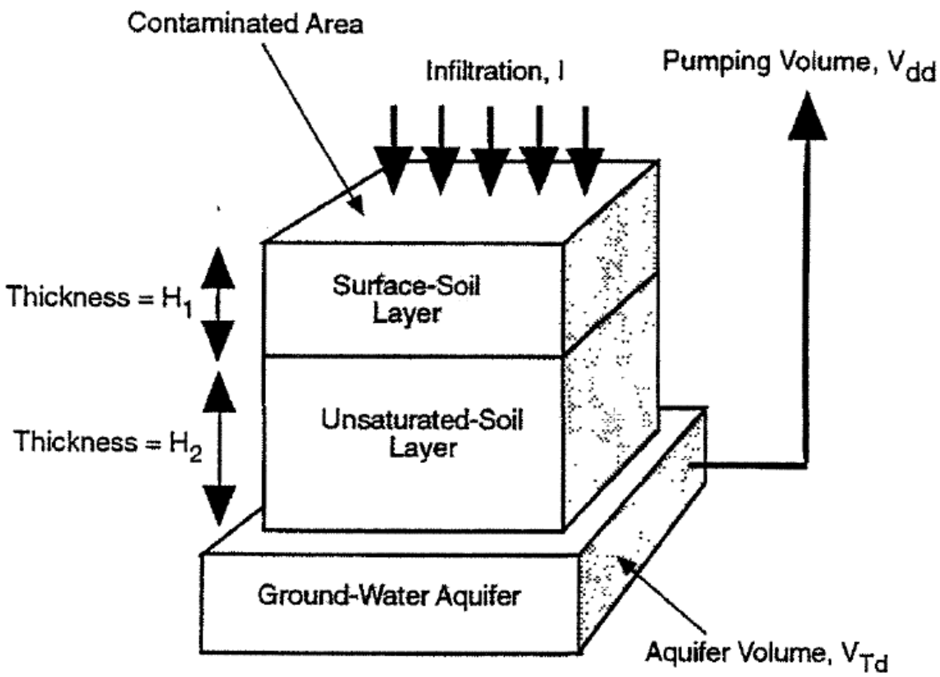


Figure 2-3. Conceptual representation of the NRC drinking water scenario water-use model.

The initial activity is assumed to be contained within the first soil layer as a reasonable approach for a generic water-use model. While some sites may exist that have contamination spread through all layers and even into the aquifer, these cases should be evaluated on a site-specific basis, rather than by using this generic model.

The annual volume of water in the aquifer is defined as the greater of two volumes: 1) the volume of water pumped annually for domestic uses or 2) the volume of water infiltrating through the surface-soil layer for one year. This definition is used to avoid the unrealistic case that can result when the area of contaminated land is large. For cases involving large areas of contamination, the annual volume of infiltrating water can exceed the annual volume of water required to meet domestic water demands. Without the above definition of aquifer water volume, the concentration in the aquifer would unrealistically increase over the concentration in the unsaturated-soil layer because the volume of water delivering the contaminant to the aquifer would be greater than the volume of the water in the aquifer.

The assumption regarding the vertical saturated hydraulic conductivity means that the soil conditions will allow water to move vertically downward at least as fast as the infiltration rate.

Figure 2-4 (extracted from Kennedy and Strenge 1992) represents the movement of radionuclides in the simple three-box leach model. Box 1 represents the initial inventory in a surface-soil layer, with removal of the short chain by either radioactive decay or leaching into box 2, an unsaturated-soil layer. The initial atom count of the parent radionuclide is defined in box 1 with the initial progeny atom counts set to zero. The initial atom counts of the short chain in box 2 and box 3 are set to zero. The short chain in box 2 is removed by radioactive decay and leaching into box 3, the GW aquifer. The short chain in box 3 can be removed by pumping to provide domestic water for an individual. The transient atom counts of the short chain in box 3 are used to determine aquifer concentrations in the GW system.

The radionuclide balance equations for the three-box water-use model are derived in Appendix A and solved numerically using the matrix exponential method applied to solutions in Appendix B.

The radionuclide balance equation for box 1 has the following form, accounting for regeneration, radioactive decay, and the rate of leaching:

(box-1)
$$\frac{dN_{1j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1i} - \lambda_j N_{1j} - L_{12j} N_{1j} \tag{2-5}$$

where

N_{1j} .... atom count of short chain in soil-surface layer, box 1

N_{1i} .... atom count of precursor radionuclide i in box 1

λ_j .... radioactive decay constant for j^{th} radionuclide (1/y)

b_{ji} .... effective branching or regeneration fractions (• 1)

i .... index of radionuclide precursors in the decay chain

j .... index of decay chain radionuclide (j=1 is the parent)

L_{12j} .... leach rate of radionuclide j from box 1 to box 2 (1/y)

For box 2, the radionuclide balance equation accounts for not only original quantities, regeneration, radioactive decay, and leaching, but also for quantities entering from box 1:

(box-2)
$$\frac{dN_{2j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{2i} + L_{12j}N_{1j} - \lambda_j N_{2j} - L_{23j} N_{2j} \tag{2-6}$$

where

N_{2j} .... atom count of short chain in unsaturated-soil layer, box 2

N_{2i} .... atom count of precursor radionuclide i in box 2

L_{23j} .... leach rate of radionuclide j from box 2 to box 3 (1/y)

while the other terms are defined above.

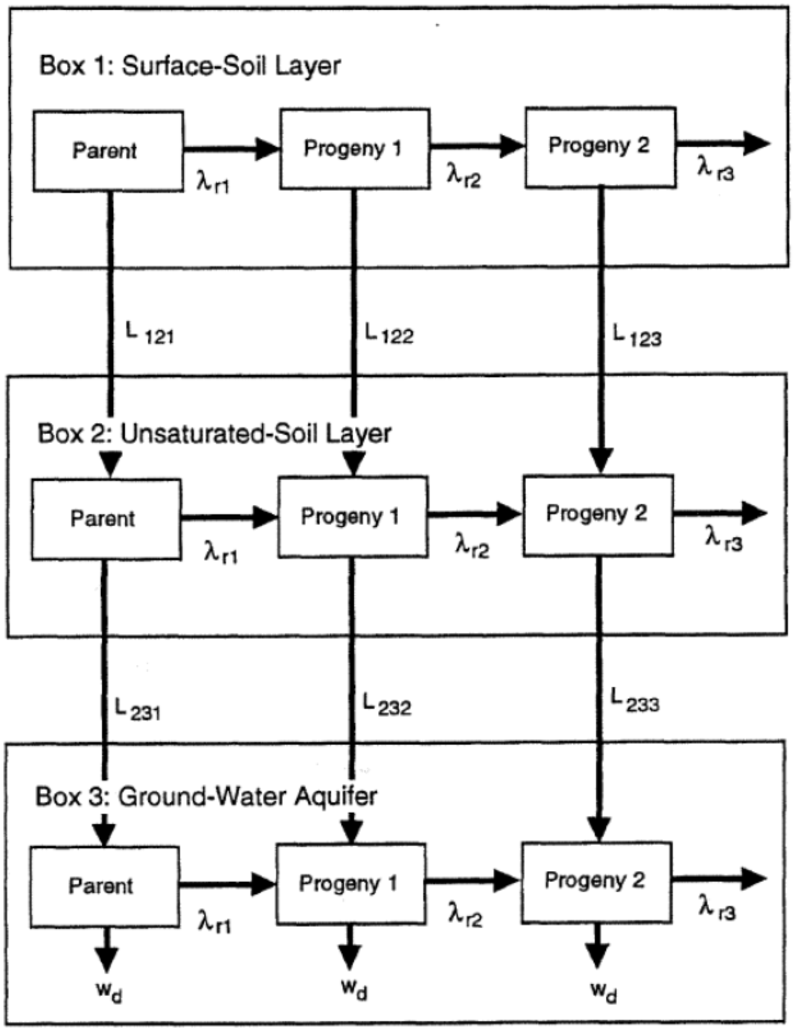


Figure 2-4. NRC three-box water-use model for the drinking water scenario.

The radionuclide balance equation for box 3 is similar to box 2:

(box-3) $$\frac{dN_{3j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{3i} + L_{23j}N_{2j} - \lambda_j N_{3j} - w_d N_{3j} \qquad (2\text{-}7)$$

where

N_{3j} .... atom count of radionuclide j in aquifer, box 3

N_{3i} .... atom count of precursor radionuclide i in aquifer, box 3

w_d .... rate constant for pumping of water from the aquifer (1/y)

and other terms are defined above. The summation term in each of the above equations is evaluated for only those terms for which a transition occurs.

The rate constants for movement between compartments or boxes are evaluated as follows. The leach rate from the surface-soil layer is

$$L_{12j} = \frac{I}{\theta_1 R_{1j} H_1} \tag{2-8}$$

where

- I .... infiltration rate of clean water, (m/y)
- H_1 .... the assumed thickness of the surface-soil layer containing the residual radioactive material (m)
- θ_1 .... volumetric water content of the surface-soil layer (-)
- R_{1j} .... the retardation factor for movement of radionuclide j from the surface-soil layer to the unsaturated-soil layer (-)

The retardation factor is calculated from the partition coefficient for the radionuclide in the surface-soil layer as follows:

$$R_{1j} = 1 + \frac{\rho_1 k_{d,1j}}{\theta_1} \tag{2-9}$$

where

- ρ_1 .... the bulk density of the surface-soil layer (g/ml)
- $k_{d,1j}$ .... the partition coefficient for radionuclide j in the surface-soil layer (ml/g)

The leach rate from the unsaturated-soil layer is defined as follows:

$$L_{23j} = \frac{I}{\theta_2 R_{2j} H_2} \tag{2-10}$$

where

- H_2 .... the assumed thickness of the unsaturated-soil layer (m)
- θ_2 .... volumetric water content of the unsaturated-soil layer (-)
- R_{2j} .... the retardation factor for movement of radionuclide j from the unsaturated-soil layer to the aquifer (-)

The retardation factor is calculated from the partition coefficient for the radionuclide in the unsaturated-soil layer as follows:

$$R_{2j} = 1 + \frac{\rho_2 k_{d,2j}}{\theta_2} \tag{2-11}$$

where

- ρ_2 .... the bulk density of the unsaturated-soil layer (g/ml)
- $k_{d,2j}$ .... the partition coefficient for radionuclide j in the unsaturated-soil layer (ml/g)

Unit conversion factors are employed in the above equations where appropriate. The atom counts, N_{3j}, computed above are converted into aquifer concentrations as shown in Appendix B.

2.3 Tier-2: PORFLOW 1D Groundwater Screening Model

The two models discussed above for Tier-1 screening analyses do not explicitly (or implicitly) address dissipative mechanisms that reduce overall peak concentrations of the transported radionuclides of interest. As such, those models are conservative and, in many cases, significantly conservative. The Tier-2 approach incorporates, to some degree, primary dissipative mechanisms to help reduce the level of conservatism present. These effects result in reduced concentration values at the downstream 100-m Point-of-Assessment (POA).

2.3.1 Tier-2 Conceptual Model

The advective, diffusive, and dispersive effects of contaminant transport within a porous media were not explicitly considered during the Tier-1 screening. In order to explicitly account for these dissipative mechanisms, some sections of the travel path must be modeled as a continuum (i.e., either 1D, 2D, or 3D). A hybrid model was chosen for Tier-2 as shown in Figure 2-1. Here a 1D transport model was employed to explicitly address advective and diffusive mechanisms through the vadose zone (i.e., waste and lower vadose zones). Note that physical dispersion was set to zero; even though, some numerical dispersion will be present. This 1D transport model was then connected to a single-cell aquifer model where implicitly diffusive and dispersive dilution aspects are handle as described in Appendix G.

The vadose zone model incorporates more realistic transport, with retardation and no physical dispersion, through the unsaturated soils of radionuclides released by infiltration and diffusion from a waste zone. A predetermined inventory for each Tier-1 radionuclide is uniformly distributed throughout the waste zone. The bake times of the short chain of Tier-1 radionuclides were varied along with multiple infiltration rates which simulate uncovered and covered DU operations. Transient contaminant fluxes of the short chain leaving the water table were written out for each groundwater screening scenario and used as sources to the single-cell aquifer transport model.

The single-cell aquifer transport model incorporates a first-order loss term that represents the dilution impact that aquifer flow has on the radionuclide concentrations at the 100-m POA. Details associated with this first-order loss term are provided in Appendix G. The first-order loss term for every DU within E-Area was computed based on PORFLOW 3D steady-state tracer transport runs making use of the General Separations Area flow model (Flach 2018). The short chain activities in the aquifer zone are converted to concentrations for the GW pathways dose calculations using the volume of infiltration in a year.

The maximum full chain aquifer concentrations are determined every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit to compute GW pathway screening factors.

Each radionuclide's inventory is multiplied by each of the GW screening factors and then compared to the corresponding screening criteria. If any of the GW screening criteria are exceeded, then the nuclide is not screened out and is added to the list of Tier-2 radionuclides.

2.3.2 Tier-2 Model Implementation Details

The PORFLOW and RadScreen computer algorithms implement the Tier-2 level of GW radionuclide screening. The Tier-2 screening process involves four levels of execution [Step 1 is external generation of radionuclide fluxes to the watertable using the PORFLOW 1D vadose zone transport simulator. Steps 2 and 4 are the "PreScreen" and "Screening" models, respectively within RadScreen, Step 3 is external generation of screening factors using the SRNL Dose Tool Kit (Aleman 2019). Below are descriptions of each step in the Tier-2 screening process:

1. A PORFLOW 1D vadose zone transport model was created for each Tier-1 radionuclide within each DU for computing transient fluxes to the watertable. The geometrical and material configurations were made identical to the configurations employed in the NRCDWSM Tier-1 analyses with the exception of a Backfill zone above the waste zone. The waste zone represents the areal footprint (scaled to a 1-cm by 10-ft model footprint) and compacted/collapsed waste height of each DU model. The initial inventory of the parent nuclide is 1 gmol scaled to the model footprint and uniformly distributed within the waste zone volume of each DU. For each of the parent radionuclides and their progeny (i.e., based on a 1-year half-life cutoff), transient fluxes to the watertable are computed for every short-chain member (every year for an 1171-year period for each GW scenario (release time and infiltration rate). The transient fluxes are then scaled to the disposal unit footprint and passed to Step 2.
2. This is the "PreScreen" step where transient fluxes to the watertable for each GW scenario are processed for the Tier-1 list of radionuclides and short chain through the PorflowPS model (i.e., a PORFLOW model whose results are inputs into the screening process). The PorflowPS model consists of transient fluxes from a PORFLOW 1D vadose zone transport model to a modified aquifer soil layer with radioactive decay, branching and aquifer dilution Aquifer dilution, mixing with regional GW, at the 100-m compliance well is implemented as an effective linear rate constant in the governing equation for each short chain nuclide. The short chain activities in the aquifer zone are converted to concentrations for the GW pathways dose calculations using the volume of infiltration in a year. The short chain concentrations (pCi/m^3 per Ci of parent) in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The maximum full chain aquifer concentrations are determined every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit.
3. This step is external to RadScreen where the transient full chain activities for each parent nuclide computed in Step 2 are processed through the SRNL Dose Tool Kit for the calculation of maximum screening factors (concentration or dose per Ci of parent) for the GW pathways. The five GW pathways include the four EPA drinking water standards (Gross Alpha, Beta-Gamma, Radium and Uranium) and the DOE All-Pathways (AP). Thus, there are five sets of screening factors for GW screening. The screening factor for each parent nuclide is the sum of doses from each member in the full chain that contributes dose to the pathway. Since the dose response is linear in concentration and parent inventory (there are no solubility limits in the screening models), the screening factors can be rolled up to the parent radionuclide. These screening factors are now available to the "Screening" step to complete the Tier-2 screening process.

4. This final step is the "Screening" step within the RadScreen computer program. Absolute values of radionuclide inventories must be specified along with the screening criteria in order to screen out or retain radionuclides. Several methods or sources for estimating inventories were used to obtain a set of limiting radionuclide disposal inventories for each of the five DU models for use in this screening step. These included projected closure inventories, inventories derived from gamma-ray dose limits in WAC procedures for handling of B-25 boxes, weight-based inventories in B-25 boxes, and the historical screening inventory of 10^7 Ci. The screening criteria is set to 0.1% of the performance measure of each GW pathway. Each radionuclide's inventory is multiplied by each of the GW screening factors and then compared to the corresponding screening criteria. If any of the GW screening criteria are exceeded, then the nuclide is not screened out and is added to the list of Tier-2 radionuclides. After Tier-2 screening is completed, the lists of remaining radionuclides will be discussed with Solid Waste Engineering to determine if process knowledge (SRS or non-SRS waste streams) can be used to reduce the list of Tier-2 radionuclides to numbers that are more practical for PA Tier 3-and Tier-4 analyses.

2.3.3 PorflowPS Screening Model

The Tier-2 bounding screening approach improves the Tier-1 leaching models by utilizing PORFLOW 1D vadose zone transport models and a modified aquifer soil layer with radioactive decay, branching and aquifer dilution. The vadose zone model incorporates more realistic transport, with retardation and no physical dispersion, through the unsaturated soils of radionuclides released by infiltration and diffusion from a waste zone. The use of a PORFLOW 1D aquifer transport model was replaced with a modified version of the aquifer model used in the NRCDWSM screening model.

To include the fate and transport aspects associated with travel through the waste and vadose zones, a PORFLOW 1D model was employed. The results from this model (i.e., fluxes to the WT) were employed as pre-screening inputs into the Tier-2 analyses. This transport model is referred to as PorflowPS.

A conceptual representation of the PorflowPS model is shown in Figure 2-5. The figure shows a vertical cross section of a 2D engineered trench reduced to our PORFLOW 1D vadose zone transport model with an underlying aquifer soil layer model.

The arrows at the top indicate the flow of water through the system with infiltration being the driving force for transfer from the surface soil to the GW aquifer. The second set of arrows represents the handshaking between the PORFLOW vadose zone and aquifer soil layer models through the fluxes to the WT. The PORFLOW 1D vadose zone model consists of three soil layers: vertically stacked backfill, waste and lower vadose zones. The following assumptions are implied by the model:

- Initial inventory is contained within the waste zone;
- The backfill, lower vadose zone, and aquifer soil layer are initially free of contamination.
- The vertical saturated hydraulic conductivity is greater than the infiltration rate (no ponding or perched water is allowed);
- There is no retardation in the aquifer;
- The atom counts in the aquifer are diluted by the volume of water in the aquifer;

- The volume of water in the aquifer volume is considered to be the volume of infiltrating water;
- The infiltration volume is the product of the infiltration rate and the area of land contaminated; and
- Water is removed from the aquifer at a constant rate during all years of interest in the analysis.

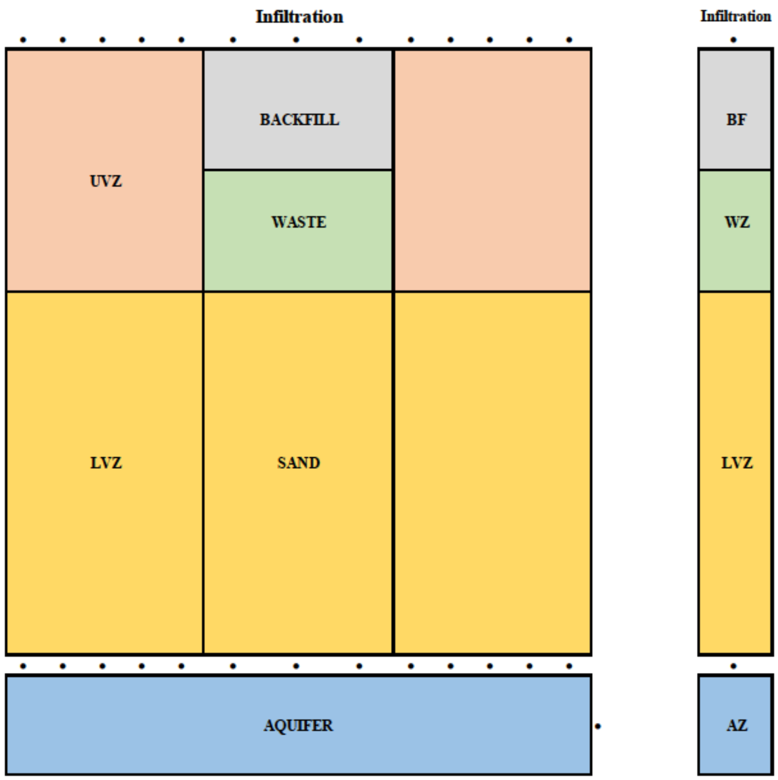


Figure 2-5. Conceptual representation of PorflowPS model.

The radionuclide balance equations for the PorflowPS model are derived in Appendix A and solved numerically using the integrating factor and matrix exponential methods as discussed in Appendix B.

The radionuclide balance equation for PorflowPS has the following form, accounting for regeneration, radioactive decay, rate of aquifer dilution, and prescribed fluxes to the WT:

$$\frac{dN_j}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - w_d N_j + f_j(t) \qquad (2\text{-}12)$$

where

N_j .... atom count of radionuclide j in aquifer, gmol

N_i .... atom count of precursor radionuclide i in aquifer, gmol

λ_j .... radioactive decay constant for radionuclide j (1/y)

b_{ji} .... effective branching or regeneration fractions (• 1)

i .... index of radionuclide precursors in the decay chain j .... index of decay chain radionuclide (j=1 is the parent)

$f_j(t)$ .... flux to the watertable (PORFLOW) of radionuclide j, gmol/yr

w_d .... first-order rate constant for aquifer dilution (1/y)

2.4 Upper Bound Inventory Estimates

Of the 1,252 radionuclides in the ICRP-107 list, only 177 have existing inventory values in WITS. Based on the current inventory limits within WITS, closure inventory projections out to the year 2065 were generated as discussed in Appendix C. These 2065 closure projections represent best estimate values on a DU by DU basis for each of the 177 radionuclides. A summary of the total 2065 closure projection activity on a DU basis is present in Table 2-1.

Table 2-1. Total activity (summed over all radionuclides within a disposal unit) based on the 2065 year projected closure inventories.

DU	Sum (Ci)[b]
Trenches	
ST01	3.97E+01
ST02	1.63E+02
ST03	1.25E+02
ST04	1.42E+02
ST05	1.27E+05
ST06	1.88E+02
ST07	1.81E+02
ST08	1.01E+02
ST09	4.02E+02
ST14	5.70E+03
ST23	2.02E+04
ET01	2.26E+02
ET02	5.62E+02
ET03	2.95E+02
max	1.27E+05
Vaults [a]	
LAWV	1.91E+08
ILV	7.17E+07
NRC Pads	
NRSDCG	8.22E+05
NRCDAS	1.89E+05

[a] For the LAWV and ILV the majority of activity is associated with H-3 (i.e., $1.91\text{x}10^8$ and $7.17\text{x}10^7$ Ci, respectively).

[b] The total projected activity within E-Area as of 2065 is $2.64\text{x}10^8$ Ci (or $1.30\text{x}10^6$ Ci if the H-3 contributions from the LAWV and ILV are omitted).

The total 2065 closure projection activity across the entire E-Area becomes:

- $2.64\text{x}10^8$ Ci (total); and
- $1.30\text{x}10^6$ Ci (where the H-3 contributions within the LAWV and ILV have been omitted).

To address those radionuclides that are not listed in WITS (i.e., 1,252 – 177 = 1,075) an upper bound estimate(s) must be made. For screening purposes, the first historical references found that refers to this is in the works of McDowell-Boyer et al. (2000, but started in 1994), Cook and Wilhite (1998), and Cook (2004), where they assumed that a DU inventory would not exceed 10^7 curies of each radionuclide (from either a GW or Intruder perspective). The following statement was extracted from McDowell-Boyer et al. (2000):

"The factor of 10^7 was selected because it presents the total number of curies, of all radionuclides combined, that has been disposed in LLW at SRS over 40 years of operation."

In a later screening report (by Taylor and Collard 2005) they employed this 10^7 Ci value as well. Taylor and Collard (2005) also indicated that the total activity contained within E-area in the year 2005 was about $5.0\text{x}10^6$ Ci. In both screening efforts the 10^7 Ci value was employed at the DU level.

As can be seen from Table 2-1, this 10^7 Ci value when employed at the DU level is very conservative for the Trenches, NRCDAG, and NRCDAS. However, the projected total activities for the LAWV and ILV exceeds this value.

Therefore, as our initial upper bound inventory estimates we assume:

- 10^7 Ci for each of the 1,252 radionuclides in any of the DU types; except
- $1.91\text{x}10^8$ Ci for H-3 within the LAWV; and
- $7.17\text{x}10^7$ Ci for H-3 within the ILV.

These initial upper bound estimates are then reduced based on maximum inventory calculations for the following operational constraints:

- Limiting gamma-ray exposure to workers (based on limits provided in WAC procedure Chapter 5, SRNS 2014) that is imposed on Trench and LAWV operations (Appendix D); and
- Container weight limitations imposed on trench and LAWV operations (Appendix E).

The resulting list is then further reduced for each of the 177 WITS radionuclides based on:

- The best estimate 2065 projected closure inventories based on two inventory snapshots (i.e. March 2016 and March 2020) to account for compositional changes and the current WITS inventory limits (Appendix C); and
- Scaling factor of ten to account for uncertainties in the projection process.

The end-result is upper bound inventory estimates for screening purposes that were employed throughout this report (but not shown given the length of such a list).

2.5 Radionuclide Screening Out Process

In the screening process, at a given tier level (i.e., Tier-1 or Tier-2), for a specific DU type, and for every pathway associated with either GW or II, a "peak" value of SOF is computed for each parent radionuclide by:

$$\mathrm{SOF}_j^k = \left[\frac{\mathrm{SF}_j^k}{\mathrm{PM}^k}\right] \times \mathrm{I}_j^{\mathrm{UB}} \tag{2-13}$$

where

SOF_j^k ....peak SOF for radionuclide j and kth pathway, (-)

SF_j^k .... peak screening factor for radionuclide j and k^{th} pathway, (dose units/Ci)

PM^k .... performance measure for k^{th} pathway, (dose units)

I_j^{UB} .... upper bound inventory estimate for radionuclide j, (Ci)

Note that the inventory estimate is in Curies of parent buried, the dose units vary depending upon which pathway is being evaluated, and a peak value refers to the largest value over the series of scenarios considered.

For screening purposes, the maximum SOF value is computed by:

$$SOF_j^{max} = Max\left[SOF_j^k\right] \quad \forall k \tag{2-14}$$

where

SOF_j^{max} .... Max SOF for radionuclide j over all pathways, (-)

k .... k index spans over all pathways of interest, (-)

A parent radionuclide is screened out of the incoming list if the following is true:

$$SOF_j^{max} > \eta_{PM} \rightarrow 0.1\% \tag{2-15}$$

where

η_{PM} .... Screening out criterion of performance measure, (-)

2.5.1 Criterion for Screening out a Radionuclide

As indicated by Eq. (2-15) within this screening report, if a radionuclide's max SOF is less than 0.1% of a performance measure (PM) (i.e., where all pathways have been considered) then it is "screened out" of future consideration and is considered to no longer require explicit tracking within WITS.

Historically (both SRNL and SRR) have made use of a screening out criterion of 1% of the PM and in this new screening effort that criterion was reduced to 0.1% of the PM. The net effect of lowering this criterion results in more radionuclides passing through to the next tier level.

In the screening out process, as can be seen in Eq. (2-13) there are two quantities that can contribute risk to prematurely (and incorrectly) screening out a radionuclide:

- **The peak SOF for radionuclide j and k^{th} pathway** – This quantity was computed based on the models chosen and every attempt was considered in biasing its value in the conservative direction (higher value). As a result, the conceptual model, in combination with modeling parameters, were typically encompassing. Thus, the risk contribution associated with this quantity is considered to be negligible; and
- **Upper bound inventory estimate for radionuclide j** – This quantity was computed based on all available information and data sources associated with is creation and ultimate dispositioning in a DU. For example, projected closure inventories were estimated based on historical WITS inventories and process knowledge. These estimates were then scaled up by a factor of ten to indirectly account for uncertainties in the inventory estimation process (note that this does not explicitly account for errors in waste generator

characterization methods which will be quantified in the PA closure analysis). Risks of underestimating a DU's final closure inventory still exists; however, that risk should be small, as discussed in Section 2.5.1, unless a new, out of the ordinary, waste stream is being considered for disposal.

To see how max SOF values vary with respect to a list of radionuclides, the max SOF values computed for the Tier-1 lists of radionuclides (i.e., 271 for Trench and LAWV, 272 for ILV, 295 for NRCDAG and NRCDAS) is shown in Figure 2-6. The actual max SOF values span a much greater range than shown in Figure 2-6 but a close up was chosen to show the general trend of these distributions. The horizontal red line represents the chosen screening criterion of 0.1% of the PM.

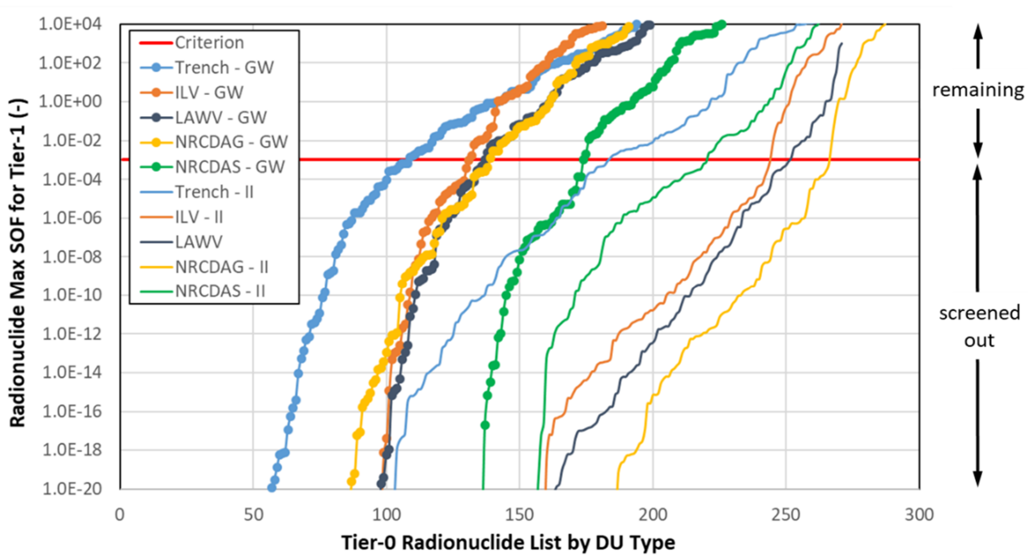


Figure 2-6. Groundwater and inadvertent intruder max SOF values for every Tier-1 radionuclide by disposal unit type.

A similar graph is provided in Figure 2-7 for the GW Tier-2 distributions on Max SOF by DU type (i.e., lists of radionuclides are 163 for Trench, 134 for LAWV, 141 for ILV, 157 for NRCDAG, and 122 for and NRCDAS).

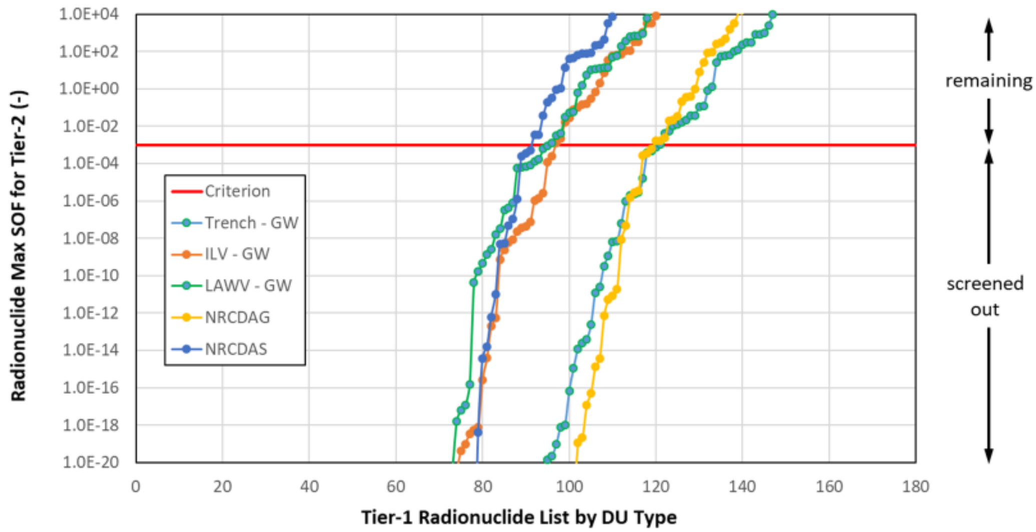


Figure 2-7. Groundwater max SOF values for every Tier-2 radionuclide by disposal unit type.

As both figures indicate these distributions have steep slopes, and we don't see large numbers of additional radionuclides being screened out as the criterion is decreased. To better see the impact of varying the PM criterion on the number of non-screened out radionuclides for the GW Tier-2 screening, Table 2-2 provides these numbers for each of the DU types over a broad range of criterion values. The results for the 0.1% and 1.0% of PMs are highlighted in orange and green, respectively. As shown, for an order-of-magnitude reduction in criterion only a few extra radionuclides are added to the list.

Table 2-2. Sensitivity of Groundwater Tier-2 radionuclide listing by disposal unit type versus performance measure.

Performance Measure	1.0E-6	1.0E-5	1.0E-4	1.0E-3	1.0E-2	1.0E-1	1.0E+0	1.0E+1	1.0E+2	>
Trenches	50	47	46	43	40	34	31	30	26	0
ILV	50	47	47	45	43	40	35	33	29	0
LAWV	47	47	43	39	36	33	32	30	23	0
NRCDAG	44	41	41	38	35	32	28	27	24	0
NRCDAS	35	34	34	31	29	28	25	24	17	0

If we assume that all of the "screened out" radionuclides are present at closure the sum of their max SOF values are computed as:

$$SOF_{Residual} = \sum_i SOF_i^{max} \tag{2-16}$$

where

$SOF_{Residual}$ .... sum of all screened out max SOF values per DU type, (-)

This unaccounted for residual represents an upper bound estimate. Those values associated with the Tier-2 GW screening results for each DU type are listed in Table 2-3, while the Inadvertent Intruder Tier-1 screening results are listed in

Table 2-4.

Table 2-3. Impact from choice of performance measure criterion for screening out radionuclides during the GW Tier-2 process.

PM Criterion (%)	Trench SOF (%)	ILV SOF (%)	LAWV SOF (%)	NRCDAG SOF (%)	NRCDAS SOF (%)
1.0%	14.87%	0.39%	1.07%	0.70%	4.41%
0.1%	0.17%	0.04%	0.21%	0.13%	0.11%
0.01%	0.00%	0.00%	0.03%	0.00%	0.00%

Table 2-4. Impact from choice of performance measure criterion for screening out radionuclides during the Inadvertent Intruder Tier-1 process.

PM Criterion (%)	Trench SOF (%)	ILV SOF (%)	LAWV SOF (%)	NRCDAG SOF (%)	NRCDAS SOF (%)
1.0%	7.20%	1.02%	3.79%	0.70%	2.83%
0.1%	0.36%	0.07%	0.28%	0.14%	0.38%
0.01%	0.01%	0.02%	0.01%	0.02%	0.06%

As Table 2-3 and

Table 2-4 indicate, a PM criterion of 1.0% could potentially yield up to a ~15% impact of operating SOF totals for trench DUs and was considered too large of a residual of unaccounted for contributors. Therefore, the PM criterion was reduced to 0.1% where no more than an upper estimate of ~0.2% in residual SOF could exist.

As Figure 2-6, Figure 2-7, and Table 2-2 demonstrate, max SOF values for the "screened out" radionuclides have steep slopes which also helps in accommodating inventory uncertainties. For the large portion of screened out radionuclide's potential errors within their estimated upper bound inventories can be accommodated by the growing degree of margin present (i.e., distance of their max SOF value beneath the PM criterion). Thus, risks have been greatly reduced.

2.6 The Use of Trigger Values

The need to employ trigger values to track unanalyzed radionuclides that are not found nor projected to be disposed in E-Area is eliminated in the new multitiered disposal limit system. Because the upper bound inventory estimates used are conservative, the multitiered approach undertaken in this report removes any need for supplemental tracking of a subset of radionuclides (i.e., trigger-value radionuclides). All possible radionuclides have been accounted for through screening or disposal limits. The approach never explicitly removed a radionuclide not based on the logic employed. All 1,252 radionuclides contained within the original ICRP-107 lists were processed.

However, given the absence of E-Area inventory for many of the radionuclides considered, extremely high upper bound inventories were assigned due to the lack of chemical process knowledge resulting in them not being "screened out." A trigger-value system can be usefully employed, to further reduce the lists of radionuclides that require complex multidimensional fate and transport analyses and subsequent tracking in WITS. The Tier-1 for Intruder and Tier-2 for GW radionuclide lists presented in Chapter 4.0 are the full listings, while proposed reductions of these lists through use of trigger values are provided in Chapter 5.0. SWM has the choice of selecting any combination of radionuclides from these lists to analyze in the PA or set aside as trigger isotopes. Practical considerations, though, would warrant developing PA inventory limits for any routinely generated radionuclide received in E-Area.

Once a particular "trigger-value" radionuclide has a requested inventory that is expected to exceed the DU's trigger value inventory threshold, an Unreviewed Disposal Question (UDQ) screening will need to be initiated. A follow up Special Analysis (SA) will most likely be performed where this particular radionuclide will have inventory limits generated and then transferred over to the limits list. The incremental increase in the Curie content of any trigger-value radionuclide is limited based on "Radionuclide Package Reporting Thresholds" listed in Chapter 3 Attachment 8.7 of the SWM Waste Acceptance Criteria (WAC) report (see SRNS 2017).

2.6.1 Trigger Value Concept

The concept of trigger values originated in 2004 when it was discovered that waste being disposed of in E-Area contained radionuclides that had not been analyzed nor screened out under the operative PA (i.e., PA2000). Following the 2000 PA screening calculation, additional radionuclides were removed from the PA analysis if they were not included in the normal SRS production waste isotopic distribution. This process was not well documented, and as a result there were cases of non-production waste being disposed of with radionuclides that were not screened out and were not analyzed in the PA. In subsequent work, a very conservative set of trigger values were calculated using screening models in lieu of PA inventory limits for those radionuclides that had not been analyzed in the PA (Cook and Wilhite 2004). This concept was carried forward and implemented in the 2008 PA.

In the 2022 PA, the new screening methodology further reduces the likelihood that future disposals will exceed performance measures and the possibility of unanalyzed radionuclides in E-Area by implementing:

- A multitiered limits system that starts by screening the ICRP-107 recommended list of 1,252 radionuclides. Radionuclides were only screened out based on well-defined logic that was implemented in FORTRAN-based algorithms. Thus, all radionuclides were explicitly accounted for greatly reducing the possibility of unanalyzed radionuclides from on-site or off-site waste generators. There is minimal risk of errors due to the systematic approach and testing/checking performed;
- A reduced screening measure from the historical value of 1% in SOF to 0.1%. Sensitivity studies on how this lower screening measure would impact the final Tier-2 radionuclide listings (Tier-1 and Tier-2 results provided in Appendix I and Appendix J, respectively) indicated that this was the more appropriate screening level;
- SOF calculations for all relevant pathways for both GW and Inadvertent Intruder performed at every tier level. The same set of dose parameters and pathways were employed that will be used in the subsequent limits generating Tier-3 and Tier-4 efforts; and
- A logical approach to estimating the upper bound inventory estimates on a DU type basis. A broad range of information was incorporated into establishing these estimates.

To eliminate this risk would require explicit inventories for every possible radionuclide (i.e., up to 1,252); however, the above features greatly reduce such risks. The recommended approach is to use the trigger-value options as discussed in Chapter 5.0.

3.0 Screening Analyses and Discussion

The results obtained from all of the tier screening analyses (i.e., Tier-0, Tier-1 and Tier-2) are presented within this section. The basis behind the models employed, the parameter settings chosen, and results obtained is provided. Detailed results associated with Tier-1 and Tier-2 are provided in Appendix I and Appendix J, respectively. Since stable nuclides (i.e., end products of decay chains) do not contribute to radiological dose factors they are not included in the original ICRP-07 list of 1,252 radionuclides; thus, do not show up in any of the reduced listing represented in this report. In this chapter the following topics are discussed:

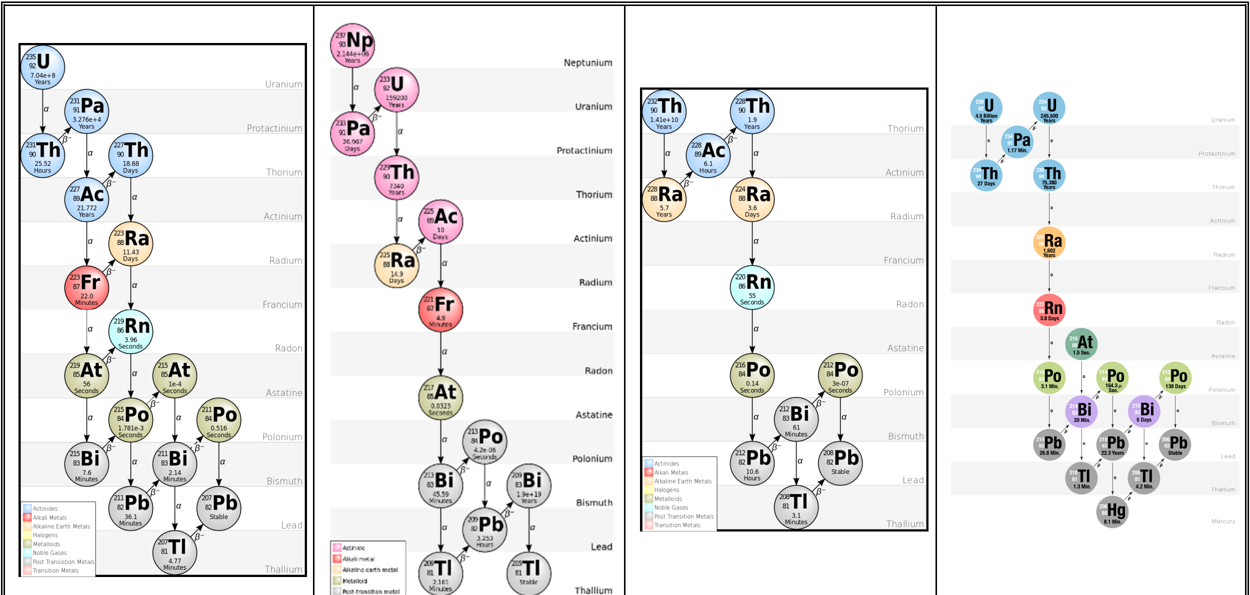
- **Tier-0 screening** – radionuclide lists are generated (based on no fate and transport aspects) for each of the five DU types;
- **Tier-1 screening** – for each DU type, as input the Tier-0 listings are processed using two bounding models (i.e., NCRP123 and NRCDWSM). The resulting lists obtained from the NCRP123 model are employed in subsequent screening, while the results from the NRCDWSM are viewed to assess sensitivities; and
- **Tier-2 screening** - for each DU type, as input the NCRP123 Tier-1 listings are processed using a hybrid PORFLOW-based fate and transport model (i.e., PorflowPS).

3.1 Tier-0 Screening Analysis

The Tier-0 process starts with the ICRP-07 list of 1,252 radionuclides. There are six processing steps performed in a sequential manner. The first two are "inclusive" (adds members to the list), while the last four are "exclusive" (potentially removes members from the list). Details of each step are discussed below. The basic overall strategy employed follows (and builds upon) similar logic as performed and discussed by Hamm (2006). The initial screening performed by Hamm (2006) was the basis employed in the creation of the Saltstone (2019) and H-Area Tank Farm (2012) PAs. Each of the six processing steps are discussed below.

3.1.1 Step 1. Member of Actinium, Neptunium, Thorium or Uranium decay series (Inclusion)

HLW sludge is known to contain the first member of each of the four radioactive decay series (Hamm 2005). Therefore, all descendants are automatically retained. All of these nuclides will be addressed in Tier-1 screening. The progression of each series is shown below in Figure 3-1. There are 62 radionuclides (not including the final stable isotope of each series) in the category as shown in Table 3-1.



Actinium	Neptunium	Thorium	Uranium

Figure 3-1. Decay chains of Actinium, Neptunium, Thorium and Uranium decay series.

Table 3-1. Radionuclides included as members of decay series.

U-235 (Actinium Series)	Pu-241 (Neptunium Series)	Th-232 (Thorium Series)	U-238 (Uranium Series)
Th-231	Am-241	Th-228	Pa-234m
Pa-231	U-237	Ra-228	U-234
Th-227	Np-237	Ac-228	Th-234
Ac-227	U-233	Ra-224	Pa-234
Ra-223	Pa-233	Rn-220	Th-230
Fr-223	Th-229	Po-216	Ra-226
Rn-219	Ra-225	Po-212	Rn-222
At-219	Ac-225	Pb-212	Rn-218
Po-215	Fr-221	Bi-212	Po-218
Bi-215	Rn-217	Tl-208	At-218
Po-211	At-217		Po-214
Pb-211	Po-213		Pb-214
Bi-211	Bi-213		Bi-214
Tl-207	Tl-209		Tl-210
	Pb-209		Po-210
			Pb-210
			Bi-210
			Tl-206
			Hg-206

At the end of Step 1, 62 radionuclides have been screened (all for inclusion) and 1190 remain to be processed in subsequent steps.

3.1.2 Step 2. Radionuclides characterized in residual sludge material estimate (inclusion)

HLW sludge has been characterized and estimates of the inventory of 64 radionuclides are available (Hamm 2005) as shown in Table 3-2. There are 50 radionuclides for inclusion based on this step, 14 of these already have been identified for inclusion based on Step 1 and are indicated with a superscript 1. These radionuclides will be automatically retained for Tier-1 screening.

Table 3-2. Radionuclides included because they are characterized in High-Level Waste.

Ac-227[1]	Al-26	Am-241[1]	Am-242m	Am-243	Ba-137m	Bk-249	C-14
Ce-144	Cf-249	Cf-251	Cf-252	Cm-242	Cm-243	Cm-244	Cm-245
Cm-247	Cm-248	Co-60	Cs-134	Cs-135	Cs-137	Eu-152	Eu-154
Eu-155	H-3	I-129	Na-22	Nb-94	Ni-59	Ni-63	Np-237[1]
Pa-231[1]	Pm-147	Pr-144	Pu-238	Pu-239	Pu-240	Pu-241[1]	Pu-242
Pu-244	Ra-226[1]	Ra-228[1]	Rh-106	Ru-106	Sb-125	Sb-126	Sb-126m
Se-79	Sm-151	Sn-126	Sr-90	Tc-99	Te-125m	Th-229[1]	Th-230[1]
Th-232[1]	U-232	U-233[1]	U-234[1]	U-235[1]	U-236	U-238[1]	Y-90

At the end of Step 2, 112 radionuclides have been screened (all for inclusion) and 1140 remain to be processed in subsequent steps.

3.1.3 Step 3. Radionuclides which are not in waste due to their physical state (exclusion)

Some elements exist only as gases. Argon, krypton, neon, radon and xenon are noble gases in this category and have 24 radionuclides as shown in Table 3-3. We assume that the liquid-phase solubilities of noble gases are very low and that during the SRS canyon dissolution process all of these gases (present during reactor core irradiation) outgas from the aqueous phase. Only radionuclides with no ongoing sources are considered in this step.

Table 3-3. Gas phase radionuclides.

Ar-37	Ar-41	Ar-42	Ar-43	Ar-44	Kr-74
Kr-75	Kr-76	Kr-87	Kr-88	Kr-89	Ne-19
Ne-24	Rn-207	Rn-209	Rn-210	Rn-211	Rn-223
Xe-120	Xe-122	Xe-127m	Xe-129m	Xe-137	Xe-138

At the end of Step 3, 136 radionuclides have been screened (112 for inclusion and 24 for exclusion) and 1116 remain to be processed in subsequent steps.

3.1.4 Step 4. Short-lived radionuclides with no precursors which decay below a threshold activity ratio (exclusion)

There are 503 radionuclides that are not created from the decay series (they have no ongoing source of formation) with a half-life below 0.23 years (which decays in 23 years below an activity ratio of 10^{-30}). The 23-year period is the average age of SRS waste produced from 1955 to 1989 at the time of the first burial in E-Area in 1995. There are 480 radionuclides excluded based on the criterion, while the rest were excluded in Step 3. The complete list of radionuclides is listed in Table 3-4.

Table 3-4. Radionuclides with no precursors which decay below a threshold activity ratio.

Ac-231	Ac-232	Ac-233	Ag-99	Ag-100m	Ag-106	Ag-106m	Ag-109m
Ag-113m	Ag-115	Ag-116	Ag-117	Al-29	Am-237	Am-244	Am-244m
Am-246	Am-247	Ar-37[3]	Ar-41[3]	Ar-43[3]	Ar-44[3]	As-68	As-69
As-74	As-76	As-79	At-204	At-205	At-206	At-220	Au-186
Au-187	Au-195m	Au-196m	Au-198m	Au-200m	Au-201	Ba-124	Ba-126
Ba-127	Ba-131m	Ba-133m	Ba-135m	Ba-141	Ba-142	Be-7	Bi-197

Bi-212n	Bk-248m	Br-72	Br-73	Br-74m	Br-78	Br-80m	Br-82m
Br-84m	Br-85	C-10	C-11	Ca-47	Ca-49	Cd-101	Cd-102
Cd-104	Cd-118	Cd-119	Cd-119m	Ce-130	Ce-131	Ce-132	Ce-133
Ce-133m	Ce-137m	Ce-145	Cf-244	Cf-246	Cf-255	Cl-34m	Cl-39
Cl-40	Cm-238	Cm-239	Cm-241	Cm-251	Co-54m	Co-55	Co-58m
Co-62m	Cr-48	Cr-49	Cr-55	Cr-56	Cs-121m	Cs-123	Cs-125
Cs-130m	Cs-132	Cs-134m	Cs-135m	Cs-136	Cs-138m	Cs-139	Cs-140
Cu-57	Cu-59	Cu-64	Cu-67	Cu-69	Dy-148	Dy-149	Dy-151
Dy-152	Dy-166	Dy-167	Dy-168	Er-154	Er-156	Er-159	Er-167m
Er-169	Er-171	Er-172	Er-173	Es-249	Es-250	Es-250m	Es-254m
Es-256	Eu-142m	Eu-148	Eu-150m	Eu-152m	Eu-152n	Eu-154m	Eu-158
Eu-159	F-17	F-18	Fe-52	Fe-53m	Fe-59	Fe-61	Fe-62
Fm-251	Fm-252	Fm-253	Fr-212	Fr-224	Fr-227	Ga-64	Ga-65
Ga-70	Ga-73	Ga-74	Gd-142	Gd-143m	Gd-144	Gd-145m	Gd-162
Ge-66	Ge-67	Ge-75	Ge-77	Ge-78	Hf-167	Hf-169	Hf-177m
Hf-179m	Hf-180m	Hf-182m	Hf-183	Hf-184	Hg-191m	Hg-192	Hg-193m
Hg-197m	Hg-199m	Hg-203	Hg-205	Hg-207	Ho-150	Ho-153	Ho-153m
Ho-154m	Ho-155	Ho-157	Ho-160	Ho-162m	Ho-164m	Ho-168m	Ho-170
I-118	I-118m	I-119	I-120m	I-124	I-126	I-128	I-130m
I-132m	I-134m	I-135	In-103	In-105	In-106	In-107	In-108
In-110	In-112m	In-114m	In-116m	In-118m	In-121m	Ir-180	Ir-182
Ir-185	Ir-190m	Ir-190n	Ir-191m	Ir-192m	Ir-195m	Ir-196m	K-38
K-45	K-46	Kr-74[3]	Kr-75[3]	Kr-76[3]	Kr-87[3]	Kr-88[3]	Kr-89[3]
La-128	La-129	La-132m	La-136	La-143	Lu-165	Lu-171m	Lu-176m
Lu-178m	Lu-180	Lu-181	Mg-27	Mg-28	Mn-50m	Mn-51	Mn-57
Mn-58m	Mo-89	Mo-90	Mo-93m	Mo-101	Mo-102	N-13	N-16
Nb-87	Nb-88	Nb-88m	Nb-89m	Nb-92m	Nb-94m	Nb-96	Nb-98m
Nb-99m	Nd-134	Nd-135	Nd-138	Nd-139m	Nd-149	Nd-151	Nd-152
Ne-19[3]	Ne-24[3]	Ni-56	Ni-65	Ni-66	Np-236m	Np-241	Np-242m
O-14	O-15	O-19	Os-181	Os-191m	Os-193	Os-196	P-30
P-33	Pa-227	Pa-230	Pa-237	Pb-194	Pb-195m	Pb-196	Pb-198
Pb-202m	Pd-96	Pd-97	Pd-98	Pd-109m	Pd-111	Pd-112	Pd-114
Pm-136	Pm-137m	Pm-140m	Pm-148m	Pm-150	Pm-152m	Pm-153	Pm-154
Pm-154m	Pr-134	Pr-138m	Pr-142m	Pr-146	Pr-147	Pr-148	Pr-148m
Pt-184	Pt-188	Pt-189	Pt-197m	Pt-199	Pt-200	Pt-202	Pu-232
Pu-235	Pu-245	Ra-221	Ra-230	Rb-77	Rb-78m	Rb-82m	Rb-84m
Rb-86m	Rb-90m	Re-178	Re-179	Re-182	Re-188m	Re-189	Re-190m
Rh-94	Rh-95m	Rh-100m	Rh-104m	Rh-106m	Rh-109	Rn-207[3]	Rn-209[3]
Rn-210[3]	Rn-211[3]	Rn-223[3]	Ru-92	Ru-103	Ru-107	Ru-108	S-37
S-38	Sb-111	Sb-116m	Sb-118m	Sb-120	Sb-120m	Sb-122m	Sb-124n
Sb-131	Sb-133	Sc-42m	Sc-43	Sc-44m	Sc-48	Sc-50	Se-70
Se-71	Se-77m	Se-81m	Se-83	Se-83m	Se-84	Si-31	Sm-139
Sm-140	Sm-141m	Sm-155	Sm-156	Sm-157	Sn-106	Sn-108	Sn-109

Sn-110	Sn-123m	Sn-125	Sn-125m	Sn-127	Sn-127m	Sn-128	Sn-129
Sn-130	Sn-130m	Sr-79	Sr-80	Sr-82	Sr-91	Sr-92	Sr-93
Sr-94	Ta-170	Ta-172	Ta-173	Ta-174	Ta-175	Ta-176	Ta-178m
Ta-180	Ta-185	Ta-186	Tb-146	Tb-147	Tb-147m	Tb-148m	Tb-152m
Tb-154	Tb-156m	Tb-156n	Tb-160	Tb-161	Tb-163	Tb-164	Tb-165
Tc-91	Tc-91m	Tc-93m	Tc-94	Tc-96m	Tc-102m	Tc-104	Tc-105
Te-113	Te-114	Te-115	Te-115m	Te-116	Te-117	Te-132	Te-134
Th-235	Th-236	Ti-45	Ti-51	Ti-52	Tl-190	Tl-190m	Tl-194m
Tl-198m	Tl-206m	Tm-161	Tm-174	Tm-175	Tm-176	U-227	U-239
U-242	V-47	V-53	W-177	W-185m	W-187	W-188	W-190
Xe-120[3]	Xe-122[3]	Xe-127m[3]	Xe-129m[3]	Xe-137[3]	Xe-138[3]	Y-81	Y-83m
Y-84m	Y-86m	Y-89m	Y-90m	Y-95	Yb-162	Yb-163	Yb-164
Yb-166	Yb-177	Yb-178	Yb-179	Zn-60	Zn-61	Zn-62	Zn-63
Zn-69m	Zn-71	Zn-71m	Zn-72	Zr-85	Zr-86	Zr-97	

At the end of Step 4, 616 radionuclides have been screened (112 for inclusion and 504 for exclusion) and 636 remain to be processed in subsequent steps.

3.1.5 Step 5. Fission fragment/product radionuclides with decay or ingrowth below a threshold activity ratio (exclusion)

Fission fragment radionuclides produced by the slow-neutron fission of U^{235} span the range of mass numbers from 72 to 162 (Benedict et al. 1981). Note that in SRS heavy water production reactors the majority of fissioning events were associated with U^{235} atoms. Fission fragments are created as parent nuclides that can decay into its progeny through isobaric decay chains. Fission fragment/products radionuclides which are members of isobaric decay chains are screened in this step. Short-lived fission fragment/products radionuclides with no precursors were screened in Step 4. There are 279 radionuclides with decay or ingrowth from 23 to 1,194 years (1995 to 3166 E-Area timeline) below an activity ratio of 10^{-30} as a parent and daughter nuclide. The radionuclides are excluded based on the criterion are listed in Table 3-5.

Table 3-5. Fission fragment radionuclides with decay or ingrowth below a threshold activity ratio from the years 1995 to 3166.

Ag-101	Ag-102	Ag-102m	Ag-103	Ag-104	Ag-104m	Ag-105	Ag-105m
Ag-111	Ag-111m	Ag-112	Ag-113	Ag-114	As-72	As-73	As-77
As-78	Ba-128	Ba-129	Ba-129m	Ba-131	Ba-139	Ba-140	Br-74
Br-75	Br-76	Br-76m	Br-77	Br-77m	Br-80	Br-82	Br-83
Br-84	Cd-103	Cd-105	Cd-107	Cd-111m	Cd-115	Cd-115m	Cd-117
Cd-117m	Ce-134	Ce-135	Ce-137	Ce-141	Ce-143	Cs-121	Cs-124
Cs-126	Cs-127	Cs-128	Cs-129	Cs-130	Cs-131	Cs-138	Dy-150
Dy-153	Dy-155	Dy-157	Er-161	Eu-142	Eu-143	Eu-144	Eu-145
Eu-146	Eu-147	Eu-156	Eu-157	Ga-72	Gd-145	Gd-146	Gd-147
Gd-149	Gd-159	Ho-154	Ho-156	Ho-159	Ho-161	Ho-162	I-120
I-121	I-122	I-123	I-125	I-130	I-131	I-132	I-133
I-134	In-106m	In-108m	In-109	In-109m	In-110m	In-111	In-111m

In-112	In-114	In-115m	In-117	In-117m	In-118	In-119	In-119m
In-121	Kr-77	Kr-79	Kr-81m	Kr-85m	La-130	La-131	La-132
La-133	La-134	La-135	La-140	La-141	La-142	Mo-91	Mo-91m
Mo-99	Nb-89	Nb-90	Nb-91m	Nb-95	Nb-95m	Nb-97	Nb-99
Nd-136	Nd-137	Nd-139	Nd-140	Nd-141	Nd-141m	Nd-147	Pd-99
Pd-100	Pd-101	Pd-103	Pd-109	Pm-139	Pm-140	Pm-141	Pm-142
Pm-148	Pm-149	Pm-151	Pm-152	Pr-134m	Pr-135	Pr-136	Pr-137
Pr-138	Pr-139	Pr-140	Pr-142	Pr-143	Pr-145	Rb-78	Rb-79
Rb-80	Rb-81	Rb-81m	Rb-82	Rb-84	Rb-86	Rb-88	Rb-89
Rb-90	Rh-95	Rh-96	Rh-96m	Rh-97	Rh-97m	Rh-98	Rh-99
Rh-99m	Rh-100	Rh-101m	Rh-103m	Rh-104	Rh-105	Rh-107	Rh-108
Ru-94	Ru-95	Ru-97	Ru-105	Sb-113	Sb-114	Sb-115	Sb-116
Sb-117	Sb-118	Sb-119	Sb-122	Sb-124	Sb-124m	Sb-127	Sb-128
Sb-128m	Sb-129	Sb-130	Sb-130m	Se-72	Se-73	Se-73m	Se-79m
Se-81	Sm-141	Sm-142	Sm-143	Sm-143m	Sm-153	Sn-111	Sn-113m
Sn-117m	Sr-81	Sr-83	Sr-85	Sr-85m	Sr-87m	Sr-89	Tb-148
Tb-149	Tb-149m	Tb-150	Tb-150m	Tb-151	Tb-151m	Tb-152	Tb-153
Tb-155	Tb-156	Tb-162	Tc-92	Tc-93	Tc-94m	Tc-95	Tc-95m
Tc-96	Tc-99m	Tc-101	Tc-102	Te-118	Te-119	Te-119m	Te-129
Te-129m	Te-131	Te-131m	Te-133	Te-133m	Tm-162	Xe-121	Xe-123
Xe-125	Xe-127	Xe-131m	Xe-133	Xe-133m	Xe-135	Xe-135m	Y-83
Y-85	Y-85m	Y-86	Y-87	Y-87m	Y-91	Y-91m	Y-92
Y-93	Y-94	Zr-87	Zr-88	Zr-89	Zr-89m	Zr-95	

At the end of this step, 895 radionuclides have been screened (112 for inclusion and 783 for exclusion) and 357 remain to be processed in the next step.

3.1.6 Step 6. Radionuclides with precursors with ingrowth below a threshold activity ratio (exclusion)

The final group of radionuclides to examine for screening include radionuclides that are only formed from radioactive decay. There are 198 radionuclides with ingrowth from 23 to 1,194 years (1995 to 3166 E-Area timeline) below an activity ratio of 10^{-30} as a daughter nuclide. The radionuclides excluded based on the criterion are listed in Table 3-6.

Table 3-6. Radionuclides with precursors with ingrowth below a threshold activity ratio from the years 1995 to 3166 years.

Ac-223	Ac-224	Ac-226	Ac-230	Al-28	Am-238	Am-239	Am-240
As-70	As-71	At-207	At-208	At-209	At-210	At-211	At-215
At-216	Au-190	Au-191	Au-192	Au-193	Au-193m	Au-196	Au-198
Au-199	Au-200	Au-202	Bi-200	Bi-201	Bi-202	Bi-203	Bi-204
Bi-205	Bi-206	Bi-216	Bk-245	Bk-246	Bk-251	Cf-247	Cf-254
Cl-34	Cl-38	Cm-240	Co-56	Co-58	Co-61	Co-62	Cr-51
Cu-60	Cu-61	Cu-62	Cu-66	Dy-165	Dy-165m	Er-163	Er-165
Es-251	Es-255	Fe-53	Fm-255	Fm-256	Fr-219	Fr-220	Fr-222

Ga-66	Ga-67	Ge-69	Ge-71	Hf-170	Hf-173	Hf-175	Hf-181
Hg-190	Hg-193	Hg-195	Hg-195m	Hg-197	Ho-164	Ho-166	Ho-167
Ho-168	Ir-183	Ir-184	Ir-186	Ir-186m	Ir-187	Ir-188	Ir-189
Ir-190	Ir-193m	Ir-195	Ir-196	K-43	K-44	Lu-167	Lu-169
Lu-169m	Lu-170	Lu-171	Lu-178	Lu-179	Mn-52	Mn-52m	Mn-56
Na-24	Ni-57	Np-232	Np-233	Np-234	Np-242	Os-180	Os-182
Os-183	Os-183m	Os-189m	Os-190m	Os-191	Pa-228	Pa-229	Pa-235
Pa-236	Pb-197	Pb-197m	Pb-199	Pb-200	Pb-201	Pb-201m	Pb-203
Pb-204m	Po-203	Po-204	Po-205	Po-206	Po-207	Po-212m	Pt-186
Pt-187	Pt-191	Pt-193m	Pt-195m	Pt-197	Pu-234	Pu-237	Ra-219
Ra-220	Ra-222	Ra-227	Rb-83	Re-180	Re-181	Re-182m	Re-183
Re-188	Re-190	Rn-212	Rn-215	Rn-216	Sc-47	Sc-49	Ta-177
Ta-178	Ta-182m	Ta-183	Ta-184	Tc-97m	Th-223	Th-224	Th-226
Th-233	Tl-194	Tl-195	Tl-196	Tl-197	Tl-198	Tl-199	Tl-200
Tl-201	Tm-163	Tm-164	Tm-165	Tm-166	Tm-167	Tm-172	Tm-173
U-228	U-230	U-231	V-48	V-52	W-178	W-179	W-179m
W-185	Yb-165	Yb-167	Yb-169	Yb-175	Zn-69		

At the end of this step, 1093 radionuclides have been screened (112 for inclusion and 981 for exclusion) and 159 remain.

3.1.7 Tier-0 Radionuclide Lists for each Disposal Unit Type

After performing the above six steps, all 1,252 radionuclides have been screened. The number of radionuclides for exclusion from further screening is 981. The final number of radionuclides for inclusion is 271 (112 for inclusion plus 159 remaining) which proceeds to Tier-1 screening and are listed in Table 3-7.

Table 3-7. SRS-based list of radionuclides for Tier-1 screening (271).

Ac-225	Ac-227	Ac-228	Ag-108	Ag-108m	Ag-110	Ag-110m	Al-26
Am-241	Am-242	Am-242m	Am-243	Am-245	Am-246m	Ar-39	At-217
At-218	At-219	Au-194	Au-195	Ba-133	Ba-137m	Be-10	Bi-207
Bi-208	Bi-210	Bi-210m	Bi-211	Bi-212	Bi-213	Bi-214	Bi-215
Bk-247	Bk-249	Bk-250	C-14	Ca-41	Ca-45	Cd-109	Cd-113
Cd-113m	Ce-139	Ce-144	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252
Cf-253	Cl-36	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cm-247
Cm-248	Cm-249	Cm-250	Co-57	Co-60	Co-60m	Cs-134	Cs-135
Cs-137	Dy-154	Dy-159	Es-253	Es-254	Eu-149	Eu-150	Eu-152
Eu-154	Eu-155	Fe-55	Fe-60	Fm-254	Fm-257	Fr-221	Fr-223
Ga-68	Gd-148	Gd-150	Gd-151	Gd-152	Gd-153	Ge-68	H-3
Hf-172	Hf-174	Hf-178m	Hf-182	Hg-194	Hg-206	Ho-163	Ho-166m
I-129	In-113m	In-115	Ir-192	Ir-192n	Ir-194	Ir-194m	K-40
K-42	Kr-81	Kr-83m	Kr-85	La-137	La-138	Lu-172	Lu-172m
Lu-173	Lu-174	Lu-174m	Lu-176	Lu-177	Lu-177m	Mn-53	Mn-54
Mo-93	Na-22	Nb-91	Nb-92	Nb-93m	Nb-94	Nd-144	Ni-59

Ni-63	Np-235	Np-236	Np-237	Np-238	Np-239	Np-240	Np-240m
Os-185	Os-186	Os-194	P-32	Pa-231	Pa-232	Pa-233	Pa-234
Pa-234m	Pb-202	Pb-205	Pb-209	Pb-210	Pb-211	Pb-212	Pb-214
Pd-107	Pm-143	Pm-144	Pm-145	Pm-146	Pm-147	Po-208	Po-209
Po-210	Po-211	Po-212	Po-213	Po-214	Po-215	Po-216	Po-218
Pr-144	Pr-144m	Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Pu-243	Pu-244	Pu-246	Ra-223	Ra-224	Ra-225
Ra-226	Ra-228	Rb-87	Re-184	Re-184m	Re-186	Re-186m	Re-187
Rh-101	Rh-102	Rh-102m	Rh-106	Rn-217	Rn-218	Rn-219	Rn-220
Rn-222	Ru-106	S-35	Sb-125	Sb-126	Sb-126m	Sc-44	Sc-46
Se-75	Se-79	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-151
Sn-113	Sn-119m	Sn-121	Sn-121m	Sn-123	Sn-126	Sr-90	Ta-179
Ta-182	Tb-157	Tb-158	Tc-97	Tc-98	Tc-99	Te-121	Te-121m
Te-123	Te-123m	Te-125m	Te-127	Te-127m	Th-227	Th-228	Th-229
Th-230	Th-231	Th-232	Th-234	Ti-44	Tl-202	Tl-204	Tl-206
Tl-207	Tl-208	Tl-209	Tl-210	Tm-168	Tm-170	Tm-171	U-232
U-233	U-234	U-235	U-235m	U-236	U-237	U-238	U-240
V-49	V-50	W-181	Y-88	Y-90	Zn-65	Zr-93	

The Tier-0 screening assumes that radionuclides in SRS High-Level waste comprise the majority of waste streams received by the ELLWF. The age and composition of SRS HLW is well known and documented. Table 3-7 represent the reduced list where SRS process knowledge has been employed in the reduction of the original 1,252 ICRP-107 list. Thus, this “SRS-based” list of 271 radionuclides applies directly as the Tier-1 list for the Trenches and LAWV DU types.

An additional radionuclide, Ar-37, was identified as a special non-SRS waste form in the ILV during the update to the 2065 E-Area closure inventory. This additional radionuclide, Ar-37, is in a special wasteform signified by TPBAR (i.e., Tritium Producing Burnable Absorber Rod) and in WITS its ID name is Ar-37T. The list of radionuclides for Tier-1 ILV are augmented to include Ar-37 for a total of 272.

The age or source of radionuclides in Naval Reactor Components and auxiliary equipment is not known or characterized. Insufficient information precluded additional steps in Tier-0 to include or exclude radionuclides in the NRCDA. The radionuclide inventory in the NRCDA was provided by the US Naval Reactor program. Therefore, the Tier-0 list of radionuclides was augmented for the NRCDA by including radionuclides from the NRCDA inventory that were not included in the Tier-0 screening (i.e., the union of both lists). Table 3-8 is the list of radionuclides for Tier-1 NRCDA screening. The radionuclides in bold are the additional 24 radionuclides added for a total of 295.

Table 3-8. List of radionuclides for Tier-1 NRCDA screening (295).

Ac-225	Ac-227	Ac-228	Ag-108	Ag-108m	**Ag-109m**	Ag-110	Ag-110m
Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245	Am-246m	Ar-39
At-217	At-218	At-219	Au-194	Au-195	Ba-133	Ba-137m	**Ba-140**
Be-10	Bi-207	Bi-208	Bi-210	Bi-210m	Bi-211	Bi-212	Bi-213
Bi-214	Bi-215	Bk-247	Bk-249	Bk-250	C-14	Ca-41	Ca-45

Cd-109	Cd-113	Cd-113m	**Cd-115m**	Ce-139	**Ce-141**	Ce-144	Cf-248
Cf-249	Cf-250	Cf-251	Cf-252	Cf-253	Cl-36	Cm-242	Cm-243
Cm-244	Cm-245	Cm-246	Cm-247	Cm-248	Cm-249	Cm-250	Co-57
Co-58	Co-60	Co-60m	**Cr-51**	Cs-134	Cs-135	Cs-137	Dy-154
Dy-159	Es-253	Es-254	Eu-149	Eu-150	Eu-152	Eu-154	Eu-155
Fe-55	**Fe-59**	Fe-60	Fm-254	Fm-257	Fr-221	Fr-223	Ga-68
Gd-148	Gd-150	Gd-151	Gd-152	Gd-153	Ge-68	H-3	Hf-172
Hf-174	**Hf-175**	Hf-178m	**Hf-181**	Hf-182	Hg-194	Hg-206	Ho-163
Ho-166m	I-129	In-113m	**In-114**	**In-114m**	In-115	Ir-192	**Ir-192m**
Ir-192n	Ir-194	Ir-194m	K-40	K-42	Kr-81	Kr-83m	Kr-85
La-137	La-138	**La-140**	Lu-172	Lu-172m	Lu-173	Lu-174	Lu-174m
Lu-176	Lu-177	Lu-177m	Mn-53	Mn-54	Mo-93	Na-22	Nb-91
Nb-92	Nb-93m	Nb-94	**Nb-95**	**Nb-95m**	Nd-144	Ni-59	Ni-63
Np-235	Np-236	Np-237	Np-238	Np-239	Np-240	Np-240m	Os-185
Os-186	Os-194	P-32	**P-33**	Pa-231	Pa-232	Pa-233	Pa-234
Pa-234m	Pb-202	Pb-205	Pb-209	Pb-210	Pb-211	Pb-212	Pb-214
Pd-107	Pm-143	Pm-144	Pm-145	Pm-146	Pm-147	Po-208	Po-209
Po-210	Po-211	Po-212	Po-213	Po-214	Po-215	Po-216	Po-218
Pr-144	Pr-144m	Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Pu-243	Pu-244	Pu-246	Ra-223	Ra-224	Ra-225
Ra-226	Ra-228	Rb-87	Re-184	Re-184m	Re-186	Re-186m	Re-187
Rh-101	Rh-102	Rh-102m	**Rh-103m**	Rh-106	Rn-217	Rn-218	Rn-219
Rn-220	Rn-222	**Ru-103**	Ru-106	S-35	**Sb-124**	Sb-125	Sb-126
Sb-126m	Sc-44	Sc-46	Se-75	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-113	Sn-119m	Sn-121	Sn-121m	Sn-123
Sn-126	**Sr-89**	Sr-90	Ta-179	Ta-182	Tb-157	Tb-158	Tc-97
Tc-98	Tc-99	Te-121	Te-121m	Te-123	Te-123m	Te-125m	Te-127
Te-127m	Th-227	Th-228	Th-229	Th-230	Th-231	Th-232	Th-234
Ti-44	Tl-202	Tl-204	Tl-206	Tl-207	Tl-208	Tl-209	Tl-210
Tm-168	Tm-170	Tm-171	U-232	U-233	U-234	U-235	U-235m
U-236	U-237	U-238	U-240	V-49	V-50	W-181	**W-185**
W-188	Y-88	Y-90	**Y-91**	Zn-65	Zr-93	**Zr-95**	

3.2 Tier-1 and Tier-2 Upper Bound Inventory Estimates

In order to screen out a parent radionuclide from further considerations, its maximum dose at the 100-m POA must remain below the performance measure (i.e., in this report a value of 0.1% of the SOF was chosen). Therefore, a method must be employed to estimate the "upper bound" inventory that this parent radionuclide would reach during the life of all of the DUs. A maximum absolute value (in units of Ci) must be specified that is DU type dependent. To accomplish this several methods (and sources) for estimating inventories were used to obtain a set of limiting radionuclide disposal inventories (see Chapter 2.0, Appendix C, Appendix D, Appendix E, and Appendix H for details):

- Projected closure inventories were created based on two separate WITS inventory times (i.e. March 2016 and March 2020). These projections also made use of available process knowledge, waste generator histories and future site missions, and current WITS inventory limits (applies to all DU types, see Appendix C for details);
- The composite projected closure inventories were scaled up by a factor of ten to address uncertainties (applies to all DU types);
- Inventory estimates from Naval Reactor forecasting of future shipments (KAPL information) (applies to NRCDAG and NRCDAS DU types, see Appendix H for details);
- Constraint on the gamma-ray dose limits in WAC procedures for handling of B-25 boxes during the burial process (applies to LAWV and Trench DUs, see Appendix D for details);
- Constraint on the historical weight of waste in B-25 boxes where a upper estimate of 0.01 wt% of pure radionuclide in each B-25 box was estimated from WITS data (applies to LAWV and Trench DUs, see Appendix E for details); and
- A historical screening inventory value of 10^7 Ci as a starting value where each of the prior items have the potential to reduce the inventory below this upper value. If none of the prior items apply this value remains (except for H-3 which can exceed this value within the two vault DUs) (applies to all DU types).

The minimum values, obtained from the appropriate items above, established the upper bound inventory estimates. The resulting upper bound inventories were used for both Tier-1 and Tier-2 screening for GW and Inadvertent Intruder where applicable.

3.3 Tier-1 Inadvertent Intruder Radionuclide Screening

For inadvertent intruder screening the various pathways listed in Table 3-9 (extracted from Smith et al. 2016) were considered for both the acute and chronic human receptors.

Inadvertent intruder analysis was performed for the five DU models using the ICRP-07 and Tier-0 list of radionuclides. The upper bound estimated radionuclide inventories as discussed in Section 3.2 were employed.

The intruder screening model consists of a parent radionuclide uniformly distributed throughout the waste zone of each DU with no depletion of the parent or progeny inventories over time due to leaching from infiltration. The full (un-collapsed) waste height for each DU was assumed in determining whether waste zone contaminants were within the standard ten-foot excavation for the basement construction scenario. The waste zone represents the areal footprint and nominal waste height of each DU model. The starting inventory of the parent nuclide is initialized to the atom number equivalent of 10^{12} pCi divided by the decay constant of the parent nuclide. For each of the radionuclides, transient atom numbers are computed for a 1-year half-life cutoff short chain every year for a 1171-year period. The short chain is solved numerically using the matrix exponential method in lieu of solving the full chain, since this method can produce numerical errors for large decay chains. The radionuclide progeny with half-lives less than 1 year are assumed to be in secular equilibrium with their precursor(s). Transient full chain activities are then produced for each parent nuclide as uniformly distributed waste zone soil concentrations (pCi/m^3 per Ci of parent) for intruder dose calculations.

Table 3-9. Inadvertent intruder exposure pathways considered.

Human Receptor	Scenario	General Exposure Pathway	Specific Exposure Pathway
Acute Intruder (PA)	Basement Construction	Ingestion	Waste Material
		Inhalation	Waste Material
		External Exposure	Waste Material
	Well Drilling	Ingestion	Waste Material
		Inhalation	Waste Material
		External Exposure	Waste Material
	Discovery	External Exposure	Waste Material
Chronic Intruder (PA)	Agriculture	Ingestion	Garden Vegetables
			Garden Soil (Dust)
		Inhalation	Garden Soil (Dust)
			Dust in Home
		External Exposure	Garden Soil
			Home
	Post Drilling	Ingestion	Garden Vegetables
			Garden Soil (Dust)
		Inhalation	Garden Soil (Dust)
		External Exposure	Garden Soil
	Residential	External Exposure	Home Residence

The waste zone transient full chain soil concentrations are processed through the SRNL Dose Toolkit for the acute and chronic intruder human receptors. The acute intruder examines the basement construction, well drilling, and discovery scenarios. The chronic intruder examines the agriculture, post drilling, and residential scenarios. For the PA inadvertent intruder, the applicable performance measures are 500 mrem/yr Effective Dose Equivalent (EDE) and 100 mrem/yr EDE for acute and chronic exposure scenarios, respectively. The screening criteria used are 0.1% of the performance measures.

Each DU is assumed to have waste buried at 1994.7 (Year 0) with an operational period extending to the time of E-Area closure, 2065.7 (Year 71,). Start of institutional control (SIC) in 2065.7 runs 100 years to 2165.7 [(Year 171), end of institutional control (EIC)]. The period-of-performance for the inadvertent intruder spans 1000 years to 3165.7 (Year 1171) during the screening period.

Critical dimensions for inadvertent intruder analysis are shown in Figure 3-2. Other relevant intruder parameters are documented in Aleman (2019).

The output of the SRNL Dose Toolkit calculations are maximum screening factors (mrem/yr per Ci of parent buried) for the acute and chronic intruder human receptors from 171 to 1171 years with progeny contributions rolled up for each radionuclide parent. The intruder screening factors are multiplied by the estimated radionuclide limiting inventories to produce acute and chronic intruder doses. The radionuclide is screened out for PA intruder analysis if the intruder doses do not exceed its screening criterion.

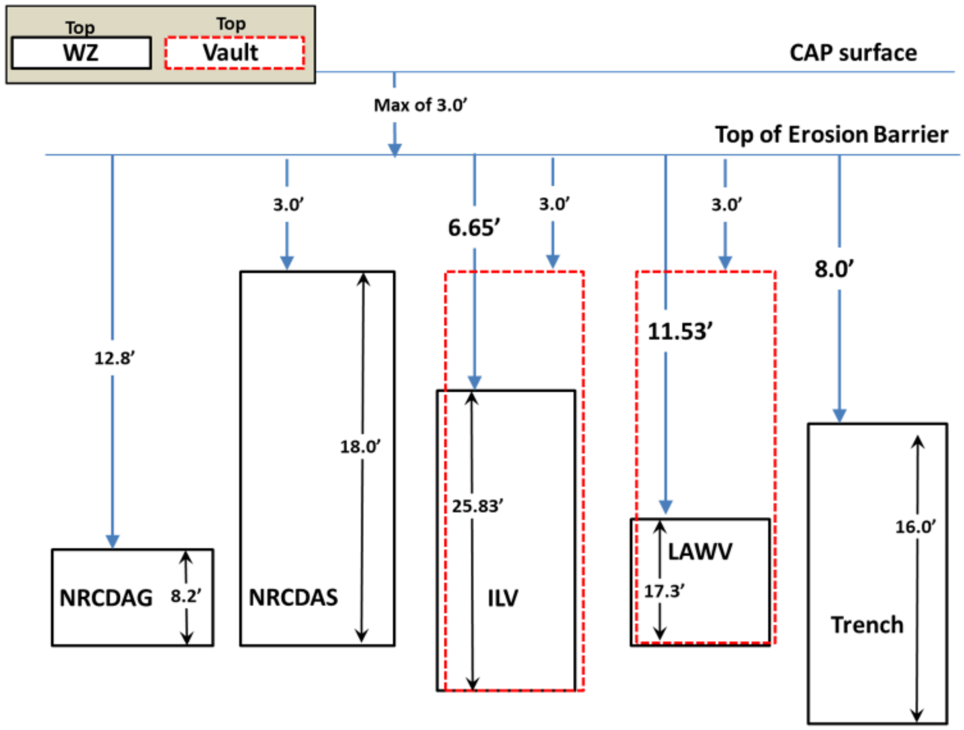


Figure 3-2. Critical dimensions for inadvertent intruder analysis.

A discussion of inadvertent intruder parameters, scenarios, and screening results are presented in the following subsections for the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench DU screening models. Lists of radionuclides that failed screening are shown for the ICRP-07 (i.e., the original list provided in ICRP-107) and Tier-0 radionuclides. The starting lists studied for each DU model were:

- Tier-0 (271) for Trench and LAWV models;
- Tier-0 (272) for ILV models;
- Tier-0 (295) for NRCDA models; and
- ICRP-07 (1,252) for all five models.

For each DU type Tier-1 lists were generated based on the Tier-0 lists and then for comparison purposes starting from the ICRP-07 list.

3.3.1 Tier-1 ILV Inadvertent Intruder Screening

The Intermediate Level Vault (ILV) is a below-grade, reinforced concrete vault. It consists of two modules, which together encompass a 279-foot (85 m) by 48-foot (15 m) area. The Intermediate Level Tritium (ILT) module contains two cells, whose inside dimensions are 25-foot (7.6 m) by 44-foot (13 m) by 26-foot (7.9 m) deep. ILT Cell #1 contains 144, 20-inch (51 cm) diameter by 20-foot (6.1 m) long vertical silos. The Intermediate Level Non-Tritium (ILNT) module contains seven identical cells, whose inside dimensions are 25-foot (7.6 m) by 44-foot (13 m) by 28-foot (8.7 m) deep. The area between the two modules provides manhole access to the subdrain system. The ILV cross-section beneath the closure cap through the short axis of the vault is shown in Figure 3-3.

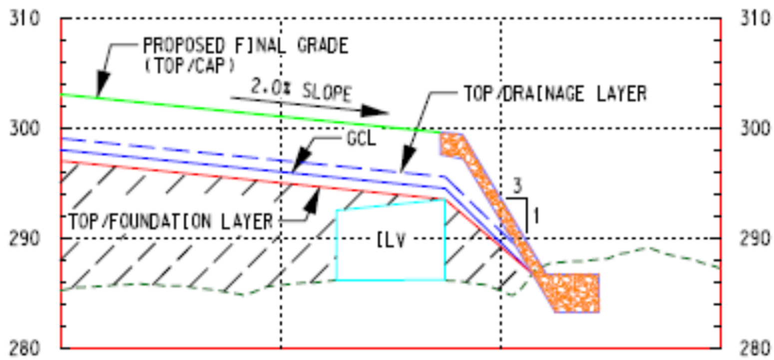


Figure 3-3. ILV cross-section through short axis of the vault.

A plan view of ILV is also provided in Figure 3-4. The ILV intruder model considers the waste in the ILT and ILNT sections as uniform and homogeneous throughout the composited waste zone.

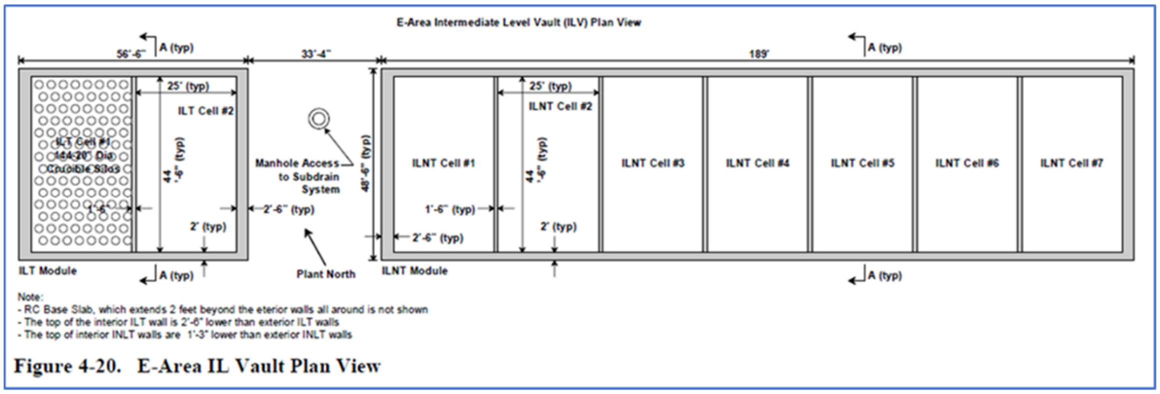


Figure 3-4. ILV plan view of the vault.

The ILV inadvertent intruder parameters shown in Table 3-10 are used to determine the state of the acute and chronic intruder scenarios and doses to the intruder as a function of time beyond EIC.

Table 3-10. ILV inadvertent intruder parameters.

Parameter	Setting	Comment
Intrusion drilling barrier	True	Concrete roof
Erosion barrier failure	False	No failure during intruder
Erosion barrier depth	3 ft (0.914 m)	Thickness of soil cover
Drilling barrier depth	6 ft (1.83 m)	Top of concrete roof
Waste zone depth	9.65 ft (2.941 m)	Closure cap, concrete roof (2.25 ft) and grout/air gap (1.4 ft)
Waste zone thickness	25.83 ft (7.873 m)	Interior height of ILNT Vault
Waste zone area	10,500 ft^2 (975.48 m^2)	77.7% of footprint Hamm (2019)
Waste zone volume	271,515 ft^2 (7680 m^2)	Concentration calculation

The ILV inadvertent intruder and general parameter settings (geometry and barriers) dictate the viability of specific intruder scenarios as shown in Table 3-11.

Table 3-11. State of ILV inadvertent intruder scenarios.

Intruder scenario	State	Comment
(Acute) Basement construction	False	10 ft basement cannot extend below concrete roof
(Acute) Well drilling	False	Concrete roof
(Acute) Discovery	True	Basement excavation stops at erosion barrier. Shielding between top of erosion barrier and top of waste zone.
(Chronic) Agriculture	False	No basement construction. No waste zone material brought to the surface.
(Chronic) Post drilling	False	Concrete roof
(Chronic) Residential	True	Basement located on top of concrete roof. Shielding between top of concrete roof and top of waste zone.

ILV intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 38 as shown in Table 3-12.

Table 3-12. ICRP-07 radionuclides that failed Tier-1 ILV intruder screening.

Ac-226	Ac-227	Al-26	Ar-42	Bi-207	Bi-208	Bi-210m	Cf-244
Cm-240	Cm-250	Cs-137	Eu-150	Fe-60	Hf-182	Hg-194	Ho-166m
Ir-192n	La-138	Nb-91	Nb-92	Np-232	Np-236	Np-236m	Pa-230
Pa-231	Pa-232	Pb-202	Po-209	Pu-232	Pu-236	Ra-226	Re-186m
Rn-211	Tb-158	Tc-98	Th-229	Ti-44	V-50		

ILV intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of Tier-0 radionuclides from 272 to 29 as shown in Table 3-13.

Table 3-13. Tier-0 radionuclides that failed Tier-1 ILV intruder screening.

Ac-227	Al-26	Bi-207	Bi-208	Bi-210m	Cm-250	Cs-137	Eu-150
Fe-60	Hf-182	Hg-194	Ho-166m	Ir-192n	La-138	Nb-91	Nb-92
Np-236	Pa-231	Pa-232	Pb-202	Po-209	Pu-236	Ra-226	Re-186m
Tb-158	Tc-98	Th-229	Ti-44	V-50			

3.3.2 Tier-1 LAWV Inadvertent Intruder Screening

The Low-Activity Waste Vault (LAWV) is an above-grade, reinforced concrete vault. It is approximately 643 feet (196 m) long, 145 feet (44 m) wide, and 27 feet (8.2 m) high at the roof crest. It is divided into 3 modules along its length, which are approximately 214 feet (65 m) long and contain 4 cells each. The modules share a common footer but have a 2-inch gap between their adjacent walls. The 12-cell total is designed to contain more than 12,000 B-25 boxes of waste. The LAWV cross-section below the cap through the long axis of the vault is shown in Figure 3-5.

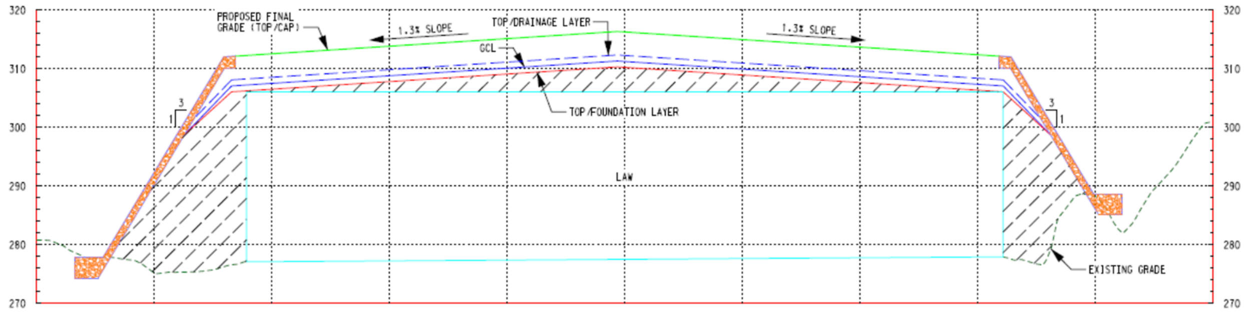


Figure 3-5. LAWV cross-section through long axis of the vault.

A plan view of LAWV is also provided in Figure 3-6 where the footprints of the three connected modules (four cells per module) are shown. The LAWV intruder model considers the waste in all modules and cells as uniform and homogeneous throughout the waste zone.

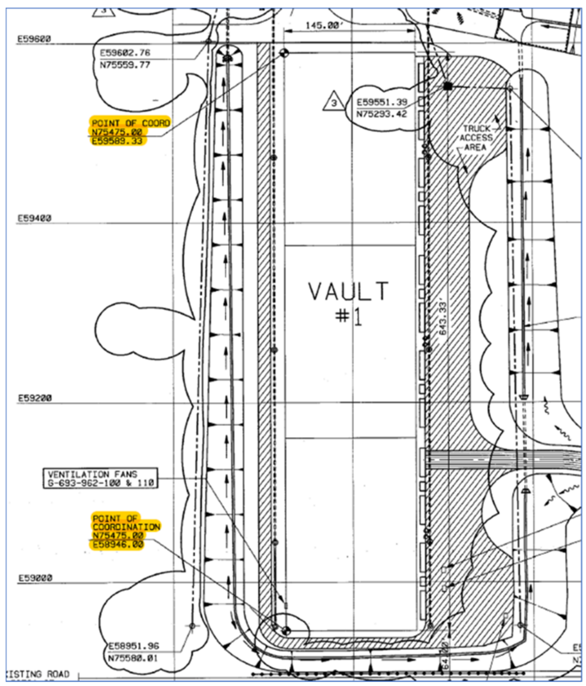


Figure 3-6. LAWV plan view of the vault.

The LAWV inadvertent intruder parameters shown in Table 3-14 are used to determine the state of the acute and chronic intruder scenarios and doses to the intruder as a function of time beyond the EIC.

Table 3-14. LAWV inadvertent intruder parameters.

Parameter	Setting	Comment
Intrusion drilling barrier	True	Concrete roof
Erosion barrier failure	False	No failure during intruder
Erosion barrier depth	3 ft (0.914 m)	Thickness of soil cover
Drilling barrier depth	6 ft (1.83 m)	Top of concrete roof
Waste zone depth	14.53 ft (4.429 m)	Closure cap, concrete roof (1.33 ft) and vault head space (7.2 ft)

Parameter	Setting	Comment
Waste zone thickness	17.3 ft (5.273 m)	Height of a B-25 box stack which includes the height of the 4-inch risers between each layer of the B-25 box stack
Waste zone area	88,800 ft^2 (8249.8 m^2)	95.2% of footprint (Hamm 2019)
Waste zone volume	1,536,240 ft^3 (43501.5 m^3)	Concentration calculation

The LAWV inadvertent intruder and general parameter settings (geometry and barriers) dictate the viability of specific intruder scenarios as shown in Table 3-15.

Table 3-15. State of LAWV inadvertent intruder scenarios.

Intruder scenario	State	Comment
(Acute) Basement construction	False	10 ft basement cannot extend below concrete roof
(Acute) Well drilling	False	Concrete roof
(Acute) Discovery	True	Basement excavation stops at erosion barrier. Shielding between top of erosion barrier and top of waste zone.
(Chronic) Agriculture	False	No basement construction. No waste zone soil brought to the surface.
(Chronic) Post drilling	False	Concrete roof
(Chronic) Residential	True	Basement located on top of concrete roof. Shielding between top of concrete roof and top of waste zone.

LAWV intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 22 as shown in Table 3-16.

Table 3-16. ICRP-07 radionuclides that failed Tier-1 LAWV intruder screening.

Ac-227	Al-26	Ar-42	Bi-208	Cm-240	Cm-250	Fe-60	Hf-182
Hg-194	Ho-166m	Ir-192n	La-138	Nb-92	Np-236	Pa-231	Pb-202
Po-209	Pu-236	Re-186m	Tb-158	Tc-98	Ti-44		

LAWV intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of Tier-0 radionuclides from 271 to 20 as shown in Table 3-17.

Table 3-17. Tier-0 radionuclides that failed Tier-1 LAWV intruder screening.

Ac-227	Al-26	Bi-208	Cm-250	Fe-60	Hf-182	Hg-194	Ho-166m
Ir-192n	La-138	Nb-92	Np-236	Pa-231	Pb-202	Po-209	Pu-236
Re-186m	Tb-158	Tc-98	Ti-44				

3.3.3 Tier-1 NRCDA (generic/special) Inadvertent Intruder Screening

Naval Reactor Component Disposal Areas (NRCDAs) are above grade gravel pads for the disposal of Naval Reactor Waste Shipping/Disposal Casks containing waste naval reactor components as well as less robust containers of other auxiliary equipment. Two NRCDAs are associated with the ELLWF. The 643-7E NRCDA contains approximately 41 casks, is a trapezoidal area consisting of approximately 0.13 acres (546 m2) and is closed to future receipts. It has an interim soil cover in place. The 643-26E NRCDA is currently in operation, is an irregularly shaped area consisting of approximately 1.1 acres (4,430 m2) and is expected to receive approximately 33 welded casks and 380 bolted casks for disposal through the year FY2040. The 643-26E NRCDA cross-section below the cap looking east is shown in Figure 3-7.

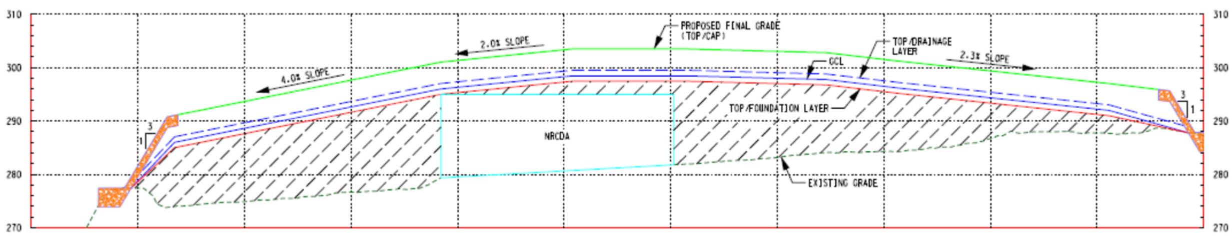


Figure 3-7. 643-26E NRCDA cross-section looking east.

The NRCDA is split into two separate intruder models: a generic waste model and a special waste form model. The NRCDAG focuses only on steel bolted (with gaskets) containers of auxiliary equipment (e.g., pumps, shield blocks) primarily containing removable surface contamination (referred to by the Naval Reactor program as “Crud”). Due to the type of container closure (bolted with gaskets) and form of contamination (surface removable) this waste is conservatively assumed to behave as generic waste and instantaneously release contaminants into the surrounding waste zone (i.e., without a rate-limiting release mechanism).

The NRCDAS focuses only on welded casks containing naval reactor components (e.g., core barrels and thermal shields) primarily consisting of neutron activated metal. For screening purposes, this activated metal is conservatively assumed to behave as a generic waste form without a rate-limiting contaminant release mechanism (e.g., metal corrosion); however, this instantaneous release is delayed until the welded cask loses its hydraulic isolation. The areal footprint of both NRCDA models is taken to be the minimum area of 643-26E and 643-7E (5,900 ft^2).

The NRCDAG inadvertent intruder parameters shown in Table 3-18 are used to determine the state of the acute and chronic intruder scenarios and doses to the intruder as a function of time beyond the EIC.

Table 3-18. NRCDAG inadvertent intruder parameters.

Parameter	Setting	Comment
Intrusion drilling barrier	True	Steel bolted containers
Erosion barrier failure	False	No failure during intruder
Erosion barrier depth	3 ft (0.914 m)	Thickness of soil cover
Drilling barrier depth	15.8 ft (4.816 m)	Top of double-stacked bolted containers
Waste zone depth	15.8 ft (4.816 m)	Closure cap (6 ft) and operational soil cover (9.8 ft)

Parameter	Setting	Comment
Waste zone thickness	8.2 ft (2.4994 m)	Height of double-stack bolted containers, 2 x 4.1 ft
Waste zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019)
Waste zone volume	48,380 ft^3 (1370 m^3)	Concentration calculation

The NRCDAG inadvertent intruder and general parameter settings (geometry and barriers) dictate the viability of specific intruder scenarios as shown in Table 3-19.

Table 3-19. State of NRCDAG inadvertent intruder scenarios.

Intruder scenario	State	Comment
(Acute) Basement construction	False	At 1171 years, the bottom of the 10 ft basement is 4.4 ft above the top of the waste zone. 1.4 ft of soil cover erosion after 1000 years.
(Acute) Well drilling	False	Concrete roof
(Acute) Discovery	True	Basement excavation stops at erosion barrier. Shielding between top of erosion barrier and top of waste zone.
(Chronic) Agriculture	False	No basement construction. No waste zone soil brought to the surface.
(Chronic) Post drilling	False	Concrete roof
(Chronic) Residential	True	Basement located above the top of waste zone. Shielding between bottom of basement and top of waste zone. The shielding thickness varies from 5.8 ft to 4.4 ft over 1000 years.

NRCDAG intruder doses computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories reduces the number of ICRP-07 radionuclides from 1,252 to 44 which fail the intruder dose screening criteria as shown in Table 3-20.

Table 3-20. ICRP-07 radionuclides that failed Tier-1 NRCDAG intruder screening.

Ac-226	Al-26	Ar-42	At-207	At-211	Bi-207	Bi-208	Bi-210m
Bk-247	Cf-244	Cm-240	Cm-250	Eu-150	Eu-152	Fe-60	Hf-182
Hg-194	Ho-166m	Ir-192n	K-40	La-138	Nb-91	Nb-92	Nb-94
Np-232	Np-236	Np-236m	Pa-229	Pa-230	Pa-232	Pb-202	Po-207
Po-209	Pu-232	Pu-236	Re-186m	Rn-211	Tb-158	Tc-98	Th-229
Ti-44	Tl-194	Tl-194m	V-50				

NRCDAG intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of Tier-0 radionuclides from 295 to 29 as shown in Table 3-21.

Table 3-21. Tier-0 radionuclides that failed Tier-1 NRCDAG intruder screening.

Al-26	Bi-207	Bi-208	Bi-210m	Bk-247	Cm-250	Eu-150	Eu-152
Fe-60	Hf-182	Hg-194	Ho-166m	Ir-192n	K-40	La-138	Nb-91
Nb-92	Nb-94	Np-236	Pa-232	Pb-202	Po-209	Pu-236	Re-186m
Tb-158	Tc-98	Th-229	Ti-44	V-50			

The NRCDAS inadvertent intruder parameters shown in Table 3-22 are used to determine the state of the acute and chronic intruder scenarios and doses to the intruder as a function of time beyond the EIC.

Table 3-22. NRCDAS inadvertent intruder parameters.

Parameter	Setting	Comment
Intrusion drilling barrier	True	Welded casks
Erosion barrier failure	False	No failure during intruder
Erosion barrier depth	3 ft (0.914 m)	Thickness of soil cover
Drilling barrier depth	6 ft (1.8288 m)	Closure cap
Waste zone depth	6 ft (1.8288 m)	Top of welded casks
Waste zone thickness	18 ft (5.4864 m)	Height of welded casks
Waste zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019)
Waste zone volume	106,200 ft^3 (3007.2 m^3)	Concentration calculation

The NRCDAS inadvertent intruder and general parameter settings (geometry and barriers) dictate the viability of specific intruder scenarios as shown in Table 3-23.

Table 3-23. State of NRCDAS inadvertent intruder scenarios.

Intruder scenario	State	Comment
(Acute) Basement construction	False	10 ft basement cannot extend below top of welded casks
(Acute) Well drilling	False	Welded casks
(Acute) Discovery	True	Basement excavation stops at erosion barrier. Shielding between top of erosion barrier and top of welded casks.
(Chronic) Agriculture	False	No basement construction. No waste zone soil brought to the surface.
(Chronic) Post drilling	False	Welded casks
(Chronic) Residential	True	Basement located on top of welded casks. No soil shielding.

NRCDAS intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 148 as shown in Table 3-24.

Table 3-24. ICRP-07 radionuclides that failed Tier-1 NRCDAS intruder screening.

Ac-226	Ac-227	Ac-230	Ac-231	Al-26	Am-241	Am-243	Am-245
Am-246	Am-246m	Ar-42	At-206	At-207	At-209	At-211	Ba-133m
Bi-202	Bi-207	Bi-208	Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m

Bk-250	Bk-251	Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244	Cf-246
Cf-247	Cf-248	Cf-250	Cf-252	Cf-253	Cf-254	Cf-255	Cm-240
Cm-241	Cm-249	Cm-250	Cm-251	Co-60	Cs-137	Dy-157	Es-249
Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Eu-145
Eu-150	Eu-152n	Fe-60	Fm-251	Fm-253	Fm-254	Fm-255	Fm-256
Fm-257	Fr-227	Hf-182	Hg-194	Ho-157	Ho-166m	Ir-192n	K-40
Kr-81	La-133	La-137	La-138	Lu-176	Mo-91	Mo-93	Nb-91
Nb-91m	Nb-92	Nb-93m	Nb-94	Nb-94m	Ni-59	Np-232	Np-234
Np-235	Np-236	Np-236m	Np-238	Np-241	Os-194	Pa-229	Pa-230
Pa-231	Pa-232	Pa-233	Pb-194	Pb-202	Pb-202m	Pb-210	Pm-145
Pm-146	Po-206	Po-207	Po-208	Po-209	Pu-232	Pu-236	Pu-237
Pu-241	Pu-243	Pu-245	Pu-246	Ra-226	Ra-227	Ra-228	Ra-230
Rb-90	Rb-90m	Re-186m	Rn-207	Rn-209	Rn-210	Rn-211	Rn-222
Sm-145	Sn-121m	Sn-126	Sr-90	Tb-149	Tb-157	Tb-158	Tc-97
Tc-98	Te-123	Th-229	Th-230	Ti-44	Tl-194	Tl-194m	U-230
U-231	V-50	Xe-137	Zr-93				

NRCDAS intruder doses (computed using maximum screening factors for Discovery and Residential intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of Tier-0 radionuclides from 295 to 75 as shown in Table 3-25.

Table 3-25. Tier-0 radionuclides that failed Tier-1 NRCDAS intruder screening.

Ac-227	Al-26	Am-241	Am-243	Am-245	Am-246m	Bi-207	Bi-208
Bi-210m	Bk-247	Bk-250	Cf-248	Cf-250	Cf-252	Cf-253	Cm-249
Cm-250	Co-60	Cs-137	Es-253	Es-254	Eu-150	Fe-60	Fm-254
Fm-257	Hf-182	Hg-194	Ho-166m	Ir-192n	K-40	Kr-81	La-137
La-138	Lu-176	Mo-93	Nb-91	Nb-92	Nb-93m	Nb-94	Ni-59
Np-235	Np-236	Np-238	Os-194	Pa-231	Pa-232	Pa-233	Pb-202
Pb-210	Pm-145	Pm-146	Po-208	Po-209	Pu-236	Pu-241	Pu-243
Pu-246	Ra-226	Ra-228	Re-186m	Rn-222	Sm-145	Sn-121m	Sn-126
Sr-90	Tb-157	Tb-158	Tc-97	Tc-98	Te-123	Th-229	Th-230
Ti-44	V-50	Zr-93					

3.3.4 Tier-1 Generic Trench (ST/ET/CIG) Inadvertent Intruder Screening

Slit Trenches (STs) are below-grade earthen DUs with vertical side slopes making them inaccessible by vehicle. Each ST is generally laid out in a series of five narrow parallel trench rows. In the typical design, each trench row is generally 20 feet (6.1 m) deep, 20 feet (6.1 m) wide, and 656 feet (200 m) long with ten feet (3 m) to 14 feet (4.3 m) of undisturbed soil separating each parallel trench row. A set of five, 20-foot (6.1 m) wide trench rows, are grouped together within a 157-foot (48 m) wide by 656-foot (200 m) long footprint forming a single Slit Trench.

The Engineered Trenches (ETs) are below grade earthen disposal units. Each ET is a vehicle-accessible, open trench design that allows stacking of containerized waste primarily packaged in B-25 boxes and SeaLand containers. Engineered Trench #1, which is operationally closed, is approximately 650 feet (198 m) long by 150 feet (46 m) wide (bottom dimensions) and varies in depth from 16 to 25 feet (4.9 to 7.6 m). It is designed to contain approximately 12,000 B-25 boxes of waste.

Component-In-Grout (CIG) DUs are below-grade earthen trenches with essentially vertical side slopes that contain grout encapsulated waste components providing a greater degree of waste isolation than Slit or Engineered Trenches. CIG Trenches are contained within 157-foot-wide (48 m) by 656-foot-long (200 m) footprints. Two such CIG Trench footprints, designated CIG-1 and CIG-2, were originally planned for E-Area with each CIG footprint laid out in five parallel, nominally 20-foot-wide (6.1 m) by 650-foot-long (198 m), trenches separated by 10 feet (3.0 m) of undisturbed soil.

A Generic Trench DU intruder model was developed to represent CIG, existing/future STs, and existing/future ETs. Since approval of PA2008, CIG Trenches have been underutilized and have no waste forecasted through the end of E-Area operations. Consequently, the remaining unused portion of CIG01 and future location of CIG02 will be repurposed as Slit Trenches in the next PA revision. The areal waste footprint of the Trench DU model was computed as the average waste zone footprint of ST01 through ST11, ST14, ST17 through ST22, ST23 (CIG01), ST24 (CIG02), and ET01 through ET09 per Hamm (2019).

The Generic Trench inadvertent intruder parameters shown in Table 3-26 are used to determine the state of the acute and chronic intruder scenarios and doses to the intruder as a function of time beyond the EIC.

Table 3-26. Generic Trench inadvertent intruder parameters.

Parameter	Setting	Comment
Intrusion drilling barrier	False	No engineered barriers
Erosion barrier failure	False	No failure during intruder
Erosion barrier depth	3 ft (0.914 m)	Thickness of soil cover
Drilling barrier depth	NA	No engineered barriers
Waste zone depth	11 ft (3.353 m)	Closure cap (6 ft), controlled compacted backfill (1 ft) and operational soil cover (4 ft)
Waste zone thickness	16 ft (4.877 m)	Height of waste
Waste zone area	73,600 ft^2 (6837.7 m^2)	Average waste footprint of ET and ST trenches. 74.9% of average footprint in Hamm (2019).
Waste zone volume	1,177,600 ft^3 (33346 m^3)	Concentration calculation

The Generic Trench inadvertent intruder and general parameter settings (geometry and barriers) dictate the viability of intruder scenarios as shown in Table 3-27.

Table 3-27. State of Generic Trench inadvertent intruder scenarios.

Intruder scenario	State	Comment
(Acute) Basement construction	False/True	Basement construction does not penetrate the waste zone until excavation occurs 218 years (erosion of 1 ft of soil cover) after the end of IC.
(Acute) Well drilling	True	No engineered barriers

Intruder scenario	State	Comment
(Acute) Discovery	True	Basement excavation stops at erosion barrier. Shielding between top of erosion barrier and top of waste zone.
(Chronic) Agriculture	False/True	Agriculture scenario is viable after basement construction occurs.
(Chronic) Post drilling	True	No engineered barriers
(Chronic) Residential	True/False	Residential scenario is viable until basement construction occurs.

Generic Trench intruder doses (computed using maximum screening factors for all active intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 128 as shown in Table 3-28.

Table 3-28. ICRP-07 radionuclides that failed Tier-1 Generic Trench intruder screening.

Ac-226	Ag-108m	Am-241	Am-242m	Am-243	Ar-42	At-207	At-209
At-211	Bi-202	Bi-208	Bi-210m	Bk-245	Bk-249	C-14	Cf-244
Cf-247	Cf-248	Cf-249	Cf-251	Cf-253	Cf-254	Cf-255	Cm-240
Cm-241	Cm-247	Cm-248	Cm-249	Cm-250	Cs-137	Dy-154	Es-249
Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Eu-150
Fe-60	Fm-251	Fm-252	Fm-253	Fm-254	Fm-255	Fm-257	Gd-148
Gd-150	Gd-152	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	I-129
In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176	Mn-53
Nb-91	Nb-91m	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-232
Np-235	Np-236	Np-236m	Np-237	Os-186	Pa-229	Pa-230	Pa-232
Pb-194	Pb-202	Pb-202m	Pm-145	Po-208	Po-209	Pt-190	Pu-232
Pu-236	Pu-237	Pu-239	Pu-240	Pu-241	Pu-243	Ra-226	Ra-230
Re-186m	Re-187	Rn-207	Rn-211	Si-32	Sm-146	Sm-147	Sm-148
Sn-126	Sr-90	Tb-157	Tb-158	Tc-97	Tc-97m	Tc-98	Tc-99
Te-123	Th-229	Th-230	Th-232	Ti-44	Tl-194	Tl-194m	U-230
U-231	U-232	U-233	U-234	U-235	U-236	U-238	V-50

Generic Trench intruder doses (computed using maximum screening factors for all active intruder scenarios with radionuclide inventories) which fail the intruder dose screening criteria reduce the number of Tier-0 radionuclides from 271 to 88 as shown in Table 3-29.

Table 3-29. Tier-0 radionuclides that failed Tier-1 Generic Trench intruder screening.

Ag-108m	Am-241	Am-242m	Am-243	Bi-208	Bi-210m	Bk-249	C-14
Cf-248	Cf-249	Cf-251	Cf-253	Cm-247	Cm-248	Cm-249	Cm-250
Cs-137	Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257
Gd-148	Gd-150	Gd-152	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163
I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176
Mn-53	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-235
Np-236	Np-237	Os-186	Pa-232	Pb-202	Pm-145	Po-208	Po-209
Pt-190	Pu-236	Pu-239	Pu-240	Pu-241	Pu-243	Ra-226	Re-186m

Re-187	Si-32	Sm-146	Sm-147	Sm-148	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232
Ti-44	U-232	U-233	U-234	U-235	U-236	U-238	V-50

3.4 Tier-1 NCRP123 Groundwater Radionuclide Screening

Historically, NCRP123 screening methodology (NCRP 1996) has been employed at many DOE facilities as the starting point for PA screening analyses. A NCRP-like screening approach is our recommended Tier-1 method. The basic NCRP123 model was modified to incorporate local site-specific information (e.g., DU geometries, measured K_d values, infiltration rates under varying conditions, GSA aquifer aspects, bake times consistent with travel timing to 100-m POA, etc.).

NCRP123 GW radionuclide screening was performed for the five DU models using the ICRP-07 and Tier-0 list of radionuclides. The upper bound estimated radionuclide inventories as discussed in Section 3.2 were employed.

The NCRP123 model consists of first-order removal (leaching) of radionuclides from the waste zone to the aquifer zone. The radionuclide screening model approach utilizes a series of release times (no leaching) followed by leaching at a constant infiltration of water through the waste zone. Prior to the release time in the waste zone, the radionuclide balance equations are solved for the short chain nuclide members with radioactive decay and branching. Once infiltration is active, leachate from the short-chain parent and progeny become source terms to the aquifer zone. The rate of leaching (pCi/yr per Ci of parent buried) is a function of infiltration rate, waste zone thickness, water content, and retardation factor as shown in Eq. (2-3). The aquifer zone is conservatively modeled as a collector of leachate with radioactive decay. There is no partitioning of inventory between the soil and the liquid in the aquifer.

The waste zone represents the areal footprint and compacted/collapsed waste height of each DU model. The waste zone is modeled as a sandy soil sediment (Nichols 2020). The starting inventory of the parent nuclide is initialized to the atom number equivalent of 10^{12} pCi divided by the decay constant of the parent nuclide. For each of the radionuclides, transient atom numbers are computed for a 1-year half-life cutoff short chain every year for an 1171-year period for each GW scenario (for unique combinations of release time and infiltration rate). The short chain activities in the aquifer zone are converted to concentrations for the GW pathway dose calculations using the volume of infiltration in a year. For conservatism, there is no dilution of these short chain concentrations with the regional aquifer flow. The short chain concentrations (pCi/m^3 per Ci of parent buried) in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The maximum full chain aquifer concentrations are determined every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit.

The transient maximum full chain aquifer concentrations are processed through the SRNL Dose Toolkit (Aleman 2019) for the EPA GW protection and PA AP human receptors. The EPA GW protection places limits on drinking water for alpha-emitting radionuclides (gross alpha), beta and/or photon emitters (beta-gamma), radium (Ra-226 and Ra-228 only) and uranium isotopes. The maximum contaminant levels (MCL) for gross alpha, beta-gamma, radium and uranium are: 15 pCi/L, 4 mrem/yr, 5 pCi/L and 30 µg/L, respectively. The PA AP provides protection for the member of public, resident farmer, who uses water from a contaminated source for human and animal consumption, irrigation of a garden, and irrigation of a pasture where farm animals are raised. Products from the garden and farm animal are used for human consumption. The contaminated water is GW from a well that is typically assumed to be 100-m downgradient from the boundary of the waste disposal facility. The PA AP performance objective is 25 mrem/yr. The screening criteria used for GW screening is 0.1% of the performance objectives.

Each DU is assumed to have waste buried at 1994.7 (0-year) with an operational period extending to the time of E-Area closure, 2065.7 (71-year). Institutional control runs from 2065.7 to 2165.7 (171-year). The POP for EPA GW protection spans 1171 years from the time of waste burial to 1171 years during the screening period. The PA GW AP POP is coincident with the inadvertent intruder POP, 171 to 1171 years.

The output of the SRNL Dose Toolkit calculations are maximum screening factors (mrem/yr per Ci of parent buried) for the EPA GW protection and PA AP with progeny contributions rolled up for each radionuclide parent. The screening factors are multiplied by the radionuclide inventories (i.e., limiting inventories) to produce maximum expected EPA GW protection and PA AP doses. The radionuclide is screened out for PORFLOW PA analysis if the EPA GW protection or PA AP doses do not exceed its screening criterion.

A discussion of NCRP123 GW parameters, scenarios, and screening results are presented in the following subsections for the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench DU screening models. Lists of radionuclides that failed screening are shown for the ICRP-07 and Tier-0 radionuclides.

3.4.1 Tier-1 ILV NCRP123 Groundwater Screening.

The ILV DU description is given in the ILV intruder screening section, Section 3.2.1. The waste zone in the NCRP123 GW model is identical to the intruder model with the exception of using the collapsed state of the ILV waste. The ILV NCRP123 waste and aquifer parameters are shown in Table 3-30.

Table 3-30. ILV NCRP123 waste and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	sandy soil sediment
Porosity	0.380	sandy soil sediment
Water content	function of infiltration rate	sandy soil sediment
Distribution coefficient	element specific, cm^3/g	sandy soil sediment
Waste zone thickness	10 ft (3.048 m)	ILV waste collapses from 25.83 ft to 10 ft at the end of IC
Waste and aquifer zone area	10,500 ft^2 (975.48 m^2)	77.7% of footprint Hamm (2019) Eq. (B-15) concentration

A series of 23 GW scenarios were simulated using the NCRP123 GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario and to provide some level of baking. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of ILV until the EIC. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1.

The water content is the product of porosity and water saturation. A summary of the ILV NCRP123 GW screening scenarios are shown in Table 3-31.

Table 3-31. ILV NCRP123 groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**214**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**194**	7.7000E-01	2.9260E-01
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

ILV NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 313 as shown in Table 3-32.

Table 3-32. ICRP-07 radionuclides that failed Tier-1 ILV NCRP123 groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-108m	Ag-113	Ag-113m
Al-26	Am-237	Am-238	Am-239	Am-240	Am-241	Am-242	Am-242m
Am-243	Am-244	Am-244m	Am-245	Am-246	Am-246m	Am-247	Ar-39
Ar-42	As-79	At-206	At-207	At-209	At-211	At-218	Au-193
Au-193m	Ba-133	Ba-133m	Be-10	Bi-202	Bi-205	Bi-207	Bi-208
Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251
C-14	Ca-41	Cd-113	Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244
Cf-246	Cf-247	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253
Cf-254	Cf-255	Cl-36	Cl-39	Cm-238	Cm-239	Cm-240	Cm-241
Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cm-247	Cm-248	Cm-249
Cm-250	Cm-251	Cs-135	Cs-135m	Cs-137	Cu-59	Dy-148	Dy-150
Dy-152	Dy-154	Dy-157	Er-154	Er-163	Es-249	Es-250	Es-250m
Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256	Eu-145	Eu-146
Eu-147	Eu-150	Eu-150m	Eu-152n	Fe-53	Fe-53m	Fe-60	Fm-251
Fm-252	Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-222	Fr-227
Gd-145	Gd-146	Gd-147	Gd-148	Gd-150	Gd-152	H-3	Hf-174
Hf-178m	Hf-182	Hf-182m	Hg-193	Hg-193m	Hg-194	Ho-150	Ho-154
Ho-154m	Ho-157	Ho-163	Ho-166m	I-129	I-135	In-115	Ir-192n
K-40	Kr-81	La-133	La-137	La-138	Lu-176	Mn-53	Mo-91
Mo-91m	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92	Nb-93m
Nb-94	Nb-94m	Nb-99	Nb-99m	Nd-137	Nd-144	Nd-147	Nd-151
Ni-59	Ni-63	Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m
Np-237	Np-238	Np-240	Np-240m	Np-241	Np-242	Np-242m	Os-186

Os-194	Pa-229	Pa-230	Pa-231	Pa-232	Pa-235	Pa-236	Pa-237
Pb-194	Pb-202	Pb-202m	Pb-205	Pb-210	Pd-97	Pd-107	Pm-137m
Pm-145	Pm-146	Pm-151	Po-205	Po-206	Po-207	Po-208	Po-209
Pr-137	Pt-190	Pt-193	Pt-193m	Pu-232	Pu-234	Pu-235	Pu-236
Pu-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-244
Pu-245	Pu-246	Ra-222	Ra-226	Ra-227	Ra-230	Rb-81	Rb-87
Rb-90	Rb-90m	Re-186m	Re-187	Rh-97	Rh-97m	Rh-107	Rn-207
Rn-209	Rn-210	Rn-211	Rn-222	Ru-97	Ru-107	Sb-129	Se-79
Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-151	Sn-126
Sn-129	Sr-90	Sr-93	Tb-148	Tb-148m	Tb-149	Tb-150	Tb-150m
Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93	Tc-93m	Tc-97	Tc-97m
Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m	Th-226	Th-229
Th-230	Th-231	Th-232	Th-233	Th-234	Th-235	Th-236	Ti-44
Tl-194	Tl-194m	Tl-210	Tm-163	U-230	U-231	U-232	U-233
U-234	U-235	U-235m	U-236	U-237	U-238	U-239	U-240
U-242	V-50	W-187	Xe-135	Xe-135m	Xe-137	Y-93	Yb-163
Zr-93							

ILV NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 272 to 141 as shown in Table 3-33.

Table 3-33. Tier-0 radionuclides that failed Tier-1 ILV NCRP123 groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Am-246m	Ar-39	At-218	Ba-133	Be-10	Bi-207	Bi-208	Bi-210m
Bk-247	Bk-249	Bk-250	C-14	Ca-41	Cd-113	Cf-248	Cf-249
Cf-250	Cf-251	Cf-252	Cf-253	Cl-36	Cm-242	Cm-243	Cm-244
Cm-245	Cm-246	Cm-247	Cm-248	Cm-249	Cm-250	Cs-135	Cs-137
Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257	Gd-148
Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163
Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138
Lu-176	Mn-53	Mo-93	Nb-91	Nb-92	Nb-93m	Nb-94	Nd-144
Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238	Np-240	Np-240m
Os-186	Os-194	Pa-231	Pa-232	Pb-202	Pb-205	Pb-210	Pd-107
Pm-145	Pm-146	Po-208	Po-209	Pt-190	Pt-193	Pu-236	Pu-238
Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-244	Pu-246	Ra-226
Rb-87	Re-186m	Re-187	Rn-222	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-126	Sr-90	Tb-157	Tb-158	Tc-97
Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-231	Th-232	Th-234
Ti-44	Tl-210	U-232	U-233	U-234	U-235	U-235m	U-236
U-237	U-238	U-240	V-50	Zr-93			

3.4.2 Tier-1 LAWV NCRP123 Groundwater Screening

The LAWV DU description is given in the LAWV intruder screening section, Section 3.2.2. The waste zone in the NCRP123 GW model is identical to the intruder model with the exception of using the collapsed state of the LAWV waste. The LAWV NCRP123 waste and aquifer parameters are shown in Table 3-34.

Table 3-34. LAWV NCRP123 waste and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	sandy soil sediment
Porosity	0.380	sandy soil sediment
Water content	function of infiltration rate	sandy soil sediment
Distribution coefficient	element specific, cm^3/g	sandy soil sediment
Waste zone thickness	2.5 ft (0.762 m)	stack of B-25 boxes collapses from 17.3ft to 2.5 ft at the end of IC
Waste and aquifer zone area	88,800 ft^2 (8249.8 m^2)	95.2% of footprint Hamm (2019) Eq. (B-15) concentration

A series of 23 GW scenarios were simulated using the NCRP123 GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of LAWV until the EIC. Water saturations for sandy soil as a function of infiltrate rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the LAWV NCRP123 GW screening scenarios are shown in Table 3-35.

Table 3-35. LAWV NCRP123 groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**220**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**195**	7.7000E-01	2.9260E-01
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

LAWV NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 280 as shown in Table 3-36.

Table 3-36. ICRP-07 radionuclides that failed Tier-1 LAWV NCRP123 groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-108m	Al-26	Am-237

Am-238	Am-239	Am-240	Am-241	Am-242	Am-242m	Am-243	Am-244
Am-244m	Am-245	Am-246	Am-246m	Ar-42	At-206	At-207	At-209
At-211	Au-193	Au-193m	Ba-133m	Be-10	Bi-202	Bi-207	Bi-208
Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251
C-14	Ca-41	Cd-113	Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244
Cf-246	Cf-247	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253
Cf-254	Cf-255	Cl-36	Cl-39	Cm-238	Cm-239	Cm-240	Cm-241
Cm-243	Cm-244	Cm-245	Cm-246	Cm-249	Cm-250	Cm-251	Cs-137
Cu-59	Dy-148	Dy-150	Dy-152	Dy-154	Er-154	Er-163	Es-249
Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256
Eu-150	Eu-150m	Eu-152	Eu-152n	Fe-53	Fe-60	Fm-251	Fm-252
Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-222	Fr-227	Gd-146
Gd-148	Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182	Hf-182m
Hg-193	Hg-193m	Hg-194	Ho-150	Ho-154	Ho-154m	Ho-157	Ho-163
Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138
Lu-176	Mn-53	Mo-91m	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m
Nb-92	Nb-93m	Nb-94	Nb-94m	Nd-137	Nd-144	Ni-59	Ni-63
Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238
Np-240	Np-240m	Np-241	Np-242	Np-242m	Os-186	Os-194	Pa-229
Pa-230	Pa-231	Pa-232	Pa-233	Pa-235	Pa-236	Pa-237	Pb-194
Pb-202	Pb-202m	Pb-205	Pb-210	Pd-97	Pd-107	Pm-137m	Pm-145
Pm-146	Pm-151	Po-205	Po-206	Po-207	Po-208	Po-209	Pr-137
Pt-190	Pt-193	Pt-193m	Pu-232	Pu-234	Pu-235	Pu-236	Pu-237
Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-245	Pu-246
Ra-222	Ra-226	Ra-227	Ra-230	Rb-87	Rb-90	Rb-90m	Re-186m
Re-187	Rh-97	Rh-97m	Rn-207	Rn-209	Rn-210	Rn-211	Ru-97
Sb-129	Se-79	Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148
Sm-151	Sn-121m	Sn-126	Sn-129	Sr-90	Tb-148	Tb-148m	Tb-149
Tb-150	Tb-150m	Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93	Tc-93m
Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m
Th-226	Th-229	Th-230	Th-231	Th-232	Th-233	Th-234	Th-235
Th-236	Ti-44	Tl-194	Tl-194m	Tm-163	U-230	U-231	U-232
U-233	U-234	U-235	U-235m	U-236	U-237	U-238	U-239
U-240	U-242	V-50	Xe-135	Xe-137	Y-93	Yb-163	Zr-93

LAWV NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 271 to 134 as shown in Table 3-37.

Table 3-37. Tier-0 radionuclides that failed Tier-1 LAWV NCRP123 groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Am-246m	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Ca-41	Cd-113	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252

Cf-253	Cl-36	Cm-243	Cm-244	Cm-245	Cm-246	Cm-249	Cm-250
Cs-137	Dy-154	Es-253	Es-254	Eu-150	Eu-152	Fe-60	Fm-254
Fm-257	Gd-148	Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182
Hg-194	Ho-163	Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81
La-137	La-138	Lu-176	Mn-53	Mo-93	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-240	Np-240m	Os-186	Os-194	Pa-231	Pa-232	Pa-233	Pb-202
Pb-205	Pb-210	Pd-107	Pm-145	Pm-146	Po-208	Po-209	Pt-190
Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243
Pu-246	Ra-226	Rb-87	Re-186m	Re-187	Se-79	Si-32	Sm-145
Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-231
Th-232	Th-234	Ti-44	U-232	U-233	U-234	U-235	U-235m
U-236	U-237	U-238	U-240	V-50	Zr-93		

3.4.3 Tier-1 NRCDA (generic) NCRP123 Groundwater Screening

The NRCDAG DU description is given in the NRCDA intruder screening section, Section 3.2.3. The waste zone in the NCRP123 GW model is identical to the intruder model. The NRCDAG NCRP123 waste and aquifer parameters are shown in Table 3-38.

Table 3-38. NRCDAG NCRP123 waste and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	sandy soil sediment
Porosity	0.380	sandy soil sediment
Water content	function of infiltration rate	sandy soil sediment
Distribution coefficient	element specific, cm^3/g	sandy soil sediment
Waste zone thickness	8.2 ft (2.4994 m)	Height of double-stack bolted containers, 2 x 4.1 ft
Waste and aquifer zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Eq. (B-15) concentration

A series of 27 GW scenarios were simulated using the NCRP123 GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltrate rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAG NCRP123 GW screening scenarios are shown in Table 3-39.

Table 3-39. NRCDAG NCRP123 groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	56	7.2170E-01	2.7425E-01

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
4 to 14	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
15, 16	4.0500E-01	22, 50	7.7000E-01	2.9260E-01
17 to 27	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAG NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 365 as shown in Table 3-40.

Table 3-40. ICRP-07 radionuclides that failed Tier-1 NRCDAG NCRP123 groundwater screening.

Ac-226	Ac-228	Ac-230	Ac-231	Ac-233	Ag-101	Ag-113	Ag-113m
Al-26	Am-237	Am-238	Am-239	Am-240	Am-241	Am-242	Am-242m
Am-243	Am-244	Am-244m	Am-245	Am-246	Am-246m	Am-247	Ar-39
Ar-42	As-79	At-205	At-206	At-207	At-208	At-209	At-211
At-218	Au-190	Au-193	Au-193m	Ba-133	Ba-133m	Bi-202	Bi-205
Bi-207	Bi-208	Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m	Bk-249
Bk-250	Bk-251	C-14	Ca-41	Cd-101	Cd-109	Cd-113	Cd-113m
Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244	Cf-246	Cf-247	Cf-248
Cf-250	Cf-252	Cf-253	Cf-254	Cf-255	Cl-36	Cl-39	Cm-238
Cm-239	Cm-240	Cm-241	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246
Cm-249	Cm-250	Cm-251	Co-55	Co-57	Co-60	Co-60m	Cs-134
Cs-134m	Cs-135	Cs-135m	Cs-137	Cu-59	Dy-148	Dy-149	Dy-150
Dy-152	Dy-154	Dy-157	Er-154	Er-163	Er-171	Es-249	Es-250
Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256	Eu-145
Eu-146	Eu-147	Eu-150	Eu-150m	Eu-152	Eu-152n	Eu-154	Eu-154m
Fe-53	Fe-53m	Fe-55	Fe-60	Fm-251	Fm-252	Fm-253	Fm-254
Fm-255	Fm-256	Fm-257	Fr-212	Fr-222	Fr-227	Gd-145	Gd-145m
Gd-146	Gd-147	Gd-148	Gd-150	Gd-152	Ge-68	H-3	Hf-172
Hf-173	Hf-174	Hf-178m	Hf-182	Hf-182m	Hg-193	Hg-193m	Hg-194
Ho-150	Ho-154	Ho-154m	Ho-157	Ho-163	Ho-166m	I-129	I-135
In-109	In-109m	In-115	In-121	In-121m	Ir-192n	K-40	Kr-81
Kr-87	La-133	La-137	La-138	Lu-173	Lu-174	Lu-174m	Lu-176
Mn-53	Mn-54	Mo-91	Mo-91m	Mo-93	Mo-93m	Mo-99	Na-22
Nb-91	Nb-91m	Nb-92	Nb-93m	Nb-94	Nb-94m	Nb-99	Nb-99m
Nd-137	Nd-144	Nd-147	Nd-151	Ni-59	Ni-63	Np-232	Np-233
Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238	Np-239	Np-240
Np-240m	Np-241	Np-242	Np-242m	Os-186	Os-194	Pa-228	Pa-229
Pa-230	Pa-232	Pa-233	Pa-235	Pa-236	Pa-237	Pb-194	Pb-202

Pb-202m	Pb-205	Pb-210	Pd-97	Pd-101	Pd-107	Pm-137m	Pm-144
Pm-145	Pm-146	Pm-147	Pm-151	Po-205	Po-206	Po-207	Po-208
Po-209	Pr-137	Pr-147	Pt-190	Pt-193	Pt-193m	Pu-232	Pu-234
Pu-235	Pu-236	Pu-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Pu-243	Pu-245	Pu-246	Ra-222	Ra-227	Ra-228	Ra-230	Rb-81
Rb-81m	Rb-87	Rb-90	Rb-90m	Re-179	Re-186m	Re-187	Rh-97
Rh-97m	Rh-101	Rh-101m	Rh-102m	Rh-107	Rn-207	Rn-209	Rn-210
Rn-211	Rn-212	Rn-218	Ru-97	Ru-106	Ru-107	Sb-125	Sb-129
Se-79	Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-151
Sm-155	Sn-109	Sn-125	Sn-125m	Sn-126	Sn-129	Sr-81	Sr-90
Sr-93	Ta-172	Ta-173	Ta-179	Tb-146	Tb-148	Tb-148m	Tb-149
Tb-150	Tb-150m	Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93	Tc-93m
Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m
Th-226	Th-228	Th-229	Th-233	Th-235	Th-236	Ti-44	Tl-194
Tl-194m	Tl-204	Tl-210	Tm-163	Tm-171	U-228	U-230	U-231
U-232	U-233	U-234	U-235	U-235m	U-237	U-238	U-239
U-240	U-242	V-49	V-50	W-179	W-179m	W-187	Xe-135
Xe-135m	Xe-137	Y-93	Yb-163	Zr-93			

NRCDAG NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 295 to 157 as shown in Table 3-41.

Table 3-41. Tier-0 radionuclides that failed Tier-1 NRCDAG NCRP123 groundwater screening.

Ac-228	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245	Am-246m
Ar-39	At-218	Ba-133	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249
Bk-250	C-14	Ca-41	Cd-109	Cd-113	Cd-113m	Cf-248	Cf-250
Cf-252	Cf-253	Cl-36	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246
Cm-249	Cm-250	Co-57	Co-60	Co-60m	Cs-134	Cs-135	Cs-137
Dy-154	Es-253	Es-254	Eu-150	Eu-152	Eu-154	Fe-55	Fe-60
Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	Ge-68	H-3	Hf-172
Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m	I-129	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-173	Lu-174	Lu-174m
Lu-176	Mn-53	Mn-54	Mo-93	Na-22	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-239	Np-240	Np-240m	Os-186	Os-194	Pa-232	Pa-233	Pb-202
Pb-205	Pb-210	Pd-107	Pm-144	Pm-145	Pm-146	Pm-147	Po-208
Po-209	Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241
Pu-242	Pu-243	Pu-246	Ra-228	Rb-87	Re-186m	Re-187	Rh-101
Rh-102m	Rn-218	Ru-106	Sb-125	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-126	Sr-90	Ta-179	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-228	Th-229	Ti-44	Tl-204

Tl-210	Tm-171	U-232	U-233	U-234	U-235	U-235m	U-237
U-238	U-240	V-49	V-50	Zr-93			

3.4.4 Tier-1 NRCDA (special) NCRP123 Groundwater Screening

The NRCDAS DU description is given in the NRCDA intruder screening section, Section 3.2.3. The waste zone in the NCRP123 GW model is identical to the intruder model. The NRCDAS NCRP123 waste and aquifer parameters are shown in Table 3-42.

Table 3-42. NRCDAS NCRP123 waste and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	sandy soil sediment
Porosity	0.380	sandy soil sediment
Water content	function of infiltration rate	sandy soil sediment
Distribution coefficient	element specific, cm^3/g	sandy soil sediment
Waste zone thickness	18 ft (5.4864 m)	Height of welded casks
Waste and aquifer zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Eq. (B-15) concentration

A series of 11 GW scenarios were simulated using the NCRP123 GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 750-year offset from the minimum travel times to account for the hydraulic isolation of welded casks. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAS NCRP123 GW screening scenarios are shown in Table 3-43.

Table 3-43. NRCDAS NCRP123 groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**806**	7.2170E-01	2.7425E-01
4 to 6	1.0000E-01	900, 1000, 1100	7.2170E-01	2.7425E-01
7	4.0500E-01	**772**	7.7000E-01	2.9260E-01
8 to 11	4.0500E-01	800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAS NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 270 as shown in Table 3-44.

Table 3-44. ICRP-07 radionuclides that failed Tier 1 NRCDAS NCRP123 groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-108m	Al-26	Am-237

Am-238	Am-239	Am-240	Am-241	Am-242m	Am-243	Am-244	Am-244m
Am-245	Am-246	Am-246m	Am-247	Ar-39	Ar-42	As-79	At-206
At-209	Au-193	Be-10	Bi-202	Bi-205	Bi-207	Bi-208	Bi-210m
Bk-245	Bk-246	Bk-247	Bk-248m	Bk-250	Bk-251	C-14	Ca-41
Cd-113	Ce-137	Ce-137m	Cf-244	Cf-246	Cf-247	Cf-248	Cf-250
Cf-252	Cf-253	Cf-254	Cf-255	Cl-36	Cl-39	Cm-238	Cm-239
Cm-240	Cm-241	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cm-249
Cm-250	Cm-251	Cs-135	Cs-135m	Cs-137	Cu-59	Dy-148	Dy-150
Dy-152	Dy-154	Dy-157	Er-154	Er-163	Es-249	Es-250	Es-250m
Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256	Eu-146	Eu-147
Eu-150	Eu-150m	Fe-53	Fe-53m	Fe-60	Fm-251	Fm-252	Fm-253
Fm-254	Fm-255	Fm-256	Fm-257	Gd-146	Gd-147	Gd-148	Gd-150
Gd-152	Hf-174	Hf-178m	Hf-182	Hf-182m	Hg-193	Hg-193m	Hg-194
Ho-150	Ho-154	Ho-154m	Ho-163	Ho-166m	I-129	I-135	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176	Mn-53	Mo-91
Mo-91m	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92	Nb-94
Nb-94m	Nb-99	Nb-99m	Nd-137	Nd-144	Nd-147	Nd-151	Ni-59
Ni-63	Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m	Np-237
Np-238	Np-240	Np-240m	Np-241	Np-242	Np-242m	Os-186	Pa-229
Pa-230	Pa-231	Pa-232	Pa-233	Pa-234	Pa-235	Pa-236	Pa-237
Pb-194	Pb-202	Pb-202m	Pb-210	Pd-97	Pd-107	Pm-137m	Pm-146
Pm-151	Po-205	Po-206	Po-208	Po-209	Pr-137	Pt-190	Pt-193m
Pu-232	Pu-234	Pu-235	Pu-236	Pu-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Pu-243	Pu-245	Pu-246	Ra-226	Ra-230	Rb-81
Rb-87	Rb-90	Rb-90m	Re-186m	Re-187	Rh-97	Rh-97m	Rh-107
Rn-209	Rn-210	Ru-97	Ru-107	Sb-129	Se-79	Se-79m	Si-32
Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sn-129	Sr-90
Sr-93	Tb-148	Tb-148m	Tb-150	Tb-150m	Tb-157	Tb-158	Tc-91
Tc-91m	Tc-93	Tc-93m	Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m
Te-123	Te-129	Te-129m	Th-229	Th-230	Th-232	Th-233	Th-235
Th-236	Ti-44	Tl-194	Tl-194m	Tm-163	U-231	U-233	U-234
U-235	U-235m	U-236	U-238	U-239	U-240	U-242	V-50
W-187	Xe-135	Xe-135m	Y-93	Yb-163	Zr-93		

NRCDAS NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 295 to 122 as shown in Table 3-45.

Table 3-45. Tier-0 radionuclides that failed Tier-1 NRCDAS NCRP123 groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242m	Am-243	Am-245	Am-246m
Ar-39	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-250	C-14
Ca-41	Cd-113	Cf-248	Cf-250	Cf-252	Cf-253	Cl-36	Cm-242

Cm-243	Cm-244	Cm-245	Cm-246	Cm-249	Cm-250	Cs-135	Cs-137
Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257	Gd-148
Gd-150	Gd-152	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m
I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176
Mn-53	Mo-93	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63
Np-235	Np-236	Np-237	Np-238	Np-240	Np-240m	Os-186	Pa-231
Pa-232	Pa-233	Pa-234	Pb-202	Pb-210	Pd-107	Pm-146	Po-208
Po-209	Pt-190	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Pu-243	Pu-246	Ra-226	Rb-87	Re-186m	Re-187	Se-79	Si-32
Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232
Ti-44	U-233	U-234	U-235	U-235m	U-236	U-238	U-240
V-50	Zr-93						

3.4.5 Tier-1 Generic Trench (ST/ETCIG) NCRP123 Groundwater Screening

The Generic Trench DU description is given in the Generic Trench intruder screening section, Section 3.2.4. The waste zone in the NCRP123 GW model is identical to the intruder model with the exception of using the compacted state of the Trench waste. The Generic Trench NCRP123 waste and aquifer parameters are shown in Table 3-46.

Table 3-46. Generic Trench NCRP123 waste and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	sandy soil sediment
Porosity	0.380	sandy soil sediment
Water content	function of infiltration rate	sandy soil sediment
Distribution coefficient	element specific, cm^3/g	sandy soil sediment
Waste zone thickness	2.5 ft (0.762 m)	Initial 16 ft waste compacted to 2.5 ft at the start of IC
Waste and aquifer zone area	73,600 ft^2 (6837.7 m^2)	Average waste footprint of ET and ST trenches. 74.9% of average footprint in Hamm (2019). eq. (B-15) concentration

A series of 28 GW scenarios were simulated using the NCRP123 GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the Generic Trench NCRP123 GW screening scenarios are shown in Table 3-47.

Table 3-47. Generic Trench NCRP123 groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
3,4	1.0000E-01	34, 50	7.2170E-01	2.7425E-01
5 to 15	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
16, 17	4.0500E-01	12.8, 50	7.7000E-01	2.9260E-01
18 to 28	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

Generic Trench NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 348 as shown in Table 3-48.

Table 3-48. ICRP-07 radionuclides that failed Tier-1 Generic Trench NCRP123 groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-101	Ag-108m	Ag-113
Ag-113m	Am-237	Am-238	Am-239	Am-240	Am-241	Am-242m	Am-243
Am-244	Am-244m	Am-245	Am-246	Am-246m	Am-247	Ar-42	As-79
At-206	At-207	At-208	At-209	At-211	At-218	Au-193	Au-193m
Au-195	Ba-133	Ba-133m	Be-10	Bi-202	Bi-208	Bi-210m	Bk-245
Bk-246	Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Cd-101
Cd-113m	Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244	Cf-246	Cf-247
Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253	Cf-254	Cf-255
Cl-36	Cl-39	Cm-238	Cm-239	Cm-240	Cm-241	Cm-242	Cm-243
Cm-244	Cm-245	Cm-246	Cm-247	Cm-248	Cm-249	Cm-250	Cm-251
Co-55	Co-60	Co-60m	Cs-134	Cs-134m	Cs-135	Cs-137	Cu-59
Dy-148	Dy-149	Dy-150	Dy-152	Dy-154	Dy-157	Er-154	Er-163
Er-171	Es-249	Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m
Es-255	Es-256	Eu-145	Eu-146	Eu-150	Eu-150m	Eu-152	Eu-152n
Eu-154	Eu-154m	Eu-155	Fe-53	Fe-55	Fe-60	Fm-251	Fm-252
Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-212	Fr-222	Fr-227
Gd-145	Gd-145m	Gd-146	Gd-148	Gd-150	Gd-152	Gd-153	Ge-68
H-3	Hf-172	Hf-173	Hf-174	Hf-178m	Hf-182	Hf-182m	Hg-193
Hg-193m	Hg-194	Ho-150	Ho-154	Ho-154m	Ho-157	Ho-163	I-129
I-135	In-109	In-109m	In-115	Ir-192n	K-40	Kr-81	La-133
La-137	La-138	Lu-173	Lu-174	Lu-174m	Lu-176	Mn-53	Mn-54
Mo-91m	Mo-93	Mo-93m	Mo-99	Na-22	Nb-91	Nb-91m	Nb-92
Nb-93m	Nb-94	Nb-94m	Nb-99m	Nd-137	Nd-144	Nd-147	Nd-151
Ni-59	Ni-63	Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m
Np-237	Np-238	Np-239	Np-240	Np-240m	Np-241	Np-242	Np-242m
Os-186	Os-194	Pa-228	Pa-229	Pa-230	Pa-231	Pa-232	Pa-233
Pa-235	Pa-236	Pa-237	Pb-194	Pb-202	Pb-202m	Pb-210	Pd-97

Pd-101	Pd-107	Pm-137m	Pm-144	Pm-145	Pm-147	Pm-151	Po-205
Po-206	Po-207	Po-208	Po-209	Pr-137	Pt-190	Pt-193	Pt-193m
Pu-232	Pu-234	Pu-235	Pu-236	Pu-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Pu-243	Pu-245	Pu-246	Ra-222	Ra-226	Ra-227
Ra-228	Ra-230	Rb-87	Rb-90	Rb-90m	Re-179	Re-184m	Re-186m
Re-187	Rh-97	Rh-97m	Rh-101	Rh-101m	Rh-102m	Rn-207	Rn-209
Rn-210	Rn-211	Rn-212	Rn-218	Rn-222	Ru-97	Ru-106	Sb-125
Sb-129	Se-79	Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148
Sm-151	Sm-155	Sn-109	Sn-121m	Sn-125	Sn-126	Sn-129	Sr-90
Ta-172	Ta-173	Ta-179	Tb-148	Tb-148m	Tb-149	Tb-150	Tb-150m
Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93	Tc-93m	Tc-97	Tc-97m
Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m	Th-226	Th-228
Th-229	Th-230	Th-231	Th-232	Th-233	Th-234	Th-235	Th-236
Ti-44	Tl-194	Tl-194m	Tl-204	Tl-210	Tm-163	U-228	U-230
U-231	U-232	U-233	U-234	U-235	U-235m	U-236	U-238
U-239	U-240	U-242	V-49	V-50	W-179	W-179m	Xe-135
Xe-137	Y-93	Yb-163	Zr-93				

Generic Trench NCRP123 model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 271 to 163 as shown in Table 3-49.

Table 3-49. Tier-0 radionuclides that failed Tier-1 Generic Trench NCRP123 groundwater screening.

Ac-227	Ag-108m	Am-241	Am-242m	Am-243	Am-245	Am-246m	At-218
Au-195	Ba-133	Be-10	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Cd-113m	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253
Cl-36	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cm-247	Cm-248
Cm-249	Cm-250	Co-60	Co-60m	Cs-134	Cs-135	Cs-137	Dy-154
Es-253	Es-254	Eu-150	Eu-152	Eu-154	Eu-155	Fe-55	Fe-60
Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	Gd-153	Ge-68	H-3
Hf-172	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	I-129	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-173	Lu-174	Lu-174m
Lu-176	Mn-53	Mn-54	Mo-93	Na-22	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-239	Np-240	Np-240m	Os-186	Os-194	Pa-231	Pa-232	Pa-233
Pb-202	Pb-210	Pd-107	Pm-144	Pm-145	Pm-147	Po-208	Po-209
Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Pu-243	Pu-246	Ra-226	Ra-228	Rb-87	Re-184m	Re-186m	Re-187
Rh-101	Rh-102m	Rn-218	Rn-222	Ru-106	Sb-125	Se-79	Si-32
Sm-145	Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90
Ta-179	Tb-157	Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-228
Th-229	Th-230	Th-231	Th-232	Th-234	Ti-44	Tl-204	Tl-210

U-232	U-233	U-234	U-235	U-235m	U-236	U-238	U-240
V-49	V-50	Zr-93					

3.5 Tier-1 NRCDWSM Groundwater Radionuclide Screening

The Nuclear Regulatory Commission Drinking Water Scenario Model screening approach is an extension of the NCRP-like approach which was developed by Kennedy and Strenge (1992) under the guidance of NRC staff and funding. The results from this model are compared to the results from the "classic" NCRP-like model for each DU type considered. Sensitivity results were also created using this model and can be found in Appendix I. As expected, the model generally results in shorter lists when all other things are equal.

NRCDWSM GW radionuclide screening was performed for the five DU models using the ICRP-07 and Tier-0 list of radionuclides. The upper bound estimated radionuclide inventories as discussed in Section 3.2 were employed.

For the NRCDWS model (referred to as the three-box model), there is leaching of radionuclides from: a) the surface-soil layer (Box 1) to the unsaturated-soil layer (Box 2); and b) the unsaturated-soil layer (Box 2) to the GW aquifer (Box 3). The three boxes employed can be related to the following E-Area zones:

- **Box-1** – represents the waste zone within a DU of interest where infiltration from above is specified;
- **Box-2** – represents the vadose zone directly beneath the waste zone extending directly down to the surface of the water table; and
- **Box-3** – represents the aquifer underneath the DU extending out to the 100-m POA.

The radionuclide screening model approach utilizes a series of release times (no leaching) followed by leaching at a constant infiltration of water through the waste zone. Prior to the release time in the waste zone, the radionuclide balance equations are solved for atom numbers of the short chain with radioactive decay and branching. Once infiltration is active, leachate from the short-chain parent and progeny from Box 1 become source terms to the unsaturated soil layer. As the unsaturated-soil layer receives leachate, Box 2 provides source terms to the GW aquifer. The rate of leachate (pCi/yr per Ci of parent buried) from Box 1 and Box 2 are functions of infiltration rate, soil layer thickness, water content, and retardation factor as shown in Eqs. (2-8) and (2-10), respectively. The GW aquifer is conservatively modeled as a collector of leachate with radioactive decay. There is no partitioning of inventory between the soil and the liquid in the aquifer.

The surface-soil layer (Box 1) represents the areal footprint and compacted/collapsed waste height of each DU model. The surface-soil layer (Box 1) and unsaturated-soil layer (Box 2) are modeled as a sandy soil sediment (Nichols 2020). The starting inventory of the parent nuclide is initialized to the atom number equivalent of 10^{12} pCi divided by the decay constant of the parent nuclide. For each of the radionuclides, transient atom numbers are computed for a 1-year half-life cutoff short chain every year for an 1171-year period for each GW scenario (release time and infiltration rate). The short chain activities in the aquifer zone are converted to concentrations for the GW pathways dose calculations using the volume of infiltration in a year. For conservatism, there is no dilution of these short chain concentrations with the regional aquifer flow (w_d set to 0 yr^{-1}). The short chain concentrations (pCi/m^3 per Ci of parent) in the GW aquifer are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The maximum full chain aquifer concentrations are determined every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit.

The transient maximum full chain aquifer concentrations are processed through the SRNL Dose Toolkit (Aleman 2019) for the EPA GW protection and PA AP human receptors. The EPA GW protection places limits on drinking water for alpha-emitting radionuclides (gross alpha), beta or photon emitters (beta-gamma), radium (Ra-226 and Ra-228) and uranium isotopes. The maximum contaminant levels (MCL) for gross alpha, beta-gamma, radium and uranium are: 15 pCi/L, 4 mrem/yr, 5 pCi/L and 30 µg/L, respectively. The PA AP provides protection for the member of public, resident farmer, who uses water from a contaminated source for human and animal consumption, irrigation of a garden, and irrigation of a pasture where farm animals are raised. Products from the garden and farm animal are used for human consumption. The contaminated water is GW from a well that is typically assumed to be 100-m downgradient from the boundary of the waste disposal facility. The PA AP performance objective is 25 mrem/yr. The screening criteria used for GW screening is 0.1% of the performance objectives.

Each disposal unit is assumed to have waste buried at 1994.7 (0-year) with an operational period extending to the time of E-Area closure, 2065.7 (71-year). Institutional control runs from 2065.7 to 2165.7 (171-year). The POP for EPA GW protection spans 1171 years from the time of waste burial to 1171 years during the screening period. The PA GW AP POP is coincident with the inadvertent intruder POP, 171 to 1171 years.

The output of the SRNL Dose Toolkit calculations are maximum screening factors (mrem/yr per Ci of parent buried) for the EPA GW protection and PA AP with progeny contributions rolled up for each radionuclide parent. The screening factors are multiplied by the radionuclide inventories to produce EPA GW protection and PA AP doses. The radionuclide is screened out for PORFLOW PA analysis if the EPA GW protection or PA AP doses do not exceed its screening criterion.

A discussion of NRCDWSM GW parameters, scenarios, and screening results are presented in the following subsections for the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench disposal unit screening models. Lists of radionuclides that failed screening are shown for the ICRP-07 and Tier-0 radionuclides.

3.5.1 Tier 1 ILV NRCDWSM Groundwater Screening

The ILV DU description is given in the ILV intruder screening section, Section 3.2.1. The surface-soil layer in the NRCDWSM GW model is identical to the intruder waste zone with the exception of using the collapsed state of the ILV waste. The ILV NRCDWSM soil and aquifer parameters are shown in Table 3-50.

Table 3-50. ILV NRCDWSM soil and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	surface-soil and unsaturated-soil layers
Porosity	0.380	surface-soil and unsaturated-soil layers
Water content	function of infiltration rate	surface-soil and unsaturated-soil layers
Distribution coefficient	element specific, cm^3/g	surface-soil and unsaturated-soil layers
Surface-soil layer thickness	10 ft (3.048 m)	ILV waste collapses from 25.83 ft to 10 ft at the end of IC

Parameter	Setting	Comment
Unsaturated-soil layer thickness	53.5 ft (16.307 m)	53.5 ft depth from waste zone bottom to water table
Rate constant for aquifer dilution	0 yr^{-1}	w_d in Eq. (A-18)
Surface-soil layer, unsaturated-soil layer and aquifer area	10,500 ft^2 (975.48 m^2)	77.7% of footprint Hamm (2019) Eq. (B-15) concentration

A series of 23 GW scenarios were simulated using the NRCDWSM GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of ILV until the EIC. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the ILV NRCDWSM GW screening scenarios are shown in Table 3-51.

Table 3-51. ILV NRCDWSM groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**214**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**194**	7.7000E-01	2.9260E-01
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

ILV NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 280 as shown in Table 3-52.

Table 3-52. ICRP-07 radionuclides that failed Tier-1 ILV NRCDWSM groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-108m	Ag-113	Al-26
Am-237	Am-238	Am-239	Am-240	Am-241	Am-242	Am-242m	Am-243
Am-244	Am-244m	Am-245	Am-246	Am-246m	Am-247	Ar-39	Ar-42
As-79	At-206	At-207	At-209	At-211	Au-193	Au-193m	Ba-133
Ba-133m	Be-10	Bi-202	Bi-205	Bi-207	Bi-208	Bi-210m	Bk-245
Bk-246	Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Ca-41
Cd-113	Ce-133m	Ce-137	Ce-137m	Cf-244	Cf-246	Cf-247	Cf-248
Cf-249	Cf-250	Cf-251	Cf-252	Cf-253	Cf-254	Cf-255	Cl-36
Cl-39	Cm-238	Cm-239	Cm-240	Cm-241	Cm-243	Cm-244	Cm-245
Cm-246	Cm-247	Cm-248	Cm-249	Cm-250	Cm-251	Cs-135	Cs-135m

Cs-137	Cu-59	Dy-148	Dy-150	Dy-152	Dy-154	Dy-157	Er-154
Es-249	Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255
Es-256	Eu-146	Eu-150	Eu-150m	Fe-53	Fe-60	Fm-251	Fm-252
Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-222	Gd-146	Gd-148
Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182	Hg-193	Hg-193m
Hg-194	Ho-154	Ho-154m	Ho-163	Ho-166m	I-129	I-135	In-115
Ir-192n	K-40	Kr-81	La-133	La-137	La-138	Lu-176	Mn-53
Mo-91	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92	Nb-94
Nb-94m	Nb-99	Nb-99m	Nd-137	Nd-144	Nd-151	Ni-59	Ni-63
Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238
Np-240	Np-240m	Np-241	Np-242	Np-242m	Os-186	Pa-229	Pa-230
Pa-231	Pa-232	Pa-235	Pa-237	Pb-194	Pb-202	Pb-202m	Pb-205
Pb-210	Pd-97	Pd-107	Pm-145	Pm-146	Pm-151	Po-206	Po-207
Po-208	Po-209	Pr-137	Pt-190	Pt-193m	Pu-232	Pu-234	Pu-235
Pu-236	Pu-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243
Pu-244	Pu-245	Pu-246	Ra-226	Ra-227	Ra-230	Rb-87	Rb-90
Rb-90m	Re-186m	Re-187	Rh-97	Rh-97m	Rh-107	Rn-209	Rn-210
Rn-211	Ru-97	Ru-107	Sb-129	Se-79	Se-79m	Si-32	Sm-145
Sm-146	Sm-147	Sm-148	Sm-151	Sn-126	Sn-129	Sr-90	Tb-148
Tb-148m	Tb-150	Tb-150m	Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93
Tc-93m	Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129
Te-129m	Th-226	Th-229	Th-230	Th-231	Th-232	Th-233	Th-235
Th-236	Ti-44	Tl-194	Tl-194m	Tm-163	U-230	U-231	U-232
U-233	U-234	U-235	U-235m	U-236	U-237	U-238	U-239
U-240	U-242	V-50	Xe-135	Xe-135m	Xe-137	Y-93	Zr-93

ILV NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 272 to 133 as shown in Table 3-53.

Table 3-53. Tier-0 radionuclides that failed Tier-1 ILV NRCDWSM groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Am-246m	Ar-39	Ba-133	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247
Bk-249	Bk-250	C-14	Ca-41	Cd-113	Cf-248	Cf-249	Cf-250
Cf-251	Cf-252	Cf-253	Cl-36	Cm-243	Cm-244	Cm-245	Cm-246
Cm-247	Cm-248	Cm-249	Cm-250	Cs-135	Cs-137	Dy-154	Es-253
Es-254	Eu-150	Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152
H-3	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m	I-129
In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176	Mn-53
Mo-93	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-235
Np-236	Np-237	Np-238	Np-240	Np-240m	Os-186	Pa-231	Pa-232
Pb-202	Pb-205	Pb-210	Pd-107	Pm-145	Pm-146	Po-208	Po-209
Pt-190	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243

Pu-244	Pu-246	Ra-226	Rb-87	Re-186m	Re-187	Se-79	Si-32
Sm-145	Sm-146	Sm-147	Sm-148	Sm-151	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-231
Th-232	Ti-44	U-232	U-233	U-234	U-235	U-235m	U-236
U-237	U-238	U-240	V-50	Zr-93			

3.5.2 Tier 1 LAWV NRCDWSM Groundwater Screening

The LAWV DU description is given in the LAWV intruder screening section, Section, 3.2.2. The surface-soil layer in the NRCDWSM GW model is identical to the intruder waste zone with the exception of using the collapsed state of the LAWV waste. The LAWV NRCDWSM soil and aquifer parameters are shown in Table 3-54.

Table 3-54. LAWV NRCDWSM soil and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	surface-soil and unsaturated-soil layers
Porosity	0.380	surface-soil and unsaturated-soil layers
Water content	function of infiltration rate	surface-soil and unsaturated-soil layers
Distribution coefficient	element specific, cm^3/g	surface-soil and unsaturated-soil layers
Surface-soil layer thickness	2.5 ft (0.762 m)	stack of B-25 boxes collapses from 17.3ft to 2.5 ft at the end of IC
Unsaturated-soil layer thickness	45.5 ft (13.868 m)	45.5 ft depth from waste zone bottom to water table
Rate constant for aquifer dilution	0 yr^{-1}	w_d in Eq. (A-18)
Surface-soil layer, unsaturated-soil layer and aquifer area	88,800 ft^2 (8249.8 m^2)	95.2% of footprint Hamm (2019) Eq. (B-15) concentration

A series of 23 GW scenarios were simulated using the NRCDWSM GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of LAWV until EIC. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the LAWV NRCDWSM GW screening scenarios are shown in Table 3-55.

Table 3-55. LAWV NRCDWSM groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**220**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**195**	7.7000E-01	2.9260E-01

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

LAWV NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 221 as shown in Table 3-56.

Table 3-56. ICRP-07 radionuclides that failed Tier-1 LAWV NRCDWSM groundwater screening.

Ac-226	Ac-227	Ac-230	Ac-231	Ac-233	Ag-108m	Al-26	Am-237
Am-238	Am-239	Am-240	Am-241	Am-242	Am-242m	Am-243	Am-244
Am-244m	Am-245	Ar-42	At-206	At-207	At-209	At-211	Au-193
Au-193m	Be-10	Bi-202	Bi-207	Bi-208	Bi-210m	Bk-245	Bk-246
Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Ca-41	Cd-113
Cf-244	Cf-246	Cf-247	Cf-248	Cf-250	Cf-251	Cf-253	Cf-254
Cf-255	Cl-36	Cl-39	Cm-238	Cm-239	Cm-240	Cm-241	Cm-244
Cm-245	Cm-246	Cm-249	Cm-250	Cm-251	Cs-137	Cu-59	Dy-148
Dy-150	Dy-152	Dy-154	Es-249	Es-250	Es-250m	Es-251	Es-253
Es-254	Es-254m	Es-255	Es-256	Eu-150	Fe-60	Fm-251	Fm-252
Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Gd-148	Gd-150	Gd-152
H-3	Hf-174	Hf-178m	Hf-182	Hg-193	Hg-193m	Hg-194	Ho-154
Ho-163	Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81	La-137
La-138	Lu-176	Mn-53	Mo-93	Mo-99	Nb-91	Nb-91m	Nb-92
Nb-94	Nd-144	Ni-59	Ni-63	Np-232	Np-233	Np-234	Np-235
Np-236	Np-236m	Np-237	Np-238	Np-240	Np-241	Np-242	Np-242m
Os-186	Pa-229	Pa-230	Pa-231	Pa-232	Pa-235	Pa-237	Pb-194
Pb-202	Pb-202m	Pb-205	Pd-97	Pd-107	Pm-145	Pm-146	Po-208
Po-209	Pr-137	Pt-190	Pt-193	Pt-193m	Pu-232	Pu-234	Pu-235
Pu-236	Pu-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243
Pu-245	Pu-246	Ra-226	Ra-230	Rb-87	Rb-90	Rb-90m	Re-186m
Re-187	Rh-97	Rh-97m	Rn-209	Rn-210	Rn-211	Ru-97	Sb-129
Se-79	Si-32	Sm-146	Sm-147	Sm-148	Sn-126	Sr-90	Tb-148
Tb-148m	Tb-150	Tb-150m	Tb-157	Tb-158	Tc-93m	Tc-97	Tc-97m
Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m	Th-229	Th-230
Th-231	Th-232	Th-233	Ti-44	Tl-194	Tl-194m	U-230	U-231
U-232	U-233	U-234	U-235	U-235m	U-236	U-237	U-238
U-239	U-240	U-242	V-50	Zr-93			

LAWV NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 271 to 120 as shown in Table 3-57.

Table 3-57. Tier-0 radionuclides that failed Tier-1 LAWV NRCDWSM groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250	C-14
Ca-41	Cd-113	Cf-248	Cf-250	Cf-251	Cf-253	Cl-36	Cm-244
Cm-245	Cm-246	Cm-249	Cm-250	Cs-137	Dy-154	Es-253	Es-254
Eu-150	Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	H-3
Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m	I-129	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176	Mn-53	Mo-93
Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236
Np-237	Np-238	Np-240	Os-186	Pa-231	Pa-232	Pb-202	Pb-205
Pd-107	Pm-145	Pm-146	Po-208	Po-209	Pt-190	Pt-193	Pu-236
Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-246	Ra-226
Rb-87	Re-186m	Re-187	Se-79	Si-32	Sm-146	Sm-147	Sm-148
Sn-126	Sr-90	Tb-157	Tb-158	Tc-97	Tc-98	Tc-99	Te-123
Th-229	Th-230	Th-231	Th-232	Ti-44	U-232	U-233	U-234
U-235	U-235m	U-236	U-237	U-238	U-240	V-50	Zr-93

3.5.3 Tier 1 NRCDA (generic) NRCDWSM Groundwater Screening

The NRCDAG DU description is given in the NRCDA intruder screening section, Section 3.2.3. The surface-soil layer in the NRCDWSM GW model is identical to the intruder waste zone. The NRCDAG NRCDWSM soil and aquifer parameters are shown in Table 3-58.

Table 3-58. NRCDAG NRCDWSM soil and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	surface-soil and unsaturated-soil layers
Porosity	0.380	surface-soil and unsaturated-soil layers
Water content	function of infiltration rate	surface-soil and unsaturated-soil layers
Distribution coefficient	element specific, cm^3/g	surface-soil and unsaturated-soil layers
Surface-soil layer thickness	8.2 ft (2.4994 m)	Height of double-stack bolted containers, 2 x 4.1 ft
Unsaturated-soil layer thickness	68.9 ft (21.0 m)	68.9 ft average depth from waste zone bottom to water table
Rate constant for aquifer dilution	0 yr^{-1}	w_d in Eq. (A-18)
Surface-soil layer, unsaturated-soil layer and aquifer area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Eq. (B-15) concentration

A series of 27 GW scenarios were simulated using the NRCDWSM GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltrate rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAG NRCDWSM GW screening scenarios are shown in Table 3-59.

Table 3-59. NRCDAG NRCDWSM groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	56	7.2170E-01	2.7425E-01
4 to 14	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
15, 16	4.0500E-01	22, 50	7.7000E-01	2.9260E-01
17 to 27	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAG NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 310 as shown in Table 3-60.

Table 3-60. ICRP-07 radionuclides that failed Tier-1 NRCDAG NRCDWSM groundwater screening.

Ac-226	Ac-228	Ac-230	Ac-231	Ac-233	Ag-113	Ag-113m	Al-26
Am-237	Am-238	Am-239	Am-240	Am-241	Am-242	Am-243	Am-244
Am-244m	Am-245	Am-246	Am-246m	Am-247	Ar-39	Ar-42	As-79
At-206	At-207	At-208	At-209	At-211	At-218	Au-193	Au-193m
Ba-133	Ba-133m	Bi-202	Bi-205	Bi-207	Bi-208	Bi-210m	Bk-245
Bk-246	Bk-247	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Ca-41
Cd-109	Cd-113	Cd-113m	Ce-133	Ce-133m	Ce-137	Ce-137m	Cf-244
Cf-246	Cf-247	Cf-248	Cf-250	Cf-252	Cf-253	Cf-254	Cf-255
Cl-36	Cl-39	Cm-238	Cm-239	Cm-240	Cm-241	Cm-242	Cm-244
Cm-246	Cm-249	Cm-250	Cm-251	Co-55	Co-60	Co-60m	Cs-134m
Cs-135	Cs-135m	Cs-137	Cu-59	Dy-148	Dy-150	Dy-152	Dy-154
Dy-157	Er-154	Er-163	Es-249	Es-250	Es-250m	Es-251	Es-253
Es-254	Es-254m	Es-255	Es-256	Eu-145	Eu-146	Eu-147	Eu-150
Eu-150m	Eu-152	Eu-152n	Eu-154m	Fe-53	Fe-55	Fe-60	Fm-251
Fm-252	Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-222	Fr-227
Gd-146	Gd-148	Gd-150	Gd-152	H-3	Hf-172	Hf-174	Hf-178m
Hf-182	Hg-193	Hg-193m	Hg-194	Ho-150	Ho-154	Ho-154m	Ho-157
Ho-163	Ho-166m	I-129	I-135	In-115	Ir-192n	K-40	Kr-81
La-133	La-137	La-138	Lu-174	Lu-174m	Lu-176	Mn-53	Mo-91
Mo-91m	Mo-93	Mo-93m	Mo-99	Na-22	Nb-91	Nb-91m	Nb-92
Nb-93m	Nb-94	Nb-94m	Nb-99	Nb-99m	Nd-137	Nd-144	Nd-147
Nd-151	Ni-59	Ni-63	Np-232	Np-233	Np-234	Np-235	Np-236

Np-236m	Np-237	Np-238	Np-239	Np-240	Np-240m	Np-241	Np-242
Np-242m	Os-186	Os-194	Pa-228	Pa-229	Pa-230	Pa-232	Pa-233
Pa-235	Pa-237	Pb-194	Pb-202	Pb-202m	Pb-205	Pb-210	Pd-97
Pd-107	Pm-145	Pm-146	Pm-151	Po-206	Po-207	Po-208	Po-209
Pr-137	Pt-190	Pt-193	Pt-193m	Pu-232	Pu-234	Pu-235	Pu-236
Pu-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-245
Pu-246	Ra-222	Ra-227	Ra-228	Ra-230	Rb-81	Rb-87	Rb-90
Rb-90m	Re-179	Re-186m	Re-187	Rh-97	Rh-97m	Rh-101	Rh-102m
Rh-107	Rn-207	Rn-209	Rn-210	Rn-211	Rn-218	Ru-97	Ru-107
Sb-125	Sb-129	Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148
Sn-125	Sn-129	Sr-90	Ta-179	Tb-148	Tb-148m	Tb-149	Tb-150
Tb-150m	Tb-157	Tb-158	Tc-91	Tc-91m	Tc-93	Tc-93m	Tc-97
Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m	Th-226
Th-228	Th-229	Th-233	Th-235	Th-236	Ti-44	Tl-194	Tl-194m
Tl-204	Tl-210	Tm-163	Tm-171	U-230	U-231	U-234	U-235
U-235m	U-237	U-238	U-239	U-240	U-242	V-50	W-179
W-187	Xe-135	Xe-135m	Xe-137	Y-93	Zr-93		

NRCDAG NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 295 to 139 as shown in Table 3-61.

Table 3-61. Tier-0 radionuclides that failed Tier-1 NRCDAG NRCDWSM groundwater screening.

Ac-228	Al-26	Am-241	Am-242	Am-243	Am-245	Am-246m	Ar-39
At-218	Ba-133	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Ca-41	Cd-109	Cd-113	Cd-113m	Cf-248	Cf-250	Cf-252
Cf-253	Cl-36	Cm-242	Cm-244	Cm-246	Cm-249	Cm-250	Co-60
Co-60m	Cs-135	Cs-137	Dy-154	Es-253	Es-254	Eu-150	Eu-152
Fe-55	Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	H-3
Hf-172	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m	I-129
In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-174	Lu-174m
Lu-176	Mn-53	Mo-93	Na-22	Nb-91	Nb-92	Nb-93m	Nb-94
Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238	Np-239
Np-240	Np-240m	Os-186	Os-194	Pa-232	Pa-233	Pb-202	Pb-205
Pb-210	Pd-107	Pm-145	Pm-146	Po-208	Po-209	Pt-190	Pt-193
Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-246
Ra-228	Rb-87	Re-186m	Re-187	Rh-101	Rh-102m	Rn-218	Sb-125
Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sr-90	Ta-179	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-228	Th-229	Ti-44
Tl-204	Tl-210	Tm-171	U-234	U-235	U-235m	U-237	U-238
U-240	V-50	Zr-93					

3.5.4 Tier-1 NRCDA (special) NRCDWSM Groundwater Screening

The NRCDA DU description is given in the NRCDA intruder screening section, Section 3.2.3. The surface-soil layer in the NRCDWSM GW model is identical to the intruder waste zone. The NRCDAS NRCDWSM soil and aquifer parameters are shown in Table 3-62.

Table 3-62. NRCDAS NRCDWSM soil and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	surface-soil and unsaturated-soil layers
Porosity	0.380	surface-soil and unsaturated-soil layers
Water content	function of infiltration rate	surface-soil and unsaturated-soil layers
Distribution coefficient	element specific, cm^3/g	surface-soil and unsaturated-soil layers
Surface-soil layer thickness	18 ft (5.4864 m)	Height of welded casks
Unsaturated-soil layer thickness	68.9 ft (21.0 m)	68.9 ft average depth from waste zone bottom to water table
Rate constant for aquifer dilution	0 yr^{-1}	w_d in Eq. (A-18)
Surface-soil layer, unsaturated-soil layer and aquifer area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Eq. (B-15) concentration

A series of 11 GW scenarios were simulated using the NRCDWSM GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 750-year offset from the minimum travel times to account for the hydraulic isolation of welded casks. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAS NRCDWSM GW screening scenarios are shown in Table 3-63.

Table 3-63. NRCDAS NRCDWSM groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**806**	7.2170E-01	2.7425E-01
4 to 6	1.0000E-01	900, 1000, 1100	7.2170E-01	2.7425E-01
7	4.0500E-01	**772**	7.7000E-01	2.9260E-01
8 to 11	4.0500E-01	800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAS NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 221 as shown in Table 3-64.

Table 3-64. ICRP-07 radionuclides that failed Tier 1 NRCDAS NRCDWSM groundwater screening.

Ac-226	Ac-230	Ac-231	Ac-233	Ag-108m	Al-26	Am-237	Am-238
Am-239	Am-240	Am-241	Am-242m	Am-243	Am-244	Am-244m	Am-245

Am-246	Am-246m	Ar-39	Ar-42	At-209	Au-193	Be-10	Bi-202
Bi-207	Bi-208	Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m	Bk-250
Bk-251	C-14	Ca-41	Cd-113	Ce-137	Ce-137m	Cf-244	Cf-246
Cf-247	Cf-248	Cf-250	Cf-252	Cf-253	Cf-254	Cf-255	Cl-36
Cl-39	Cm-238	Cm-239	Cm-240	Cm-241	Cm-242	Cm-244	Cm-245
Cm-249	Cm-250	Cm-251	Cs-135	Cs-135m	Cu-59	Dy-154	Es-249
Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256
Eu-146	Eu-150	Eu-150m	Fe-60	Fm-251	Fm-252	Fm-253	Fm-254
Fm-255	Fm-256	Fm-257	Gd-146	Gd-148	Gd-150	Gd-152	Hf-174
Hf-178m	Hf-182	Hg-193	Hg-193m	Hg-194	Ho-163	Ho-166m	I-129
I-135	In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176
Mn-53	Mo-91	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92
Nb-94	Nb-94m	Nb-99	Nb-99m	Nd-144	Ni-59	Ni-63	Np-232
Np-233	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238	Np-240
Np-240m	Np-241	Np-242	Np-242m	Os-186	Pa-229	Pa-230	Pa-231
Pa-232	Pa-233	Pa-234	Pa-235	Pa-237	Pb-194	Pb-202	Pb-202m
Pd-97	Pd-107	Pm-146	Pm-151	Po-206	Po-209	Pt-190	Pt-193m
Pu-232	Pu-234	Pu-235	Pu-236	Pu-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Pu-243	Pu-245	Pu-246	Ra-226	Ra-230	Rb-81
Rb-87	Re-186m	Re-187	Rh-97	Rh-97m	Rh-107	Rn-209	Rn-210
Ru-97	Sb-129	Se-79	Si-32	Sm-146	Sm-147	Sm-148	Sn-129
Sr-90	Tb-148	Tb-150	Tb-157	Tb-158	Tc-93	Tc-93m	Tc-97
Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m	Th-229
Th-230	Th-233	Th-235	Ti-44	Tl-194	Tl-194m	U-231	U-233
U-234	U-235	U-235m	U-236	U-238	U-239	U-240	U-242
V-50	Xe-135	Xe-135m	Y-93	Zr-93			

NRCDAS NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 295 to 112 as shown in Table 3-65.

Table 3-65. Tier-0 radionuclides that failed Tier-1 NRCDAS NRCDWSM groundwater screening.

Ag-108m	Al-26	Am-241	Am-242m	Am-243	Am-245	Am-246m	Ar-39
Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-250	C-14	Ca-41
Cd-113	Cf-248	Cf-250	Cf-252	Cf-253	Cl-36	Cm-242	Cm-244
Cm-245	Cm-249	Cm-250	Cs-135	Dy-154	Es-253	Es-254	Eu-150
Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	Hf-174	Hf-178m
Hf-182	Hg-194	Ho-163	Ho-166m	I-129	In-115	Ir-192n	K-40
Kr-81	La-137	La-138	Lu-176	Mn-53	Mo-93	Nb-91	Nb-92
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-240	Np-240m	Os-186	Pa-231	Pa-232	Pa-233	Pa-234	Pb-202
Pd-107	Pm-146	Po-209	Pt-190	Pu-236	Pu-238	Pu-239	Pu-240

Pu-241	Pu-242	Pu-243	Pu-246	Ra-226	Rb-87	Re-186m	Re-187
Se-79	Si-32	Sm-146	Sm-147	Sm-148	Sr-90	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Ti-44	U-233
U-234	U-235	U-235m	U-236	U-238	U-240	V-50	Zr-93

3.5.5 Tier 1 Generic Trench (ST/ET/CIG) NRCDWSM Groundwater Screening

The Generic Trench DU description is given in the Generic Trench intruder screening section, Section 3.2.4. The surface-soil layer in the NRCDWSM GW model is identical to the intruder model with the exception of using the compacted state of the Trench waste. The Generic Trench NRCDWSM soil and aquifer parameters are shown in Table 3-66.

Table 3-66. Generic Trench NRCDWSM soil and aquifer parameters.

Parameter	Setting	Comment
Bulk soil density	1.66 g/cm^3	surface-soil and unsaturated-soil layers
Porosity	0.380	surface-soil and unsaturated-soil layers
Water content	function of infiltration rate	surface-soil and unsaturated-soil layers
Distribution coefficient	element specific, cm^3/g	surface-soil and unsaturated-soil layers
Surface-soil layer thickness	2.5 ft (0.762 m)	Initial 16 ft waste compacted to 2.5 ft at the start of IC
Unsaturated-soil layer thickness	41.7 ft (12.71 m)	41.7 ft average depth from waste zone bottom to water table
Rate constant for aquifer dilution	0 yr^{-1}	w_d in Eq. (A-18)
Surface-soil layer, unsaturated-soil layer and aquifer area	73,600 ft^2 (6837.7 m^2)	Average waste footprint of ET and ST trenches. 74.9% of average footprint in Hamm (2019). eq. (B-15) concentration

A series of 28 GW scenarios were simulated using the NRCDWSM GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the Generic Trench NRCDWSM GW screening scenarios are shown in Table 3-67.

Table 3-67. Generic Trench NRCDWSM groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3,4	1.0000E-01	34, 50	7.2170E-01	2.7425E-01
5 to 15	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
16, 17	4.0500E-01	12.8, 50	7.7000E-01	2.9260E-01
18 to 28	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

Generic Trench NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 276 as shown in Table 3-68.

Table 3-68. ICRP-07 radionuclides that failed Tier-1 Generic Trench NRCDWSM groundwater screening.

Ac-226	Ac-230	Ac-231	Ac-233	Ag-108m	Ag-113	Am-237	Am-238
Am-239	Am-240	Am-241	Am-242m	Am-243	Am-244	Am-244m	Am-245
Am-246	Am-246m	Ar-42	At-206	At-207	At-208	At-209	At-211
Au-193	Au-193m	Ba-133	Ba-133m	Be-10	Bi-202	Bi-208	Bi-210m
Bk-245	Bk-246	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Cd-113m
Ce-133	Ce-133m	Cf-244	Cf-246	Cf-247	Cf-248	Cf-249	Cf-250
Cf-251	Cf-253	Cf-254	Cf-255	Cl-36	Cl-39	Cm-238	Cm-239
Cm-240	Cm-241	Cm-243	Cm-244	Cm-245	Cm-246	Cm-247	Cm-248
Cm-249	Cm-250	Cm-251	Co-60	Co-60m	Cs-134	Cs-134m	Cs-135
Cs-137	Cu-59	Dy-148	Dy-150	Dy-152	Dy-154	Er-154	Es-249
Es-250	Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Es-256
Eu-150	Eu-150m	Eu-152	Eu-152n	Eu-154	Eu-154m	Fe-55	Fe-60
Fm-251	Fm-252	Fm-253	Fm-254	Fm-255	Fm-256	Fm-257	Fr-212
Fr-222	Fr-227	Gd-146	Gd-148	Gd-150	Gd-152	H-3	Hf-172
Hf-174	Hf-178m	Hf-182	Hg-193	Hg-193m	Hg-194	Ho-154	Ho-154m
Ho-163	I-129	In-115	Ir-192n	K-40	Kr-81	La-133	La-137
La-138	Lu-174	Lu-174m	Lu-176	Mn-53	Mo-93	Mo-93m	Mo-99
Nb-91	Nb-91m	Nb-92	Nb-94	Nb-94m	Nd-144	Ni-59	Ni-63
Np-232	Np-233	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238
Np-239	Np-240	Np-240m	Np-241	Np-242	Np-242m	Os-186	Os-194
Pa-229	Pa-230	Pa-231	Pa-232	Pa-235	Pa-237	Pb-194	Pb-202
Pb-202m	Pb-210	Pd-97	Pd-107	Pm-145	Pm-151	Po-208	Po-209
Pr-137	Pt-190	Pt-193m	Pu-232	Pu-234	Pu-235	Pu-236	Pu-237
Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-245	Pu-246
Ra-222	Ra-226	Ra-227	Ra-228	Ra-230	Rb-87	Rb-90	Rb-90m
Re-179	Re-186m	Re-187	Rh-97	Rh-97m	Rh-101	Rh-102m	Rn-207
Rn-209	Rn-210	Rn-211	Rn-212	Ru-97	Ru-106	Sb-129	Se-79
Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-151	Sn-109	Sn-126
Sn-129	Sr-90	Ta-179	Tb-148	Tb-148m	Tb-150	Tb-150m	Tb-157
Tb-158	Tc-91	Tc-91m	Tc-93m	Tc-97	Tc-97m	Tc-98	Tc-99
Tc-99m	Te-123	Te-129	Te-129m	Th-226	Th-229	Th-230	Th-231
Th-232	Th-233	Th-234	Th-235	Th-236	Ti-44	Tl-194	Tl-194m
Tl-204	Tm-163	U-230	U-231	U-232	U-233	U-234	U-235
U-235m	U-236	U-238	U-239	U-240	U-242	V-50	W-179
W-179m	Xe-135	Xe-137	Zr-93				

Generic Trench NRCDWSM model doses (computed using maximum screening factors for gross alpha, beta-gamma, radium, uranium and PA AP with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-0 radionuclides from 271 to 138 as shown in Table 3-69.

Table 3-69. Tier-0 radionuclides that failed Tier-1 Generic Trench NRCDWSM groundwater screening.

Ag-108m	Am-241	Am-242m	Am-243	Am-245	Am-246m	Ba-133	Be-10
Bi-208	Bi-210m	Bk-249	Bk-250	C-14	Cd-113m	Cf-248	Cf-249
Cf-250	Cf-251	Cf-253	Cl-36	Cm-243	Cm-244	Cm-245	Cm-246
Cm-247	Cm-248	Cm-249	Cm-250	Co-60	Co-60m	Cs-134	Cs-135
Cs-137	Dy-154	Es-253	Es-254	Eu-150	Eu-152	Eu-154	Fe-55
Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	H-3	Hf-172
Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	I-129	In-115	Ir-192n
K-40	Kr-81	La-137	La-138	Lu-174	Lu-174m	Lu-176	Mn-53
Mo-93	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-235
Np-236	Np-237	Np-238	Np-239	Np-240	Np-240m	Os-186	Os-194
Pa-231	Pa-232	Pb-202	Pb-210	Pd-107	Pm-145	Po-208	Po-209
Pt-190	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243
Pu-246	Ra-226	Ra-228	Rb-87	Re-186m	Re-187	Rh-101	Rh-102m
Ru-106	Se-79	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-151
Sn-126	Sr-90	Ta-179	Tb-157	Tb-158	Tc-97	Tc-98	Tc-99
Te-123	Th-229	Th-230	Th-231	Th-232	Th-234	Ti-44	Tl-204
U-232	U-233	U-234	U-235	U-235m	U-236	U-238	U-240
V-50	Zr-93						

3.6 Tier-2 Inadvertent Intruder Screening

For inadvertent intruder, the Tier-1 screening resulted in an acceptable number of radionuclides for Tier-3 inventory limits. As such, the Tier-2 lists for inadvertent intruder are set equal to the Tier-1 lists. Inadvertent intruder limits for every DU within E-Area, to be supplied to WITS, will be based on the Tier-1 NCRP models discussed within this report. Parameter settings that are unique to each DU will be employed in what is referred to as a Tier-3 limit inventory processing step.

3.7 Tier-2 PORFLOW-Based Groundwater Screening Analysis

As discussed earlier, a Tier-2 screening option was planned on a contingency basis. The Tier-1 models are fairly simple methods; whereas, the Tier-3 and Tier-4 methods are much more involved requiring multi-dimensional (2-to-3D vadose and 3D aquifer) fate and transport modeling efforts. Based on the number of radionuclides remaining after application of the Tier-1 GW screening, SRNL recommended (Aleman and Hamm 2020) following up with Tier-2 efforts focusing on a PORFLOW 1D vadose zone and an underlying single-cell aquifer soil layer fate and transport analysis approach.

PorflowPS GW radionuclide screening was performed for the five DU models using the NCRP123 Tier-1 list of radionuclides. The upper bound estimated radionuclide inventories as discussed in Section 3.2 were employed.

Each DU is assumed to have waste buried at 1994.7 (0-year) with an operational period extending to the time of E-Area closure, 2065.7 (71-year). Institutional control runs from 2065.7 to 2165.7 (171-year). The POP for EPA GW protection spans 1171 years from the time of waste burial to 1171 years during the screening period. The PA GW AP POP is coincident with the inadvertent intruder POP, 171 to 1171 years.

The PorflowPS model consists of a PORFLOW 1D vadose zone transport model developed for each Tier-1 radionuclide within each DU for computing transient fluxes to the watertable. The geometrical and material configurations were made identical to the configurations employed in the NCR123 Tier-1 analyses with the exception of a Backfill zone above the waste zone. The geometry of the waste zone is represented by an aerial footprint (scaled to a 1-cm thick by 10-ft wide slice) and compacted/collapsed waste height of each DU model. Its vertical layout is shown in Figure K-1. The initial inventory of the parent nuclide is 1 gmol scaled to the model footprint and uniformly distributed within the waste zone volume of each DU. For each of the parent radionuclides and their progeny (i.e., based on a 1-year half-life cutoff), transient fluxes to the watertable are computed for every short-chain member (every year for an 1171-year period for each GW scenario (release time and infiltration rate). The transient fluxes are then scaled to the DU footprint.

The transient fluxes to the watertable for each GW scenario are processed for the Tier-1 list of radionuclides and short chain through the PorflowPS model. The PorflowPS model consists of transient fluxes from a PORFLOW 1D vadose zone transport model to a modified aquifer soil layer with radioactive decay, branching and aquifer dilution. There is no partitioning of inventory between the soil and the liquid in the aquifer. Aquifer dilution, mixing with regional GW, at the 100-m compliance well is implemented as an effective linear rate constant in the governing equation for each short chain nuclide. The baseline cases have aquifer dilution applied within the model while an additional set of runs were made with no aquifer dilution. Results with and without aquifer dilution are presented in Section 3.7.1 through Section 3.7.5.

The short chain activities in the aquifer zone are converted to concentrations for the GW pathways dose calculations using the volume of infiltration in a year. The short chain concentrations (pCi/m^3 per Ci of parent) in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The maximum full chain aquifer concentrations are determined every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit.

The transient full chain activities for each parent nuclide computed are processed through the SRNL Dose Tool Kit for the calculation of maximum screening factors for the GW pathways. The five GW pathways include the four EPA drinking water standards (Gross Alpha, Beta-Gamma, Radium and Uranium) and the DOE All-Pathways (AP). Thus, there are five sets of screening factors for GW screening. The screening factor for each parent nuclide is the sum of doses from each member in the full chain that contributes dose to the pathway. Since the dose response is linear in concentration and parent inventory (there are no solubility limits in the screening models), the screening factors can be rolled up to the parent radionuclide. These screening factors are used to complete the Tier-2 screening process

Absolute values of radionuclide inventories for each DU type must be specified along with the screening criteria in order to screen out or retain radionuclides. The upper bound estimated radionuclide inventories at closure as discussed in Section 3.2 were employed. The screening criteria is set to 0.1% of the performance measure of each GW pathway. Each radionuclide's inventory is multiplied by each of the GW and screening factors and then compared to the corresponding screening criteria. If any of the GW screening criteria are exceeded, then the nuclide is not screened out and is added to the list of Tier-2 radionuclides.

A discussion of PorflowPS GW parameters, scenarios, and screening results are presented in the following subsections for the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench DU screening models. Lists of radionuclides that failed screening are shown for the Tier-2 radionuclides with and without aquifer dilution.

For each DU type, material properties (e.g., total porosity and particle density) were set to the values for sandy soil (lower vadose zone properties) within each zone in the PorflowPS vadose model. For the vaults and naval pads the engineered barriers (e.g., concrete walls and metal containers) were not explicitly accounted for; instead, their impacts were inherently addressed through their timeline for inventory releases. Aquifer dilution rate constants used for groundwater screening purposes are explained in Appendix G and presented in Table G-7.

3.7.1 Tier-2 ILV PorflowPS Groundwater Screening

The ILV DU description is given in the ILV intruder screening section, Section 3.3.1. The waste zone in the PorflowPS GW model is identical to the intruder waste zone with the exception of using the collapsed state of the ILV waste. The ILV PorflowPS vadose and aquifer zone parameters are shown in Table 3-70.

Table 3-70. ILV PorflowPS vadose and aquifer zone parameters

Parameter	Setting	Comment
Particle soil density	2.667 g/cm^3	Backfill, waste and lower vadose zone
Porosity	0.380	Backfill, waste and lower vadose zone
Water content	function of infiltration rate	Backfill, waste and lower vadose zone
Distribution coefficient	element specific, cm^3/g	Best Sand Kd for all soil layers
Effective pore diffusion coefficient	167.25528 cm^2/yr	Backfill, waste and lower vadose zone
Transverse and longitudinal dispersivities	0 cm	No mechanical dispersion
Backfill zone thickness	5 ft (1.524 m)	Thickness of soil cover
Waste zone thickness	10 ft (3.048 m)	ILV waste collapses from 25.83 ft to 10 ft at the end of IC
Lower vadose zone thickness	53.5 ft (16.307 m)	Depth from WZ to WT
Rate constant for aquifer dilution	0 and 10.7 yr^{-1}	w_d in (2-12). Table G-7
Backfill, waste, lower vadose and aquifer zone area	10,500 ft^2 (975.48 m^2)	77.7% of footprint Hamm (2019) Used in denominator of (B-37).

A series of 23 GW scenarios were simulated using the PorflowPS GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of ILV until the EIC. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the ILV PorflowPS GW screening scenarios are shown in Table 3-71.

Table 3-71. ILV PorflowPS groundwater screening scenarios

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**214**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**194**	7.7000E-01	2.9260E-01
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

ILV PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 141 to 47 as shown in Table 3-72 with no aquifer dilution.

Table 3-72. Tier-1 radionuclides that failed Tier-2 ILV PorflowPS groundwater screening (no aquifer dilution).

Ag-108m	Am-241	Am-245	Ar-39	Be-10	Bk-247	Bk-249	C-14
Ca-41	Cd-113	Cf-249	Cf-253	Cl-36	Cm-245	Cm-249	Cs-135
Cs-137	Es-253	Fm-257	H-3	I-129	K-40	Kr-81	Mn-53
Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231	Pd-107	Pt-190
Pu-239	Pu-241	Ra-226	Rb-87	Re-186m	Re-187	Si-32	Sr-90
Tc-97	Tc-98	Tc-99	Th-231	U-235	U-235m	U-237	

ILV PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 141 to 45 as shown in Table 3-73 with aquifer dilution.

Table 3-73. Tier-1 radionuclides that failed Tier-2 ILV PorflowPS groundwater screening (with aquifer dilution)

Ag-108m	Am-241	Am-245	Ar-39	Be-10	Bk-247	Bk-249	C-14
Ca-41	Cd-113	Cf-249	Cf-253	Cl-36	Cm-245	Cm-249	Cs-135
Cs-137	Es-253	Fm-257	H-3	I-129	K-40	Kr-81	Mn-53
Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231	Pd-107	Pt-190
Pu-239	Pu-241	Ra-226	Rb-87	Re-186m	Re-187	Si-32	Sr-90
Tc-97	Tc-98	Tc-99	U-235	U-237			

3.7.2 Tier-2 LAWV PorflowPS Groundwater Screening

The LAWV DU description is given in the LAWV intruder screening section, Section 3.3.2. The waste zone in the PorflowPS GW model is identical to the intruder waste zone with the exception of using the collapsed state of the LAWV waste. The LAWV PorflowPS vadose and aquifer zone parameters are shown in Table 3-74.

Table 3-74. LAWV PorflowPS vadose and aquifer zone parameters

Parameter	Setting	Comment
Particle soil density	2.667 g/cm^3	Backfill, waste and lower vadose zone
Porosity	0.380	Backfill, waste and lower vadose zone
Water content	function of infiltration rate	Backfill, waste and lower vadose zone
Distribution coefficient	element specific, cm^3/g	Best Sand Kd for all soil layers
Effective pore diffusion coefficient	167.25528 cm^2/yr	Backfill, waste and lower vadose zone
Transverse and longitudinal dispersivities	0 cm	No mechanical dispersion
Backfill zone thickness	5 ft (1.524 m)	Thickness of soil cover
Waste zone thickness	2.5 ft (0.762 m)	Stack of B-25 boxes which collapse from 17.3 ft to 2.5 ft at the end of IC
Lower vadose zone thickness	45.5 ft (13.868 m)	Depth from WZ to WT
Rate constant for aquifer dilution	0 and 8 yr^{-1}	w_d in (2-12). Table G-7
Backfill, waste, lower vadose and aquifer zone area	88,800 ft^2 (8249.8 m^2)	95.2% of footprint Hamm (2019). Used in denominator of (B-37)

A series of 23 GW scenarios were simulated using the PorflowPS GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 171-year offset from the minimum travel times to account for the hydraulic isolation of LAWV until EIC. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the LAWV PorflowPS GW screening scenarios are shown in Table 3-75.

Table 3-75. LAWV PorflowPS groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**220**	7.2170E-01	2.7425E-01
4 to 12	1.0000E-01	300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
13	4.0500E-01	**195**	7.7000E-01	2.9260E-01
14 to 23	4.0500E-01	200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

LAWV PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 134 to 43 as shown in Table 3-76 without aquifer dilution.

Table 3-76. Tier-1 radionuclides that failed Tier-2 LAWV PorflowPS GW screening (without aquifer dilution).

Ag-108m	Am-241	Am-245	Be-10	Bk-249	C-14	Ca-41	Cd-113
Cf-253	Cl-36	Cm-245	Cm-249	Cs-137	Es-253	Fm-257	H-3
I-129	K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236
Np-237	Pa-231	Pd-107	Pt-190	Pu-239	Pu-241	Ra-226	Rb-87
Re-186m	Re-187	Si-32	Sr-90	Tc-97	Tc-98	Tc-99	Th-231
U-234	U-235	U-237					

LAWV PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 134 to 39 as shown in Table 3-77 with aquifer dilution.

Table 3-77. Tier-1 radionuclides that failed Tier-2 LAWV PorflowPS groundwater screening (with aquifer dilution).

Ag-108m	Am-241	Be-10	Bk-249	C-14	Ca-41	Cd-113	Cf-253
Cl-36	Cm-245	Cs-137	Es-253	Fm-257	H-3	I-129	K-40
Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231
Pd-107	Pt-190	Pu-239	Pu-241	Ra-226	Rb-87	Re-186m	Re-187
Si-32	Sr-90	Tc-97	Tc-98	Tc-99	U-235	U-237	

3.7.3 Tier-2 NRCDA (generic) PorflowPS Groundwater Screening

The NRCDAG DU description is given in the NRCDA intruder screening section, Section 3.3.3. The waste zone in the PorflowPS GW model is identical to the intruder waste zone with the exception of using the collapsed state of the NRCDAG waste. The NRCDAG PorflowPS vadose and aquifer zone parameters are shown in Table 3-78.

Table 3-78. NRCDAG PorflowPS vadose and aquifer zone parameters.

Parameter	Setting	Comment
Particle soil density	2.667 g/cm^3	Backfill, waste and lower vadose zone
Porosity	0.380	Backfill, waste and lower vadose zone
Water content	function of infiltration rate	Backfill, waste and lower vadose zone
Distribution coefficient	element specific, cm^3/g	Best Sand Kd for all soil layers
Effective pore diffusion coefficient	167.25528 cm^2/yr	Backfill, waste and lower vadose zone
Transverse and longitudinal dispersivities	0 cm	No mechanical dispersion
Backfill zone thickness	5 ft (1.524 m)	Thickness of soil cover
Waste zone thickness	8.2 ft (2.4994 m)	Height of double-stack bolted containers, 2 x 4.1 ft
Lower vadose zone thickness	68.9 ft (21.0 m)	Average depth from WZ to WT
Rate constant for aquifer dilution	0 and 12.5 yr^{-1}	w_d in (2-12). Table G-7
Backfill, waste, lower vadose and aquifer zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Used in denominator of (B-37)

A series of 27 GW scenarios were simulated using the PorflowPS GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltrate rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAG PorflowPS GW screening scenarios are shown in Table 3-79.

Table 3-79. NRCDAG PorflowPS groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	56	7.2170E-01	2.7425E-01
4 to 14	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
15, 16	4.0500E-01	22, 50	7.7000E-01	2.9260E-01
17 to 27	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAG PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 157 to 41 as shown in Table 3-80 without aquifer dilution.

Table 3-80. Tier-1 radionuclides that failed Tier-2 NRCDAG PorflowPS groundwater screening (without aquifer dilution).

Am-241	Am-245	Ar-39	Bk-247	Bk-249	C-14	Ca-41	Cd-113
Cf-253	Cl-36	Cm-249	Cs-135	Es-253	Fm-257	H-3	I-129
K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236	Np-237
Np-239	Pd-107	Pt-190	Pt-193	Pu-239	Pu-241	Rb-87	Re-186m
Re-187	Si-32	Sr-90	Tc-97	Tc-98	Tc-99	U-235	U-235m
U-237							

NRCDAG PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 157 to 38 as shown in Table 3-81 with aquifer dilution.

Table 3-81. Tier-1 radionuclides that failed Tier-2 NRCDAG PorflowPS groundwater screening (with aquifer dilution).

Am-241	Am-245	Ar-39	Bk-247	Bk-249	C-14	Ca-41	Cd-113
Cf-253	Cl-36	Cm-249	Cs-135	Es-253	Fm-257	H-3	I-129
K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236	Np-237
Pd-107	Pt-190	Pt-193	Pu-241	Rb-87	Re-186m	Re-187	Si-32
Sr-90	Tc-97	Tc-98	Tc-99	U-235	U-237		

3.7.4 Tier-2 NRCDA (special) PorflowPS Groundwater Screening

The NRCDA DU description is given in the NRCDA intruder screening section, Section 3.3.3. The waste zone in the PorflowPS GW model is identical to the intruder waste zone with the exception of using the collapsed state of the NRCDAS waste. The NRCDAS PorflowPS vadose and aquifer zone parameters are shown in Table 3-82.

Table 3-82. NRCDAS PorflowPS vadose and aquifer zone parameters.

Parameter	Setting	Comment
Particle soil density	2.667 g/cm^3	Backfill, waste and lower vadose zone
Porosity	0.380	Backfill, waste and lower vadose zone
Water content	function of infiltration rate	Backfill, waste and lower vadose zone
Distribution coefficient	element specific, cm^3/g	Best Sand Kd for all soil layers
Effective pore diffusion coefficient	167.25528 cm^2/yr	Backfill, waste and lower vadose zone
Transverse and longitudinal dispersivities	0 cm	No mechanical dispersion
Backfill zone thickness	5 ft (1.524 m)	Thickness of soil cover
Waste zone thickness	18 ft (5.4864 m)	Height of welded casks
Lower vadose zone thickness	68.9 ft (21.0 m)	Average depth from WZ to WT
Rate constant for aquifer dilution	0 and 12.5 yr^{-1}	w_d in (2-12). Table G-7
Backfill, waste, lower vadose and aquifer zone area	5,900 ft^2 (8249.8 m^2)	643-7E footprint (Hamm 2019) Used in denominator of (B-37)

A series of 11 GW scenarios were simulated using the PorflowPS GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. The minimum release times (bold) for the other infiltration rates include a 750-year offset from the minimum travel times to account for the hydraulic isolation of welded casks. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the NRCDAS PorflowPS GW screening scenarios are shown in Table 3-83.

Table 3-83. NRCDAS PorflowPS groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3	1.0000E-01	**806**	7.2170E-01	2.7425E-01
4 to 6	1.0000E-01	900, 1000, 1100	7.2170E-01	2.7425E-01
7	4.0500E-01	**772**	7.7000E-01	2.9260E-01
8 to 11	4.0500E-01	800, 900, 1000, 1100	7.7000E-01	2.9260E-01

NRCDAS PorflowPS doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 122 to 34 as shown in Table 3-84 without aquifer dilution.

Table 3-84. Tier-1 radionuclides that failed Tier 2 NRCDAS PorflowPS groundwater screening (without aquifer dilution).

Am-241	Am-245	Ar-39	Be-10	Bk-247	C-14	Ca-41	Cf-253
Cl-36	Cm-245	Cm-249	Es-253	Fm-257	I-129	K-40	Kr-81
Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231	Pt-190	Pu-239
Pu-241	Rb-87	Re-186m	Re-187	Si-32	Tc-97	Tc-98	Tc-99
U-235	U-235m						

NRCDAS PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 122 to 31 as shown in Table 3-85 with aquifer dilution.

Table 3-85. Tier-1 radionuclides that failed Tier-2 NRCDAS PorflowPS groundwater screening (with aquifer dilution)

Am-241	Am-245	Ar-39	Be-10	Bk-247	C-14	Ca-41	Cf-253
Cl-36	Cm-249	Es-253	Fm-257	I-129	K-40	Kr-81	Ni-59
Ni-63	Np-235	Np-236	Np-237	Pa-231	Pt-190	Pu-241	Rb-87
Re-186m	Re-187	Si-32	Tc-97	Tc-98	Tc-99	U-235	

3.7.5 Tier-2 Generic Trench (ST/ET/CIG) PorflowPS Groundwater Screening

The Generic Trench DU description is given in the Generic Trench intruder screening section, Section 3.3.4. The waste zone in the PorflowPS GW model is identical to the intruder waste zone with the exception of using the collapsed state of the Trench waste. The Trench PorflowPS vadose and aquifer zone parameters are shown in Table 3-86.

Table 3-86. Generic Trench PorflowPS vadose and aquifer zone parameters.

Parameter	Setting	Comment
Particle soil density	2.667 g/cm^3	Backfill, waste and lower vadose zone
Porosity	0.380	Backfill, waste and lower vadose zone
Water content	function of infiltration rate	Backfill, waste and lower vadose zone
Distribution coefficient	element specific, cm^3/g	Best Sand Kd for all soil layers
Effective pore diffusion coefficient	167.25528 cm^2/yr	Backfill, waste and lower vadose zone
Transverse and longitudinal dispersivities	0 cm	No mechanical dispersion
Backfill zone thickness	5 ft (1.524 m)	Thickness of soil cover
Waste zone thickness	2.5 ft (0.762 m)	Initial 16 ft waste compacted to 2.5 ft at the start of IC
Lower vadose zone thickness	41.7 ft (12.71 m)	Average depth from WZ to WT
Rate constant for aquifer dilution	0 and 1.3 yr^{-1}	w_d in (2-12). Table G-7
Backfill, waste, lower vadose and aquifer zone area	73,600 ft^2 (6837.7 m^2)	Average waste footprint of ET/ST trenches. 74.9% of average footprint in Hamm (2019). Used in denominator of (B-37)

A series of 28 GW scenarios were simulated using the PorflowPS GW model where infiltration rates and release rates were varied based on PORFLOW vadose zone infiltration rates and minimum travel times as presented in Table F-5. The minimum release time at an infiltration rate of 3.5E-5 m/yr is 112,105 years but was set to 1071 years to avoid a null scenario. Water saturations for sandy soil as a function of infiltration rate are given in Table F-1. The water content is the product of porosity and water saturation. A summary of the Generic Trench PorflowPS GW screening scenarios are shown in Table 3-87.

Table 3-87. Generic Trench PorflowPS groundwater screening scenarios.

GW Screening Scenario	Infiltration rate (m/yr)	Release time (yr)	Water saturation (Vw/Vv)	Water content (Vw/V)
1	3.5000E-05	*1071*	6.3600E-01	2.4168E-01
2	3.5000E-05	1100	6.3600E-01	2.4168E-01
3,4	1.0000E-01	34, 50	7.2170E-01	2.7425E-01
5 to 15	1.0000E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.2170E-01	2.7425E-01
16, 17	4.0500E-01	12.8, 50	7.7000E-01	2.9260E-01
18 to 28	4.0500E-01	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100	7.7000E-01	2.9260E-01

Generic Trench PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 163 to 44 as shown in Table 3-88 without aquifer dilution.

Table 3-88. Tier-1 radionuclides that failed Tier-2 Generic Trench PorflowPS groundwater screening (without aquifer dilution)

Ag-108m	Am-241	Am-245	Be-10	Bk-249	C-14	Cf-249	Cf-253
Cl-36	Cm-245	Cm-249	Cs-135	Cs-137	Es-253	Fm-257	H-3
I-129	K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236
Np-237	Pa-231	Pd-107	Pt-190	Pu-238	Pu-239	Pu-241	Ra-226
Rb-87	Re-186m	Re-187	Si-32	Sr-90	Tc-97	Tc-98	Tc-99
Th-230	Th-231	U-234	U-235				

Generic Trench PorflowPS model doses (computed using maximum screening factors for all GW pathways with radionuclide inventories) which fail the GW screening criteria reduce the number of Tier-1 radionuclides from 163 to 43 as shown in Table 3-89 with aquifer dilution.

Table 3-89. Tier-1 radionuclides that failed Tier-2 Generic Trench PorflowPS groundwater screening (with aquifer dilution).

Ag-108m	Am-241	Am-245	Be-10	Bk-249	C-14	Cf-249	Cf-253
Cl-36	Cm-245	Cm-249	Cs-135	Cs-137	Es-253	Fm-257	H-3
I-129	K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236
Np-237	Pa-231	Pd-107	Pt-190	Pu-239	Pu-241	Ra-226	Rb-87
Re-186m	Re-187	Si-32	Sr-90	Tc-97	Tc-98	Tc-99	Th-230
Th-231	U-234	U-235					

4.0 Summary of Screening Analyses

The screening analysis described in this report significantly reduced the number of parent radionuclides requiring further complex fate and transport analyses (i.e., explicit WITS inventory limits). This greatly reduces the upfront costs and maintenance costs throughout the life cycle of a PA.

The multitiered approach employed in this analysis systematically screens out radionuclides or retains them for further detailed PA analysis. Those radionuclides that fail a screening step are carried on as input into the next screening step. None of the original ICRP-107 list of 1252 radionuclides fall outside of this systematic treatment thus eliminating the need for supplemental tracking of a subset of "unanalyzed" radionuclides. However, there may be justification for tracking a portion of the radionuclides retained for detailed PA analyses using conservative trigger values as described in Section 2.6. The implementation of trigger values and integration into the inventory limits system is described in Chapter 5.0). Key aspects and results associated with each tier are discussed in Sections 4.1 through 4.4.

4.1 Tier-0 Radionuclides that Failed Screening

Tier-0 screening analysis was presented in Section 3.1 and reduced the list of ICRP-07 radionuclides from 1,252 to 271. An additional radionuclide, Ar-37, was identified as a special non-SRS waste form in the ILV during the update to the 2065 E-Area closure inventory. The list of radionuclides for Tier-1 ILV are augmented to include Ar-37 for a total of 272. The list of Tier-0 radionuclides was augmented for the NRCDAG and NRCDAS DU screening models to include radionuclides identified in the NRCDA inventories as discussed in Appendix H. The NRCDA Tier-1 list increased to 295 radionuclides.

The six steps used in the Tier-0 screening were derived from the SRS HLW tank farm closure radionuclide screening developed by Hamm (2006). The Hamm (2006) report included Tier-0 and Tier-1 screening analyses which reduced a comprehensive list of 849 radionuclides to 159. This list of radionuclides was used in the Saltstone and Tank Farm Performance Assessments (Saltstone 2019 and H-Tank Farm 2012, respectively) as approved by the DOE.

The Tier-0 screening analysis used in this study is an exhaustive examination of the full-chain activities of all ICRP-07 radionuclides at the start of ELLWF operations in 1994. Any radioactive parent or progeny with an activity 30 orders of magnitude below that of the parent in the chain were excluded as not likely to exist during the 1100-year screening period. The approach taken in this work, conceptually similar to Hamm (2006), reduces through sequentially logical steps, the original list down to more manageable lists for more complex/complete fate and transport modeling.

The composite Tier-0 radionuclide listing for all DU types is provided in Table 4-1. The 271 radionuclides in black apply to all disposal units. The radionuclide in red is an additional nuclide for the ILV. The 24 radionuclides in cyan are unique to the NRCDAG and NRCDAS DUs.

Table 4-1. Radionuclides[a] that failed Tier-0 screening for each disposal unit type.

Ac-225	Ac-227	Ac-228	Ag-108	Ag-108m	**Ag-109m**	Ag-110	Ag-110m
Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245	Am-246m	**Ar-37**
Ar-39	At-217	At-218	At-219	Au-194	Au-195	Ba-133	Ba-137m

Ba-140	Be-10	Bi-207	Bi-208	Bi-210	Bi-210m	Bi-211	Bi-212
Bi-213	Bi-214	Bi-215	Bk-247	Bk-249	Bk-250	C-14	Ca-41
Ca-45	Cd-109	Cd-113	Cd-113m	Cd-115m	Ce-139	Ce-141	Ce-144
Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253	Cl-36	Cm-242
Cm-243	Cm-244	Cm-245	Cm-246	Cm-247	Cm-248	Cm-249	Cm-250
Co-57	Co-58	Co-60	Co-60m	Cr-51	Cs-134	Cs-135	Cs-137
Dy-154	Dy-159	Es-253	Es-254	Eu-149	Eu-150	Eu-152	Eu-154
Eu-155	Fe-55	Fe-59	Fe-60	Fm-254	Fm-257	Fr-221	Fr-223
Ga-68	Gd-148	Gd-150	Gd-151	Gd-152	Gd-153	Ge-68	H-3
Hf-172	Hf-174	Hf-175	Hf-178m	Hf-181	Hf-182	Hg-194	Hg-206
Ho-163	Ho-166m	I-129	In-113m	In-114	In-114m	In-115	Ir-192
Ir-192m	Ir-192n	Ir-194	Ir-194m	K-40	K-42	Kr-81	Kr-83m
Kr-85	La-137	La-138	La-140	Lu-172	Lu-172m	Lu-173	Lu-174
Lu-174m	Lu-176	Lu-177	Lu-177m	Mn-53	Mn-54	Mo-93	Na-22
Nb-91	Nb-92	Nb-93m	Nb-94	Nb-95	Nb-95m	Nd-144	Ni-59
Ni-63	Np-235	Np-236	Np-237	Np-238	Np-239	Np-240	Np-240m
Os-185	Os-186	Os-194	P-32	P-33	Pa-231	Pa-232	Pa-233
Pa-234	Pa-234m	Pb-202	Pb-205	Pb-209	Pb-210	Pb-211	Pb-212
Pb-214	Pd-107	Pm-143	Pm-144	Pm-145	Pm-146	Pm-147	Po-208
Po-209	Po-210	Po-211	Po-212	Po-213	Po-214	Po-215	Po-216
Po-218	Pr-144	Pr-144m	Pt-190	Pt-193	Pu-236	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Pu-243	Pu-244	Pu-246	Ra-223	Ra-224
Ra-225	Ra-226	Ra-228	Rb-87	Re-184	Re-184m	Re-186	Re-186m
Re-187	Rh-101	Rh-102	Rh-102m	Rh-103m	Rh-106	Rn-217	Rn-218
Rn-219	Rn-220	Rn-222	Ru-103	Ru-106	S-35	Sb-124	Sb-125
Sb-126	Sb-126m	Sc-44	Sc-46	Se-75	Se-79	Si-32	Sm-145
Sm-146	Sm-147	Sm-148	Sm-151	Sn-113	Sn-119m	Sn-121	Sn-121m
Sn-123	Sn-126	Sr-89	Sr-90	Ta-179	Ta-182	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-121	Te-121m	Te-123	Te-123m	Te-125m
Te-127	Te-127m	Th-227	Th-228	Th-229	Th-230	Th-231	Th-232
Th-234	Ti-44	Tl-202	Tl-204	Tl-206	Tl-207	Tl-208	Tl-209
Tl-210	Tm-168	Tm-170	Tm-171	U-232	U-233	U-234	U-235
U-235m	U-236	U-237	U-238	U-240	V-49	V-50	W-181
W-185	W-188	Y-88	Y-90	Y-91	Zn-65	Zr-93	Zr-95

[a] 271 radionuclides in black apply to all DUs. The radionuclide in red is an additional nuclide for the ILV. The 24 radionuclides in cyan are unique to the NRCDAG and NRCDAS DUs.

4.2 Tier-1 and Tier-2 Common Calculational Aspects

There are several computational aspects that are common between the Tier-1 and the Tier-2 screening efforts for each DU type (e.g., upper bound estimates for inventories and dose analyses). Both screening efforts employed the following common features:

- Several methods or sources for estimating inventories were used to obtain a set of limiting radionuclide disposal inventories including: projected closure inventories (scaled up by a factor of ten), inventories derived from gamma-ray dose limits in WAC procedures for handling of B-25 boxes, weight-based inventories in B-25 boxes, or the historical screening inventory of 10^7 Ci. Also, historical WITS inventories, operational constraints, and available process knowledge was employed;
- Site-specific features of existing DUs were incorporated into generic or composite GW screening models;
- The short-chain of each radionuclide with a half-life cutoff of 1 year were modeled in the soil-layers and aquifer for Tier-1 and Tier-2;
- Aquifer short-chain concentrations were expanded into full-chain concentrations assuming secular equilibrium for subsequent dose calculations;
- A series of GW screening scenarios were executed with various infiltration rates and bake (then release) times;
- Release of contaminants from the waste zone due to leaching after the minimum bake time is reached;
- The series of coupled ordinary differential equations (ODEs) representing soil-layer(s) for Tier-1 and aquifer for Tier-1 and Tier-2 were solved efficiently using the matrix exponential method;
- The maximum aquifer concentration time series was computed from the full-chain concentrations of each GW screening scenario;
- The GW screening model aquifer results were then processed through the EPA GW protection and PA AP human receptors analyzed in the ELLWF PA;
- Maximum dose screening factors during the EPA GW and PA AP POC were computed for all radionuclides;
- The list of radionuclide inventories used in the intruder screening were used for GW screening; and
- The screening criterion of 0.1% of the performance objective were used.

With regard to the last few bullets, historically, a dose (or concentration level) has been compared with a screening criterion set to 1% of a performance measure (e.g., a beta-gamma dose not to exceed the 4 mrem/yr beta-gamma performance measure x 0.01 = 0.04 mrem/yr). Thus, if a radionuclide produced a bounding or screening-level dose (or concentrations) less than the screening criterion, it could be safely removed from further consideration. Several tiers of screening and bounding level analyses have been considered in this report. In this new screening effort, the performance measure and estimator were tightened up by:

- Consistently looking at every exposure pathway regardless of the tier level;
- Rolling up dose contributions for the entire full-chain members; and
- Requiring that a pathway's maximum exposure not exceed 0.1% of the applicable performance measure (e.g., 0.1% of the 4 mrem/y performance measure x 0.001 = 0.004 mrem/yr) over the entire period of performance.

Bullet one ensures that no inconsistencies exists in between varying tiers such that a radionuclide passed on to the PA-level analysis would not have been first screened out at a higher level. Bullet two addresses the possibility that one of a parent's progeny can contribute significantly to overall dose. Bullet three provides additional risk reduction in the very unlikely scenario that a set of radionuclides screened out from further consideration in a pathway would produce a cumulative dose impact approaching the applicable performance measure.

4.3 Tier-1 Radionuclides that Failed Screening

Tier-1 inadvertent intruder and GW radionuclide screening of the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench DUs are presented in Sections 3.3 and 3.4, respectively. The calculational aspects listed in Section 4.2 were employed along with aspects that are specific to Tier-1 screening. For the Tier-1 intruder screening the following additional aspects were considered:

- Models were exercised through the full spectrum of acute and chronic intruder scenarios analyzed in the ELLWF PA; and
- Maximum dose screening factors during the inadvertent intruder CP were computed for all radionuclides.

For the Tier-1 GW the following additional aspects were considered:

- The full spectrum of EPA drinking water and All-Pathways PMs were considered; and
- Maximum dose screening factors during the GW CPs were computed for all radionuclides.

Based on the recommended (i.e., the "NCRP-like") GW and intruder screening methodologies the list of parent nuclides that fail the screening criterion (i.e., 0.1% SOF) are summarized in Table 4-2 through Table 4-11 for each of the DU screening models. These are the actual parent radionuclides that fail the Tier-1 GW and inadvertent intruder screening processes and were subjected to a Tier-2 screening process.

4.3.1 Tier-1 ILV Radionuclides that Failed Screening

Radionuclides that failed Tier-1 ILV intruder and GW screening are shown in Table 4-2 and Table 4-3, respectively. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – 272 reduced to 29; and
- **Groundwater** - 272 reduced to 141.

Table 4-2. Radionuclides (29) that failed Tier-1 ILV intruder screening.

Ac-227	Al-26	Bi-207	Bi-208	Bi-210m	Cm-250	Cs-137	Eu-150
Fe-60	Hf-182	Hg-194	Ho-166m	Ir-192n	La-138	Nb-91	Nb-92
Np-236	Pa-231	Pa-232	Pb-202	Po-209	Pu-236	Ra-226	Re-186m
Tb-158	Tc-98	Th-229	Ti-44	V-50			

Table 4-3. Radionuclides[a] (141) that failed Tier-1 ILV groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Am-246m	Ar-39	At-218	Ba-133	Be-10	Bi-207	Bi-208	Bi-210m
Bk-247	Bk-249	Bk-250	C-14	Ca-41	Cd-113	Cf-248	Cf-249
Cf-250	Cf-251	Cf-252	Cf-253	Cl-36	Cm-242	Cm-243	Cm-244
Cm-245	Cm-246	Cm-247	Cm-248	Cm-249	Cm-250	Cs-135	Cs-137

Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257	Gd-148
Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163
Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138
Lu-176	Mn-53	Mo-93	Nb-91	Nb-92	Nb-93m	Nb-94	Nd-144
Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238	Np-240	Np-240m
Os-186	Os-194	Pa-231	Pa-232	Pb-202	Pb-205	Pb-210	Pd-107
Pm-145	Pm-146	Po-208	Po-209	Pt-190	Pt-193	Pu-236	Pu-238
Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-244	Pu-246	Ra-226
Rb-87	Re-186m	Re-187	Rn-222	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-126	Sr-90	Tb-157	Tb-158	Tc-97
Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-231	Th-232	Th-234
Ti-44	Tl-210	U-232	U-233	U-234	U-235	U-235m	U-236
U-237	U-238	U-240	V-50	Zr-93			

[a] The six radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.3.2 Tier-1 LAWV Radionuclides that Failed Screening

Radionuclides that failed Tier-1 LAWV intruder and GW screening are shown in Table 4-4 and Table 4-5, respectively. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – 271 reduced to 20; and
- **Groundwater** - 271 reduced to 134.

Table 4-4. Radionuclides (20) that failed Tier-1 LAWV intruder screening.

Ac-227	Al-26	Bi-208	Cm-250	Fe-60	Hf-182	Hg-194	Ho-166m
Ir-192n	La-138	Nb-92	Np-236	Pa-231	Pb-202	Po-209	Pu-236
Re-186m	Tb-158	Tc-98	Ti-44				

Table 4-5. Radionuclides[a] (134) that failed Tier-1 LAWV groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Am-246m	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Ca-41	Cd-113	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252
Cf-253	Cl-36	Cm-243	Cm-244	Cm-245	Cm-246	Cm-249	Cm-250
Cs-137	Dy-154	Es-253	Es-254	Eu-150	Eu-152	Fe-60	Fm-254
Fm-257	Gd-148	Gd-150	Gd-152	H-3	Hf-174	Hf-178m	Hf-182
Hg-194	Ho-163	Ho-166m	I-129	In-115	Ir-192n	K-40	Kr-81
La-137	La-138	Lu-176	Mn-53	Mo-93	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-240	Np-240m	Os-186	Os-194	Pa-231	Pa-232	Pa-233	Pb-202
Pb-205	Pb-210	Pd-107	Pm-145	Pm-146	Po-208	Po-209	Pt-190
Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-243

Pu-246	Ra-226	Rb-87	Re-186m	Re-187	Se-79	Si-32	Sm-145
Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-231
Th-232	Th-234	Ti-44	U-232	U-233	U-234	U-235	U-235m
U-236	U-237	U-238	U-240	V-50	Zr-93		

[a] The six radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.3.3 Tier-1 NRCDAG Radionuclides that Failed Screening

Radionuclides that failed Tier-1 NRCDA (generic) intruder and GW screening are shown in Table 4-6 and Table 4-7, respectively. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – 295 reduced to 29; and
- **Groundwater** - 295 reduced to 157.

Table 4-6. Radionuclides (29) that failed Tier-1 NRCDA (generic) intruder screening.

Al-26	Bi-207	Bi-208	Bi-210m	Bk-247	Cm-250	Eu-150	Eu-152
Fe-60	Hf-182	Hg-194	Ho-166m	Ir-192n	K-40	La-138	Nb-91
Nb-92	Nb-94	Np-236	Pa-232	Pb-202	Po-209	Pu-236	Re-186m
Tb-158	Tc-98	Th-229	Ti-44	V-50			

Table 4-7. Radionuclides[a] (157) that failed Tier-1 NRCDA (generic) groundwater screening.

Ac-228	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245	Am-246m
Ar-39	At-218	Ba-133	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249
Bk-250	C-14	Ca-41	Cd-109	Cd-113	Cd-113m	Cf-248	Cf-250
Cf-252	Cf-253	Cl-36	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246
Cm-249	Cm-250	Co-57	Co-60	Co-60m	Cs-134	Cs-135	Cs-137
Dy-154	Es-253	Es-254	Eu-150	Eu-152	Eu-154	Fe-55	Fe-60
Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	Ge-68	H-3	Hf-172
Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m	I-129	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-173	Lu-174	Lu-174m
Lu-176	Mn-53	Mn-54	Mo-93	Na-22	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-239	Np-240	Np-240m	Os-186	Os-194	Pa-232	Pa-233	Pb-202
Pb-205	Pb-210	Pd-107	Pm-144	Pm-145	Pm-146	Pm-147	Po-208
Po-209	Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241
Pu-242	Pu-243	Pu-246	Ra-228	Rb-87	Re-186m	Re-187	Rh-101
Rh-102m	Rn-218	Ru-106	Sb-125	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-126	Sr-90	Ta-179	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-228	Th-229	Ti-44	Tl-204

Tl-210	Tm-171	U-232	U-233	U-234	U-235	U-235m	U-237
U-238	U-240	V-49	V-50	Zr-93			

[a] The six radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.3.4 Tier-1 NRCDAS Radionuclides that Failed Screening

Radionuclides that failed Tier-1 NRCDA (special) intruder and GW screening are shown in Table 4-8 and Table 4-9, respectively. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – 295 reduced to 75; and
- **Groundwater** - 295 reduced to 122.

Table 4-8. Radionuclides[a] (75) that failed Tier-1 NRCDA (special) intruder screening.

Ac-227	Al-26	Am-241	Am-243	Am-245	Am-246m	Bi-207	Bi-208
Bi-210m	Bk-247	Bk-250	Cf-248	Cf-250	Cf-252	Cf-253	Cm-249
Cm-250	Co-60	Cs-137	Es-253	Es-254	Eu-150	Fe-60	Fm-254
Fm-257	Hf-182	Hg-194	Ho-166m	Ir-192n	K-40	Kr-81	La-137
La-138	Lu-176	Mo-93	Nb-91	Nb-92	Nb-93m	Nb-94	Ni-59
Np-235	Np-236	Np-238	Os-194	Pa-231	Pa-232	Pa-233	Pb-202
Pb-210	Pm-145	Pm-146	Po-208	Po-209	Pu-236	Pu-241	Pu-243
Pu-246	Ra-226	Ra-228	Re-186m	Rn-222	Sm-145	Sn-121m	Sn-126
Sr-90	Tb-157	Tb-158	Tc-97	Tc-98	Te-123	Th-229	Th-230
Ti-44	V-50	Zr-93					

[a] The five radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

Table 4-9. Radionuclides[a] (122) that failed Tier-1 NRCDA (special) groundwater screening.

Ac-227	Ag-108m	Al-26	Am-241	Am-242m	Am-243	Am-245	Am-246m
Ar-39	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-250	C-14
Ca-41	Cd-113	Cf-248	Cf-250	Cf-252	Cf-253	Cl-36	Cm-242
Cm-243	Cm-244	Cm-245	Cm-246	Cm-249	Cm-250	Cs-135	Cs-137
Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257	Gd-148
Gd-150	Gd-152	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	Ho-166m
I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176
Mn-53	Mo-93	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63
Np-235	Np-236	Np-237	Np-238	Np-240	Np-240m	Os-186	Pa-231
Pa-232	Pa-233	Pa-234	Pb-202	Pb-210	Pd-107	Pm-146	Po-208
Po-209	Pt-190	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Pu-243	Pu-246	Ra-226	Rb-87	Re-186m	Re-187	Se-79	Si-32
Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232

Ti-44	U-233	U-234	U-235	U-235m	U-236	U-238	U-240
V-50	Zr-93						

[a] The five radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.3.5 Tier-1 Generic Trench Radionuclides that Failed Screening

Radionuclides that failed Tier-1 Generic Trench intruder and GW screening are shown in Table 4-10 and Table 4-11, respectively. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – 271 reduced to 88; and
- **Groundwater** - 271 reduced to 163.

Table 4-10. Radionuclides[a] (88) that failed Tier-1 Generic Trench intruder screening.

Ag-108m	Am-241	Am-242m	Am-243	Bi-208	Bi-210m	Bk-249	C-14
Cf-248	Cf-249	Cf-251	Cf-253	Cm-247	Cm-248	Cm-249	Cm-250
Cs-137	Dy-154	Es-253	Es-254	Eu-150	Fe-60	Fm-254	Fm-257
Gd-148	Gd-150	Gd-152	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163
I-129	In-115	Ir-192n	K-40	Kr-81	La-137	La-138	Lu-176
Mn-53	Nb-91	Nb-92	Nb-94	Nd-144	Ni-59	Ni-63	Np-235
Np-236	Np-237	Os-186	Pa-232	Pb-202	Pm-145	Po-208	Po-209
Pt-190	Pu-236	Pu-239	Pu-240	Pu-241	Pu-243	Ra-226	Re-186m
Re-187	Si-32	Sm-146	Sm-147	Sm-148	Sn-126	Sr-90	Tb-157
Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232
Ti-44	U-232	U-233	U-234	U-235	U-236	U-238	V-50

[a] The six radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

Table 4-11. Radionuclides[a] (163) that failed Tier-1 Generic Trench groundwater screening.

Ac-227	Ag-108m	Am-241	Am-242m	Am-243	Am-245	Am-246m	At-218
Au-195	Ba-133	Be-10	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Cd-113m	Cf-248	Cf-249	Cf-250	Cf-251	Cf-252	Cf-253
Cl-36	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cm-247	Cm-248
Cm-249	Cm-250	Co-60	Co-60m	Cs-134	Cs-135	Cs-137	Dy-154
Es-253	Es-254	Eu-150	Eu-152	Eu-154	Eu-155	Fe-55	Fe-60
Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	Gd-153	Ge-68	H-3
Hf-172	Hf-174	Hf-178m	Hf-182	Hg-194	Ho-163	I-129	In-115
Ir-192n	K-40	Kr-81	La-137	La-138	Lu-173	Lu-174	Lu-174m
Lu-176	Mn-53	Mn-54	Mo-93	Na-22	Nb-91	Nb-92	Nb-93m
Nb-94	Nd-144	Ni-59	Ni-63	Np-235	Np-236	Np-237	Np-238
Np-239	Np-240	Np-240m	Os-186	Os-194	Pa-231	Pa-232	Pa-233
Pb-202	Pb-210	Pd-107	Pm-144	Pm-145	Pm-147	Po-208	Po-209

Pt-190	Pt-193	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Pu-243	Pu-246	Ra-226	Ra-228	Rb-87	Re-184m	Re-186m	Re-187
Rh-101	Rh-102m	Rn-218	Rn-222	Ru-106	Sb-125	Se-79	Si-32
Sm-145	Sm-146	Sm-147	Sm-148	Sm-151	Sn-121m	Sn-126	Sr-90
Ta-179	Tb-157	Tb-158	Tc-97	Tc-98	Tc-99	Te-123	Th-228
Th-229	Th-230	Th-231	Th-232	Th-234	Ti-44	Tl-204	Tl-210
U-232	U-233	U-234	U-235	U-235m	U-236	U-238	U-240
V-49	V-50	Zr-93					

[a] The six radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.4 Tier-2 Radionuclides that Failed Screening

Only Tier-2 GW screening analyses were explicitly performed (i.e., no Tier-2 inadvertent intruder screening analyses were performed). The Tier-2 GW radionuclide screening of the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench are presented in Section 3.7 for the PorflowPS GW screening model. The calculational aspects listed in Section 4.2 were employed along with aspects that are specific to Tier-2 screening. For the Tier-2 GW screening the following additional aspects were considered:

- The short-chain of each parent radionuclide (i.e., 1-yr cutoff) were modeled in the PORFLOW 1D vadose zone;
- Aquifer dilution was included assuming a first-order rate constant approach; and
- The series of coupled ODEs representing the radionuclide balances of the short chain, with transient fluxes to the WT, in the aquifer were solved efficiently using integrating factors and the matrix exponential method.

Based on the PorflowPS GW screening methodology **with aquifer dilution**, the list of parent nuclides that fail the screening criterion (i.e., 0.1% SOF) are summarized in Table 4-12 through Table 4-16 for each of the DU screening models. These are the actual parent radionuclides that failed the Tier-2 GW screening process.

4.4.1 Tier-2 ILV Radionuclides that Failed Screening

Radionuclides that failed Tier-2 ILV GW screening are shown in Table 4-12. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – no screening performed; and
- **Groundwater** - 141 reduced to 45.

Table 4-12. Radionuclides[a] (45) that failed Tier-2 ILV groundwater screening.

Ag-108m	Am-241	Am-245	Ar-39	Be-10	Bk-247	Bk-249	C-14
Ca-41	Cd-113	Cf-249	Cf-253	Cl-36	Cm-245	Cm-249	Cs-135
Cs-137	Es-253	Fm-257	H-3	I-129	K-40	Kr-81	Mn-53
Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231	Pd-107	Pt-190
Pu-239	Pu-241	Ra-226	Rb-87	Re-186m	Re-187	Si-32	Sr-90

Tc-97	Tc-98	Tc-99	U-235	U-237

[a] The four radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.4.2 Tier-2 LAWV Radionuclides that Failed Screening

Radionuclides that failed Tier-2 LAWV GW screening are shown in Table 4-13. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – no screening performed; and
- **Groundwater** - 134 reduced to 39.

Table 4-13. Radionuclides[a] (39) that failed Tier-2 LAWV groundwater screening.

Ag-108m	Am-241	Be-10	Bk-249	C-14	Ca-41	Cd-113	Cf-253
Cl-36	Cm-245	Cs-137	Es-253	Fm-257	H-3	I-129	K-40
Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236	Np-237	Pa-231
Pd-107	Pt-190	Pu-239	Pu-241	Ra-226	Rb-87	Re-186m	Re-187
Si-32	Sr-90	Tc-97	Tc-98	Tc-99	U-235	U-237	

[a] The four radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.4.3 Tier-2 NRCDAG Radionuclides that Failed Screening

Radionuclides that failed Tier-2 NRCDA (generic) GW screening are shown in Table 4-14. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – no screening performed; and
- **Groundwater** - 157 reduced to 38.

Table 4-14. Radionuclides[a] (38) that failed Tier-2 NRCDA (generic) groundwater screening.

Am-241	Am-245	Ar-39	Bk-247	Bk-249	C-14	Ca-41	Cd-113
Cf-253	Cl-36	Cm-249	Cs-135	Es-253	Fm-257	H-3	I-129
K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236	Np-237
Pd-107	Pt-190	Pt-193	Pu-241	Rb-87	Re-186m	Re-187	Si-32
Sr-90	Tc-97	Tc-98	Tc-99	U-235	U-237		

[a] The four radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.4.4 Tier-2 NRCDAS Radionuclides that Failed Screening

Radionuclides that failed Tier-2 NRCDA (special) GW screening are shown in Table 4-15. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – no screening performed; and

- **Groundwater** - 122 reduced to 31.

Table 4-15. Radionuclides[a] (31) that failed Tier-2 NRCDA (special) groundwater screening.

Am-241	Am-245	Ar-39	Be-10	Bk-247	C-14	Ca-41	Cf-253
Cl-36	Cm-249	Es-253	Fm-257	I-129	K-40	Kr-81	Ni-59
Ni-63	Np-235	Np-236	Np-237	Pa-231	Pt-190	Pu-241	Rb-87
Re-186m	Re-187	Si-32	Tc-97	Tc-98	Tc-99	U-235	

[a] The three radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

4.4.5 Tier-2 Generic Trench Radionuclides that Failed Screening

Radionuclides that failed Tier-2 Generic Trench GW screening are shown in Table 4-16. Remaining radionuclides after screening are:

- **Inadvertent Intruder** – no screening performed; and
- **Groundwater** - 163 reduced to 43.

Table 4-16. Radionuclides[a] (43) that failed Tier-2 Generic Trench groundwater screening.

Ag-108m	Am-241	Am-245	Be-10	Bk-249	C-14	Cf-249	Cf-253
Cl-36	Cm-245	Cm-249	Cs-135	Cs-137	Es-253	Fm-257	H-3
I-129	K-40	Kr-81	Mn-53	Ni-59	Ni-63	Np-235	Np-236
Np-237	Pa-231	Pd-107	Pt-190	Pu-239	Pu-241	Ra-226	Rb-87
Re-186m	Re-187	Si-32	Sr-90	Tc-97	Tc-98	Tc-99	Th-230
Th-231	U-234	U-235					

[a] The four radionuclides shaded in orange are heavy elements that can also be screened out based on the post-analysis provided in Appendix L.

5.0 Implementation of Trigger Values

As mentioned throughout various sections of this report, the use of trigger values is not required; however, its use may be deemed useful. The complete radionuclide listings in Section 4.3 for Inadvertent Intruder and Section 4.4 for Groundwater are acceptable and no trigger-value radionuclides are required. Trigger-value candidates are possible on the basis of:

- **Disposal Unit Type** – ILV, LAWV, NRCDAG, NRCDAS or Generic Trench; and
- **Category** – Inadvertent Intruder or Groundwater.

These recommended trigger-value radionuclides can be used individually or by combining either DU type values or category values. No matter which options are employed the resulting limits system will be acceptable from a radiological perspective. The actual trigger values (in Ci) provided do not address any co-mingling of contaminant plumes from neighboring DUs; therefore, these values represent:

- "preliminary" trigger values for GW considerations since aquifer plume overlap typically occurs; and
- "final" trigger values for inadvertent intruder considerations since exposure scenarios do not involve either the aquifer or the atmosphere.

Trigger values were created for every radionuclide contained within the complete listings (i.e., Section 4.3 and Section 4.4) that does not currently have a WITS inventory. The GW trigger values provided in this report are "preliminary" values where the impacts associated with plume overlap (i.e., the co-mingling of contaminant plumes emanating out from neighboring DUs) have not been included. In a follow up report addressing plume interaction factors (PIF), these preliminary trigger values will be adjusted downward to account for plume overlap. SRNL recommends using all of these trigger-value radionuclides and their corresponding trigger values once adjusted by appropriate PIFs, since this reduces the subsequent Tier-3 and Tier-4 analyses efforts to a minimum. Since all inadvertent intruder exposure scenarios do not involve either the aquifer or the atmosphere, the inadvertent intruder trigger values are final values.

In this chapter the lists of radionuclides and their corresponding trigger values are provided, along with the reduced screening lists where all trigger-value radionuclides were removed.

5.1 Trigger-value radionuclide lists by Disposal Unit Type

For each of the five DU types (i.e., ILV, LAWV, NRCDAG, NRCDAS, and Generic Trench) and each category (i.e., In advertent Intruder and Groundwater), the recommended radionuclides to have trigger values and their inventory values (Ci) are provided in the following set of ten tables.

5.1.1 Inadvertent Intruder Tier-1 List Reduction

In Sections 4.3.1 through 4.3.5 the recommended Tier-1 radionuclide lists for Inadvertent Intruder are provided on a DU type basis. The following tables (i.e., Table 5-1 through Table 5-5) have the corresponding listing of radionuclides with final trigger values in Curies.

Table 5-1. Radionuclides (27) with trigger values for ILV inadvertent intruder screening.

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Ac-227	1.13E+05	Fe-60	1.79E+00	Nb-92	1.63E+01	Re-186m	1.21E+05
Al-26	6.90E-01	Hf-182	5.06E+00	Np-236	2.81E+00	Tb-158	3.58E+01
Bi-207	2.05E+02	Hg-194	3.36E+00	Pa-231	4.90E+02	Tc-98	3.35E+01
Bi-208	1.23E-01	Ho-166m	2.46E+01	Pa-232	3.69E+04	Th-229	6.30E+01
Bi-210m	2.98E+03	Ir-192n	1.28E+03	Pb-202	1.80E+04	Ti-44	3.67E+01
Cm-250	1.50E+02	La-138	2.92E+00	Po-209	1.19E+04	V-50	1.63E+00
Eu-150	3.79E+02	Nb-91	2.84E+05	Pu-236	4.44E+01		

Table 5-2. Radionuclides (20) with trigger values for LAWV inadvertent intruder screening.

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Ac-227	6.40E+05	Hf-182	2.87E+01	Nb-92	9.26E+01	Pu-236	2.52E+02
Al-26	3.91E+00	Hg-194	1.90E+01	Np-236	1.59E+01	Re-186m	6.87E+05
Bi-208	6.96E-01	Ho-166m	1.40E+02	Pa-231	2.78E+03	Tb-158	2.03E+02
Cm-250	8.48E+02	Ir-192n	7.24E+03	Pb-202	1.02E+05	Tc-98	1.90E+02
Fe-60	1.02E+01	La-138	1.65E+01	Po-209	6.72E+04	Ti-44	2.08E+02

Table 5-3. Radionuclides (28) with trigger values for NRCDAG inadvertent intruder screening.

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Al-26	5.73E-02	Eu-152	6.91E+03	La-138	2.22E-01	Pu-236	7.93E+00
Bi-207	3.65E+01	Fe-60	1.33E-01	Nb-91	2.52E+04	Re-186m	7.23E+03
Bi-208	1.20E-02	Hf-182	3.66E-01	Nb-92	1.05E+00	Tb-158	6.38E+00
Bi-210m	1.51E+02	Hg-194	5.99E-01	Np-236	2.72E-01	Tc-98	1.98E+00
Bk-247	1.79E+06	Ho-166m	2.24E+00	Pa-232	6.59E+03	Th-229	5.21E+00
Cm-250	1.08E+01	Ir-192n	2.28E+02	Pb-202	5.24E+02	Ti-44	6.54E+00
Eu-150	6.76E+01	K-40	1.29E+00	Po-209	2.12E+03	V-50	1.29E-01

Table 5-4. Radionuclides (62) with trigger values for NRCDAS inadvertent intruder screening.

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Ac-227	1.10E-01	Es-254 [a]	2.49E+02	Np-235	3.18E+05	Ra-226	1.01E-04

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Al-26	5.95E-05	Eu-150	2.87E-03	Np-236	5.93E-04	Ra-228	4.71E+04
Am-245	9.95E+04	Fe-60	6.39E-05	Np-238	5.13E+05	Re-186m	1.02E-02
Am-246m	4.46E+06	Fm-254 [a]	5.13E+05	Os-194	7.02E+05	Rn-222	2.02E+05
Bi-207	4.09E-03	Fm-257 [a]	1.04E+00	Pa-231	4.42E-04	Sm-145	6.28E+02
Bi-208	5.56E-05	Hf-182	1.14E-04	Pa-232	1.12E+01	Tb-157	1.22E+00
Bi-210m	7.49E-04	Hg-194	2.15E-04	Pa-233	1.40E+04	Tb-158	4.23E-04
Bk-247	1.76E-03	Ho-166m	1.21E-04	Pb-202	4.29E-04	Tc-97	1.78E+00
Bk-250	5.17E+05	Ir-192n	3.75E-04	Pb-210	9.52E+01	Tc-98	1.22E-04
Cf-248	3.20E+04	K-40	9.84E-04	Pm-145	3.49E+01	Te-123	1.22E+02
Cf-250	1.45E+01	Kr-81	2.37E-01	Pm-146	4.86E+05	Th-229	6.93E-04
Cf-252	1.63E+01	La-137	9.19E-02	Po-208	3.17E+05	Th-230	2.38E-04
Cf-253[a]	5.85E+00	La-138	1.30E-04	Po-209	9.44E-02	Ti-44	5.55E-04
Cm-249	2.34E+03	Lu-176	4.31E-04	Pu-236	1.35E-02	V-50	1.10E-04
Cm-250	1.90E-03	Nb-91	1.28E-01	Pu-243	1.52E+04		
Es-253 [a]	5.09E+00	Nb-92	1.14E-04	Pu-246	7.14E+03		

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

Table 5-5. Radionuclides (56) with trigger values for Generic Trench inadvertent intruder screening.

Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)	Radionuclide	Trigger Value (Ci)
Bi-208	6.16E-04	Gd-148	4.18E+02	Mn-53	9.73E+01	Pu-243	1.73E+05
Bi-210m	7.78E-03	Gd-150	8.63E-01	Nb-91	1.84E+00	Re-186m	8.94E-02
Bk-249 [a]	5.70E+00	Gd-152	1.10E+00	Nb-92	1.26E-03	Re-187	3.23E+02
Cf-248	2.61E+04	Hf-174	2.41E+00	Nd-144	1.11E+00	Si-32	1.98E+01
Cf-253 [a]	1.06E+02	Hf-178m	3.20E+02	Np-235	3.36E+06	Sm-146	8.33E-01
Cm-249	4.23E+04	Hf-182	1.26E-03	Np-236	6.44E-03	Sm-147	9.13E-01
Cm-250	1.32E-02	Hg-194	3.55E-03	Os-186	9.09E-01	Sm-148	1.06E+00
Dy-154	8.04E-01	Ho-163	1.82E+04	Pa-232	1.57E+03	Tb-157	1.59E+02
Es-253 [a]	9.21E+01	In-115	2.68E+01	Pb-202	4.77E-03	Tb-158	1.24E-02
Es-254 [a]	2.92E+03	Ir-192n	8.59E-03	Pm-145	2.85E+06	Tc-97	1.51E-01
Eu-150	2.61E+00	Kr-81	2.62E+00	Po-208	3.51E+06	Tc-98	1.10E-03
Fe-60	7.03E-04	La-137	1.02E+00	Po-209	5.80E+00	Te-123	2.95E+00
Fm-254 [a]	5.97E+06	La-138	1.44E-03	Pt-190	4.84E+00	Ti-44	1.13E-01
Fm-257 [a]	1.88E+01	Lu-176	4.76E-03	Pu-236	1.89E+00	V-50	1.21E-03

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

5.1.2 Groundwater Tier-2 List Reduction

In Sections 4.4.1 through 4.4.5 the recommended Tier-1 radionuclide lists for Groundwater are provided on a DU type basis. The following tables (i.e., Table 5-6 through Table 5-10) have the corresponding listing of radionuclides with preliminary trigger values in Curies.

Table 5-6. Radionuclides (25) with preliminary trigger values for ILV groundwater screening.

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Am-245	1.52E+04	Cm-249	6.58E+04	Np-236	9.53E-08	Si-32	1.11E-07
Be-10	3.64E-06	Cs-135	3.50E-06	Pa-231	2.61E-08	Tc-97	5.68E-06
Bk-247	3.43E+04	Es-253 [a]	1.43E+02	Pd-107	1.07E-04	Tc-98	5.77E-07
Bk-249 [a]	8.91E+00	Fm-257 [a]	2.93E+01	Pt-190	5.75E-08	U-237	3.01E+00
Ca-41	1.92E-05	Kr-81	3.45E-01	Rb-87	1.17E-06		
Cd-113	1.61E-06	Mn-53	1.02E-03	Re-186m	1.76E-07		
Cf-253 [a]	1.65E+02	Np-235	2.99E+01	Re-187	8.52E-06		

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

Table 5-7. Radionuclides (20) with preliminary trigger values for LAWV groundwater screening.

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Be-10	2.45E-05	Fm-257 [a]	1.75E+02	Pa-231	9.62E-08	Re-187	5.74E-05
Bk-249 [a]	5.34E+01	Kr-81	2.33E+00	Pd-107	7.24E-04	Si-32	7.33E-07
Cd-113	1.76E-06	Mn-53	1.12E-03	Pt-190	3.88E-07	Tc-97	3.83E-05
Cf-253 [a]	9.86E+02	Np-235	1.10E+02	Rb-87	7.76E-06	Tc-98	3.89E-06
Es-253 [a]	8.58E+02	Np-236	3.55E-07	Re-186m	1.19E-06	U-237	1.12E+01

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

Table 5-8. Radionuclides (25) with preliminary trigger values for NRCDAG groundwater screening.

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Am-245	1.04E+04	Cm-249	4.70E+04	Np-236	1.00E-07	Si-32	3.20E-08
Ar-39	1.89E-01	Es-253 [a]	1.02E+02	Pd-107	6.64E-05	Tc-97	3.51E-06
Bk-247	2.70E+04	Fm-257 [a]	2.09E+01	Pt-190	3.55E-08	Tc-98	3.56E-07
Bk-249 [a]	6.37E+00	K-40	4.27E-07	Pt-193	5.82E-02	U-237	3.16E+00

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Ca-41	1.19E-05	Kr-81	2.13E-01	Rb-87	7.29E-07		
Cd-113	2.97E-06	Mn-53	1.88E-03	Re-186m	1.09E-07		
Cf-253 [a]	1.18E+02	Np-235	3.17E+01	Re-187	5.27E-06		

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

Table 5-9. Radionuclides (20) with preliminary trigger values for NRCDAS groundwater screening.

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Am-245	1.13E+04	Cm-249	5.20E+04	Np-235	4.22E+01	Re-186m	1.22E-07
Ar-39	1.32E+00	Es-253 [a]	1.13E+02	Np-236	1.37E-07	Re-187	5.89E-06
Bk-247	3.12E+04	Fm-257 [a]	2.31E+01	Pa-231	3.75E-08	Si-32	1.67E-06
Ca-41	3.21E-04	K-40	1.15E-05	Pt-190	3.94E-03	Tc-97	3.93E-06
Cf-253 [a]	1.30E+02	Kr-81	2.14E-01	Rb-87	2.78E+05	Tc-98	3.99E-07

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

Table 5-10. Radionuclides (16) with preliminary trigger values for Generic Trench groundwater screening.

Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)	Radionuclide	Preliminary Trigger Value (Ci)
Am-245	1.51E+04	Es-253 [a]	1.59E+02	Np-235	2.00E+01	Re-187	1.10E-05
Bk-249 [a]	9.86E+00	Fm-257 [a]	3.24E+01	Np-236	6.73E-08	Si-32	5.22E-08
Cf-253	1.82E+02	Kr-81	4.46E-01	Pt-190	7.42E-08	Tc-97	7.33E-06
Cm-249 [a]	7.28E+04	Mn-53	1.77E-04	Re-186m	2.27E-07	Tc-98	7.44E-07

[a] Could also be eliminated based on the heavy element analyses presented in Appendix L.

5.2 Reduced Radionuclide lists by Disposal Unit Type

For each of the five DU types (i.e., ILV, LAWV, NRCDAG, NRCDAS, and Generic Trench) and each category (i.e., In advertent Intruder and Groundwater), the recommended radionuclide lists are provided where every trigger-value radionuclide has been removed. These are the minimum listings requiring subsequent Tier-3 and/or Tier-4 limits analyses. The total number of radionuclides remaining for both categories and each of the five DU types is provided in Table 5-11. The three lists presented in Table 5-11 refer to:

- **Complete List** – Number of radionuclides prior to removal of trigger-value radionuclides;

- **Trigger List** – Number of radionuclides with trigger values (i.e., the number of radionuclides without WITS inventories that were not screened out in Tier-1 for Inadvertent Intruder or Tier-2 for Groundwater); and
- **Reduced List** - Number of radionuclides after removal of trigger-value radionuclides.

Table 5-11. Summary of the total number of radionuclides remaining after removing the trigger-value radionuclides.

Category	DU Type	Complete List	Trigger List	Reduced List
Inadvertent Intruder	ILV	29	27	2
	LAWV	20	20	0
	NRCDAG	29	28	1
	NRCDAS	75 (70)[a]	62 (57)[a]	13 (13)[a]
	Trench	88 (82)[a]	56 (50)[a]	32 (32)[a]
Groundwater	ILV	45 (41)[a]	25 (21)[a]	20 (20)[a]
	LAWV	39 (35)[a]	20 (16)[a]	19 (19)[a]
	NRCDAG	38 (34)[a]	25 (21)[a]	13 (13)[a]
	NRCDAS	31 (28)[a]	20 (17)[a]	11 (11)[a]
	Trench	43 (39)[a]	16 (12)[a]	27 (27)[a]

[a] Total number after eliminating heavy elements consistent with the analyses presented in Appendix L.

As Table 5-11 indicates, for the GW category the final reduced list is not impacted by the elimination of heavy elements, while the trigger list is (since these heavy elements had already been screened out).

5.2.1 Reduced Inadvertent Intruder Tier-1 Lists

In Sections 4.3.1 through 4.3.5 the complete Tier-1 radionuclide lists for Inadvertent Intruder are provided on a DU type basis. The following tables (i.e., Table 5-12 through Table 5-16) have the corresponding reduced radionuclides listings where every trigger-value radionuclide has been removed.

Table 5-12. Radionuclides (2) after removal of trigger-value radionuclides for ILV inadvertent intruder.

Cs-137	Ra-226

Table 5-13. Radionuclides (0) after removal of trigger-value radionuclides for LAWV inadvertent intruder screening.

none

Table 5-14. Radionuclides (1) after removal of trigger-value radionuclides for NRCDAG inadvertent intruder screening.

Nb-94

Table 5-15. Radionuclides (13) after removal of trigger-value radionuclides for NRCDAS inadvertent intruder screening.

Am-241	Am-243	Co-60	Cs-137	Mo-93	Nb-93m	Nb-94	Ni-59
Pu-241	Sn-121m	Sn-126	Sr-90	Zr-93			

Table 5-16. Radionuclides (32) after removal of trigger-value radionuclides for Generic Trench inadvertent intruder screening.

Ag-108m	Am-241	Am-242m	Am-243	C-14	Cf-249	Cf-251	Cm-247
Cm-248	Cs-137	I-129	K-40	Nb-94	Ni-59	Ni-63	Np-237
Pu-239	Pu-240	Pu-241	Ra-226	Sn-126	Sr-90	Tc-99	Th-229
Th-230	Th-232	U-232	U-233	U-234	U-235	U-236	U-238

5.2.2 Reduced Groundwater Tier-2 Lists

In Sections 4.4.1 through 4.4.5 the complete Tier-1 radionuclide lists for Groundwater are provided on a DU type basis. The following tables (i.e., Table 5-17 through Table 5-21) have the corresponding reduced radionuclides listings where every trigger-value radionuclide has been removed.

Table 5-17. Radionuclides (20) after removal of trigger-value radionuclides for ILV groundwater screening.

Ag-108m	Am-241	Ar-39	C-14	Cf-249	Cl-36	Cm-245	Cs-137
H-3	I-129	K-40	Ni-59	Ni-63	Np-237	Pu-239	Pu-241
Ra-226	Sr-90	Tc-99	U-235				

Table 5-18. Radionuclides (19) after removal of trigger-value radionuclides for LAWV groundwater screening.

Ag-108m	Am-241	C-14	Ca-41	Cl-36	Cm-245	Cs-137	H-3
I-129	K-40	Ni-59	Ni-63	Np-237	Pu-239	Pu-241	Ra-226
Sr-90	Tc-99	U-235					

Table 5-19. Radionuclides (13) after removal of trigger-value radionuclides for NRCDAG groundwater screening.

Am-241	C-14	Cl-36	Cs-135	H-3	I-129	Ni-59	Ni-63

Np-237	Pu-241	Sr-90	Tc-99	U-235

Table 5-20. Radionuclides (11) after removal of trigger-value radionuclides for NRCDAS groundwater screening.

Am-241	Be-10	C-14	Cl-36	I-129	Ni-59	Ni-63	Np-237
Pu-241	Tc-99	U-235					

Table 5-21. Radionuclides (27) after removal of trigger-value radionuclides values for Generic Trench groundwater screening.

Ag-108m	Am-241	Be-10	C-14	Cf-249	Cl-36	Cm-245	Cs-135
Cs-137	H-3	I-129	K-40	Ni-59	Ni-63	Np-237	Pa-231
Pd-107	Pu-239	Pu-241	Ra-226	Rb-87	Sr-90	Tc-99	Th-230
Th-231	U-234	U-235					

6.0 Conclusions, Recommendations, Path Forward, and Future Work

The Tier-0 list of radionuclides are recommended for the Tier-1 inadvertent intruder and GW radionuclide screening for all DUs. The Tier-1 lists of inadvertent intruder radionuclides that failed screening are recommended for the next revision of the ELLWF PA. The Tier-1 list for the NRCDA includes separate lists for generic and special waste forms (NRCDAG and NRCDAS).

Because the NCRP123 screening model is the methodology for radionuclide screening commonly used in the DOE complex, SRNL recommends the enhanced version of NCRP123 developed in this study for GW screening (e.g., enhanced to take into account site-specific features). SRNL recommended using this enhanced NCRP123 model for establishing the Tier-1 GW and inadvertent intruder radionuclide lists for every DU type.

To include fate and transport aspects into the screening model, SRNL compared:

- The NRCDWSM model that provides, beyond the NCRP123 model, additional storage and leaching mechanisms from a single-cell unsaturated-soil zone between the waste and aquifer; and
- The PorflowPS model that explicitly adds a 1D multi-cell unsaturated-soil zone between the waste and aquifer.

Because of the large number of radionuclides retained from the GW Tier-1 screening effort, SRNL recommended using the PorflowPS model for the subsequent GW Tier-2 screening. The resulting list of radionuclides that failed Tier-2 GW screening, based on the PorflowPS model, for all DUs are recommended for the Tier-3 and Tier-4 GW analyses in the ongoing PA2022.

Though not required, SRNL recommends further reducing Tier-3 and Tier-4 PA lists by continuing the use of trigger values for the reasons discussed in Section 2.6 for the lists of radionuclides proposed in Chapter 5.0. SWM currently is tracking a subset of PA2008 radionuclides with trigger-values. In the PA2022, SWM has the option to eliminate use of all, some, or none of the trigger-value list proposed in Chapter 5.0. Practical consideration would argue against expanding the use of trigger values to those isotopes routinely generated and received in E-Area. SRNL will proceed with Tier-3 and/or Tier-4 analyses of the lists of radionuclides selected by SWM.

All radionuclides requiring explicit tracking, having inventory limits or trigger values, are contained within the Tier-1 lists for Inadvertent Intruder and Tier-2 lists for Groundwater as presented in Chapter 4.0.

6.1 Future Work

The final Tier-1 and Tier-2 radionuclide listings for each DU type presented in Chapter 4.0 can potentially be further reduced if additional "process knowledge" is considered. For example,

- **Noble Gases** – low solubility within the liquid-phase;
- **Heavy Elements** – low production yields in weapons-grade Pu production reactor operations (i.e., initial focus on this aspect resulted in a reduction of six heavy elements but others could also be considered in the future if warranted);
- **Fission Products** – low fission yields by mass number for many elements; and
- **Neutron Activation Products** – some neutron activation products result from trace amounts of various impurities.

If warranted these potential list reductions can be considered and if reductions are possible, this report could be updated to reflect the reduced lists. Some initial supporting material for addressing these aspects is provided in Appendix L where six heavy elements were found that could be eliminated from further considerations (i.e., be considered "screened out").

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Appendix A. Derivation of Water and Soil Radionuclide Balances in Soils with Leaching

Consider a region of porous soil with volume V and cross-sectional area A illustrated in Figure A-1. The soil contains water and solid phases contaminated with radionuclides. Infiltration of clean water occurs at rate *I* (volume/area/time). Within the volume, the concentration of radioactive species j is $C_{w,j}(t)$ in the water phase and $C_{s,j}(t)$ in the soil. The flux of radionuclide out of the volume is at the infiltration rate *I* with concentration $\{c_{w,j}(t)\}_{out}$.

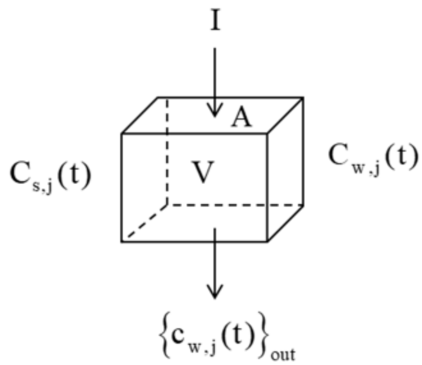


Figure A-1. Volume of contaminated soil.

Taking a lumped parameter approach, the rates of change of radionuclide in the liquid and solid phases within the soil volume are given by the equations:

$$\frac{d(\alpha_w V C_{w,j})}{dt} = \alpha_w V \sum_{i=1}^{j-1} b_{ji}\lambda_i C_{w,i} - \alpha_w V \lambda_j C_{w,j} - IA\{c_{w,j}(t)\}_{out} + F_j \tag{A-1}$$

$$\frac{d(\alpha_s \rho_s V C_{s,j})}{dt} = \alpha_s \rho_s V \sum_{i=1}^{j-1} b_{ji}\lambda_i C_{s,i} - \alpha_s \rho_s V \lambda_j C_{s,j} - F_j \tag{A-2}$$

where

α_w, α_s ....water and solid volume fractions (-)
λ_j ....radioactive decay constant (1/y)
ρ_s ....solid material density (g/ml)
A ....cross-sectional or projected area of soil layer (m^2)
b_{ji} ....effective branching or regeneration fractions (• 1)
$\{c_{w,j}(t)\}_{out}$ ....concentration of radionuclide j in outlet stream (atoms/m^3)
$C_{w,j}(t)$ ....concentration of radionuclide j in water phase (atoms/m^3)
$C_{w,i}(t)$ ....concentration of precursor radionuclide i in water phase (atoms/m^3)
$C_{s,j}(t)$ ....concentration of radionuclide j in solid phase (atoms/g)
$C_{s,i}(t)$ ....concentration of precursor radionuclide i in solid phase (atoms/g)
F_j ....rate of transfer of radionuclide j from solid to water phase (atoms/yr)

I .... infiltration rate of clean water, (m/y)
i .... index of radionuclide precursors in the decay chain
j .... index of decay chain radionuclide (j=1 is the parent)
V .... total volume of soil layer, solid + water + gas (m^3)

Defining ϕ as solid porosity, $\theta_w = S_w \phi$, where θ_w is moisture content and S_w is water saturation. The solid fraction is then $\alpha_s = 1 - \phi$. When water saturation is less than one, a gas phase is present. However; this gas phase represents a small mass of material and is neglected so that $\alpha_w = \theta_w$. Using a lumped parameter approach, it is assumed that the material volume is well mixed and the concentration of radionuclide in the outlet stream is the same as the concentration within the liquid volume:

$$\{c_{w,j}(t)\}_{out} = C_{w,j}(t) \tag{A-3}$$

It is also assumed that the radionuclide concentration in the solid phase is in equilibrium with the concentration in the liquid phase and the equilibrium is represented by a linear k_d dependence:

$$C_{s,j}(t) = k_{d,j} C_{w,j}(t) \tag{A-4}$$

where

$k_{d,j}$ .... solid-liquid equilibrium constant for radionuclide j (ml/g)

Introducing assumptions (A-3) and (A-4) into (A-1) and (A-2) and adding the resulting equations eliminates the solid-water transfer rate and gives a single equation:

$$\frac{d(\{\theta_w + \alpha_s \rho_s k_{d,j}\} V C_{w,j})}{dt} = \sum_{i=1}^{j-1} \{\theta_w + \alpha_s \rho_s k_{d,i}\} V b_{ji} \lambda_i C_{w,i} - \{\theta_w + \alpha_s \rho_s k_{d,j}\} V \lambda_j C_{w,j} - IAC_{w,j} \tag{A-5}$$

Introducing the retardation factor R_j and defining the effective concentration of radionuclide j in the porous matrix per total volume of soil $C_{e,j}$, (A-5) can be expressed as:

$$\frac{d(VC_{e,j})}{dt} = \sum_{i=1}^{j-1} b_{ji} \lambda_i V C_{e,i} - \lambda_j V C_{e,j} - IAC_{w,j} \tag{A-6}$$

where

$$R_j = 1 + \frac{\rho_s (1-\phi) k_{d,j}}{\theta_w} = 1 + \frac{\rho_b k_{d,j}}{\theta_w} \tag{A-7}$$

$$C_{e,j} = \theta_w R_j C_{w,j} \tag{A-8}$$

In (A-7), the product of solid density and porosity is replaced with the solid bulk density ρ_b.

The total number of atoms of radionuclide j in the porous matrix is defined as

$$N_j = VC_{e,j} \tag{A-9}$$

The concentration of radionuclide j in the water phase $C_{w,j}$ can now be related to the total number of atoms N_j using (A-8) and (A-9) as:

$$C_{w,j} = \frac{N_j}{\theta_w R_j V} \tag{A-10}$$

Substituting the expressions in (A-9) and (A-10) into (A-6) yields:

$$\frac{dN_j}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - \frac{IA}{\theta_w R_j V} N_j = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - \frac{I}{\theta_w R_j H} N_j \tag{A-11}$$

where

H .... thickness or height of soil layer (m)

The leach rate in (A-11) is defined for each radionuclide j as:

$$L_j = \frac{I}{\theta_w R_j H} \tag{A-12}$$

Update of (A-11) with the expression from (A-12) leads to:

$$\frac{dN_j}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - L_j N_j \tag{A-13}$$

In a multilayer soil model, leachate from an overlying soil layer can enter another unsaturated (vadose) or saturated soil layer (aquifer). To accommodate such a mass transfer mechanism, we add the leachate term as a source term to (A-13).

In the NCRP123 model, we designate the overlying soil layer as 1 and the saturated soil layer (aquifer) as 2. The new set of radionuclide balance equations for the NCRP123 model are written as:

$$\frac{dN_{1j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1i} - \lambda_j N_{1j} - L_{12j} N_{1j} \tag{A-14}$$

$$\frac{dN_{2j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{2i} + L_{12j} N_{1j} - \lambda_j N_{2j} \tag{A-15}$$

where

N_{1j} .... atom count of radionuclide j in soil layer 1

N_{1i} .... atom count of precursor radionuclide i in soil layer 1

N_{2j} .... atom count of radionuclide j in soil layer 2 (aquifer)

N_{2i} .... atom count of precursor radionuclide i in soil layer 2 (aquifer)

L_{12j} .... leach rate of radionuclide j from soil 1 to soil 2 (1/y)

In the NRCDWSM (3-box) model, we designate the surface-soil layer as 1, the unsaturated-soil layer as 2 and the GW aquifer as 3. The new set of radionuclide balance equations for NRCDWSM model are written as:

$$\frac{dN_{1j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1i} - \lambda_j N_{1j} - L_{12j} N_{1j} \tag{A-16}$$

$$\frac{dN_{2j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{2i} + L_{12j} N_{1j} - \lambda_j N_{2j} - L_{23j} N_{2j} \tag{A-17}$$

$$\frac{dN_{3j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{3i} + L_{23j} N_{2j} - \lambda_j N_{3j} - w_d N_{3j} \tag{A-18}$$

where

N_{1j} ....atom count of radionuclide j in surface-soil layer 1
N_{1i} ....atom count of precursor radionuclide i in surface-soil layer 1
N_{2j} ....atom count of radionuclide j in unsaturated-soil layer 2
N_{2i} ....atom count of precursor radionuclide i in unsaturated-soil layer 2
N_{3j} ....atom count of radionuclide j in soil layer 3 (aquifer)
N_{3i} ....atom count of precursor radionuclide i in soil layer 3 (aquifer)
L_{12j} ....leach rate of radionuclide j from soil 1 to soil 2 (1/y)
L_{23j} ....leach rate of radionuclide j from soil 2 to soil 3 (1/y)
w_d ....rate constant for aquifer dilution (1/y)

In the PorflowPS model, a version of (A-18) is used where the leachate term ($L_j N_j$) is replaced by the flux to the watertable computed by PORFLOW as:

$$\frac{dN_j}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - w_d N_j + f_j(t) \tag{A-19}$$

where

N_j ....atom count of radionuclide j in aquifer, gmol
N_i ....atom count of precursor radionuclide i in aquifer, gmol
$f_j(t)$ ....flux to the watertable (PORFLOW) of radionuclide j, gmol/yr

Appendix B. Numerical Solution of Radionuclide Balances in Multilayer Soils

This general radioactive decay problem describes the decay of an initial quantity, e.g. Pu-241, where the full chain has been reduced to a short chain with progeny half-lives greater than 1 year. The parent nuclide decays through two chains of four progeny (Am-241, Np-237, U-233 and Th-229). Green shading is the stable nuclide, Bi-209.

Pu-241 $t_{1/2}$ = 1.435E+01	Am-241 $t_{1/2}$ = 4.322E+02	Np-237 $t_{1/2}$ = 2.144E+06	U-233 t1/2 = 1.592E+05	Th-229 $t_{1/2}$ = 7.340E+03	*Bi-209*
	0.9999755	1	1	1	1
	Np-237 t1/2 = 2.144E+06	U-233 t1/2 = 1.592E+05	Th-229 $t_{1/2}$ = 7.340E+03	*Bi-209*	
	0.0000245	1	1	1	

The radioactive decay problem for the Pu-241 decay can be represented as a lower-triangular matrix as:

$$\begin{pmatrix} \dot{N}_1(t) \\ \dot{N}_2(t) \\ \dot{N}_3(t) \\ \dot{N}_4(t) \\ \dot{N}_5(t) \end{pmatrix} + \begin{pmatrix} \lambda_1 & 0 & 0 & 0 & 0 \\ -b_{21}\lambda_1 & \lambda_2 & 0 & 0 & 0 \\ -b_{31}\lambda_1 & -b_{32}\lambda_2 & \lambda_3 & 0 & 0 \\ 0 & 0 & -b_{43}\lambda_3 & \lambda_4 & 0 \\ 0 & 0 & 0 & -b_{54}\lambda_4 & \lambda_5 \end{pmatrix} \begin{pmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ N_4(t) \\ N_5(t) \end{pmatrix} = \dot{\vec{N}}(t) + \Lambda\vec{N}(t) = 0 \quad \text{(B-1)}$$

NCRP123 Screening Model

The NCRP123 model consists of first-order removal (leaching) of radionuclides from the waste zone to the aquifer zone. The radionuclide screening model approach utilizes a series of bake times (no leaching) followed by leaching at a constant infiltration of water through the waste zone. During the bake period in the waste zone, the homogenous (B-1) is solved for atom numbers of the chain with radioactive decay and branching. Once leaching has started, the lambda matrix Λ is augmented on the diagonal by the leach rate of each radionuclide as:

$$\tilde{\Lambda}_{12} = \begin{pmatrix} L_{121} & 0 & 0 & 0 & 0 \\ 0 & L_{122} & 0 & 0 & 0 \\ 0 & 0 & L_{123} & 0 & 0 \\ 0 & 0 & 0 & L_{124} & 0 \\ 0 & 0 & 0 & 0 & L_{125} \end{pmatrix} \quad \text{(B-2)}$$

Adding the contribution of (B-2) to Eq. (B-1) with leaching yields:

$$\dot{\vec{N}}_1(t) + (\Lambda + \tilde{\Lambda}_{12})\vec{N}_1(t) = 0 \quad \text{(B-3)}$$

where

$\vec{N}_1(t)$ ....atom count of short chain in waste zone, soil layer 1
Λ ....radioactive decay and regeneration matrix
$\tilde{\Lambda}_{12}$ ....leach rate matrix from soil layer 1 to 2

The solution of (B-3) that incorporates a delayed start of leaching, t_r, is given by the following set of equations

$$\begin{aligned} \vec{N}_1(t) &= e^{-\Lambda t}\vec{N}_1(0) \qquad t \le t_r \\ \vec{N}_1(t) &= e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \quad t > t_r \\ \vec{N}_1(0) &= \left\{10^{12}\text{pCi}/\lambda_1 \quad 0 \quad 0 \quad 0 \quad 0\right\} \end{aligned} \tag{B-4}$$

The matrix exponential method Harr (2007) is used to solve the system of linear first order differential equations with constant coefficients in (B-4).

The members of the radionuclide chain formed in the aquifer zone by leaching and decay satisfy the following nonhomogeneous differential equation

$$\dot{\vec{N}}_2(t) + \Lambda\vec{N}_2(t) = \tilde{\Lambda}_{12}\vec{N}_1(t) \tag{B-5}$$

where

$\vec{N}_2(t)$ .... atom count of short chain in aquifer zone, soil layer 2

The general solution of (B-5) consists of a homogeneous and a particular solution as

$$\vec{N}_2(t) = \vec{N}_{2h}(t) + \vec{N}_{2p}(t) \tag{B-6}$$

The homogeneous solution of (B-5) is

$$\begin{aligned} \vec{N}_{2h}(t) &= 0 \qquad t \le t_r \\ \vec{N}_{2h}(t) &= e^{-\Lambda(t-t_r)}\vec{C} \quad t > t_r \end{aligned} \tag{B-7}$$

The particular solution of (B-5) for $t > t_r$ should have the form of the forcing function on the RHS (leachate source term) as

$$\vec{N}_{2p}(t) = Ae^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \tag{B-8}$$

Substitution of the particular solution, (B-8), and the leachate source term from (B-4) into (B-6) yields

$$\begin{gathered} -A\left(\Lambda+\tilde{\Lambda}_{12}\right)e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \\ +\Lambda Ae^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) = \tilde{\Lambda}_{12}e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \\ -A\tilde{\Lambda}_{12}e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) = \tilde{\Lambda}_{12}e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \\ A = -I \end{gathered} \tag{B-9}$$

The general solution of (B-5) becomes

$$\vec{N}_2(t) = e^{-\Lambda(t-t_r)}\vec{C} - e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) \tag{B-10}$$

Applying the initial condition of (B-10) as $\vec{N}_2(t_r) = \vec{0}$ yields

$$\vec{C} = \vec{N}_1(t_r) \tag{B-11}$$

The general solution of the nonhomogeneous (B-5) is

$$\begin{aligned} \vec{N}_2(t) &= 0 & t \le t_r \\ \vec{N}_2(t) &= e^{-\Lambda(t-t_r)}\vec{N}_1(t_r) - e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) & t > t_r \end{aligned} \tag{B-12}$$

$\vec{N}_1(t)$ and $\vec{N}_2(t)$ are the atom counts of the short chain in the waste and aquifer zones, respectively. The atom counts are converted to activities as

$$\vec{A}_1(t) = \vec{\lambda}\vec{N}_1(t),\ \vec{A}_2(t) = \vec{\lambda}\vec{N}_2(t) \tag{B-13}$$

where

- $\vec{A}_1(t)$ .... short chain activities in waste zone (pCi/Ci)
- $\vec{A}_2(t)$ .... short chain activities in aquifer zone (pCi/Ci)
- $\vec{\lambda}$ .... short chain decay constants (1/yr)

The short chain activities in the waste zone are converted to soil concentrations as

$$\vec{C}_{wz}(t) = \vec{A}_1(t)/V_1 \tag{B-14}$$

where

- $\vec{C}_{wz}(t)$ .... short chain concentrations in waste zone (pCi/m^3/Ci)
- V_1 .... volume of waste zone, A×H (m^3)

The short chain concentrations in the waste zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The full chain concentrations for each parent radionuclide are used to compute inadvertent intruder maximum dose factors for screening.

The short chain activities in the aquifer zone are converted to concentrations as

$$\vec{C}_{az}(t) = \frac{\vec{A}_2(t)}{I \times A \times 1\,y} \tag{B-15}$$

where

- $\vec{C}_{az}(t)$ .... short chain concentrations in aquifer zone (pCi/m^3/Ci)
- A .... cross-sectional or projected area of soil layer (m^2)
- I .... infiltration rate of clean water, (m/y)

The short chain concentrations in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium) for each GW screening scenario. The maximum full chain concentrations for each parent radionuclide over all GW screening scenarios are used to compute GW pathways maximum dose factors for screening.

NRC Drinking Waste Scenario Screening Model

For the NRCDWS model (three box model), there is leaching of radionuclides from a) the surface-soil layer (box 1) to the unsaturated-soil layer (box 2) and b) the unsaturated-soil layer (Box 2) to the GW aquifer (box 3).

The solution of the surface-soil layer (box 1) atom count in (B-3) with a delayed start of leaching, t_r , is given by the following set of equations

$$\begin{aligned} \vec{N}_1(t) &= e^{-\Lambda t}\vec{N}_1(0) && t \le t_r \\ \vec{N}_1(t) &= e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) && t > t_r \\ \vec{N}_1(0) &= \left\{10^{12}\,pCi/\lambda_1 \quad 0 \quad 0 \quad 0 \quad 0\right\} \end{aligned} \tag{B-16}$$

where

$\vec{N}_1(t)$ ....atom count of short chain in soil-surface layer, box 1
Λ ....radioactive decay and regeneration matrix
$\tilde{\Lambda}_{12}$ ....leach rate matrix from box 1 to box 2

The members of the radionuclide chain formed in the unsaturated-soil layer (box 2) by leaching satisfy the following nonhomogeneous differential equation

$$\dot{\vec{N}}_2(t) + (\Lambda + \tilde{\Lambda}_{23})\vec{N}_2(t) = \tilde{\Lambda}_{12}\vec{N}_1(t) \tag{B-17}$$

where

$\vec{N}_2(t)$ ....atom count of short chain in the unsaturated-soil layer, box 2
$\tilde{\Lambda}_{23}$ ....leach rate matrix from box 2 to box 3

The general solution of (B-17) consists of a homogeneous and a particular solution as

$$\vec{N}_2(t) = \vec{N}_{2h}(t) + \vec{N}_{2p}(t) \tag{B-18}$$

The homogeneous solution of (B-17) is

$$\begin{aligned} \vec{N}_{2h}(t) &= 0 && t \le t_r \\ \vec{N}_{2h}(t) &= Ce^{-(\Lambda+\tilde{\Lambda}_{23})(t-t_r)}\vec{N}_1(t_r) && t > t_r \end{aligned} \tag{B-19}$$

The particular solution of (B-17) for $t > t_r$ should have the form of the forcing function on the RHS (leachate source term) as

$$\vec{N}_{2p}(t) = Ae^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \tag{B-20}$$

Substitution of the particular solution, (B-20), and the leachate source term from (B-16) into (B-18) yields

$$\begin{aligned} -\left(\Lambda + \tilde{\Lambda}_{12}\right)Ae^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) + (\Lambda + \tilde{\Lambda}_{23})Ae^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ = \tilde{\Lambda}_{12}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ -A(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23})e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) = \tilde{\Lambda}_{12}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ A = -\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23})^{-1} \end{aligned} \tag{B-21}$$

The general solution of (B-17) becomes

$$\vec{N}_2(t) = Ce^{-(\Lambda+\tilde{\Lambda}_{23})(t-t_r)}\vec{N}_1(t_r) - \tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \qquad \text{(B-22)}$$

Applying the initial condition of (B-22) as $\vec{N}_2(t_r) = \vec{0}$ yields

$$C = \tilde{\Lambda}_{12}(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23})^{-1} \qquad \text{(B-23)}$$

The general solution of the nonhomogeneous (B-17) is

$$\begin{aligned} &\vec{N}_2(t) = 0 && t \le t_r \\ &\vec{N}_2(t) = \tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} e^{-(\Lambda+\Lambda_{23})(t-t_r)}\vec{N}_1(t_r) && \\ &\quad -\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) && t > t_r \end{aligned} \qquad \text{(B-24)}$$

The members of the radionuclide chain formed in the GW aquifer (box 3) by leaching from the unsaturated-soil layer satisfy the following nonhomogeneous differential equation

$$\dot{\vec{N}}_3(t) + (\Lambda + W)\vec{N}_3(t) = \tilde{\Lambda}_{23}\vec{N}_2(t) \qquad \text{(B-25)}$$

where the lambda matrix Λ is augmented on the diagonal by the aquifer dilution rate constant of each radionuclide as

$$W = \begin{pmatrix} w_d & 0 & 0 & 0 & 0 \\ 0 & w_d & 0 & 0 & 0 \\ 0 & 0 & w_d & 0 & 0 \\ 0 & 0 & 0 & w_d & 0 \\ 0 & 0 & 0 & 0 & w_d \end{pmatrix} \qquad \text{(B-26)}$$

where

$\vec{N}_3(t)$ .... atom count of short chain in the GW aquifer, box 3
W .... rate constant for aquifer dilution (1/y)

The general solution of (B-25) consists of a homogeneous and a particular solution as

$$\vec{N}_3(t) = \vec{N}_{3h}(t) + \vec{N}_{3p}(t) \qquad \text{(B-27)}$$

The homogeneous solution of (B-25) is

$$\begin{aligned} &\vec{N}_{3h}(t) = 0 && t \le t_r \\ &\vec{N}_{3h}(t) = Ce^{-(\Lambda+W)(t-t_r)}\vec{N}_1(t_r) && t > t_r \end{aligned} \qquad \text{(B-28)}$$

The particular solution of (B-25) for $t > t_r$ should have the form of the forcing function on the RHS (leachate source term) as

$$\vec{N}_{3p}(t) = Ae^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r) + Be^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \qquad \text{(B-29)}$$

Substitution of the particular solution, (B-29), and the leachate source term from (B-24) into (B-27) yields

$$
\begin{aligned}
&-\left(\Lambda+\tilde{\Lambda}_{23}\right)Ae^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)-\left(\Lambda+\tilde{\Lambda}_{12}\right)Be^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)\\
&+(\Lambda+W)Ae^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)+(\Lambda+W)Be^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)\\
&=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23}\right)^{-1}e^{-(\Lambda+\Lambda_{23})(t-t_r)}\vec{N}_1(t_r)\\
&-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23}\right)^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)
\end{aligned}
\tag{B-30a}
$$

$$
\begin{aligned}
-A(\tilde{\Lambda}_{23}-W)e^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)&=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23}\right)^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)\\
A&=-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{23}-W)^{-1}\\
-B(\tilde{\Lambda}_{12}-W)e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)&=-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23}\right)^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)\\
B&=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{12}-W)^{-1}
\end{aligned}
\tag{B-30b}
$$

The general solution of (B-25) becomes

$$
\begin{aligned}
&\vec{N}_3(t)=Ce^{-(\Lambda+W)(t-t_r)}\vec{N}_1(t_r)-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{23}-W)^{-1}\\
&e^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)+\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{12}-W)^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)
\end{aligned}
\tag{B-31}
$$

Applying the initial condition of (B-31) as $\vec{N}_3(t_r)=\vec{0}$ yields

$$
\begin{aligned}
C&=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{23}-W)^{-1}-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{12}-W)^{-1}\\
&=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}\left\{(\tilde{\Lambda}_{23}-W)^{-1}-(\tilde{\Lambda}_{12}-W)^{-1}\right\}
\end{aligned}
\tag{B-32}
$$

The general solution of the nonhomogeneous (B-25) is

$$
\begin{aligned}
&\vec{N}_3(t)=0 && t\le t_r\\
&\vec{N}_3(t)=\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}\left\{(\tilde{\Lambda}_{23}-W)^{-1}-(\tilde{\Lambda}_{12}-W)^{-1}\right\}\\
&e^{-(\Lambda+W)(t-t_r)}\vec{N}_1(t_r)-\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{23}-W)^{-1} && t>t_r\\
&e^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r)+\tilde{\Lambda}_{23}\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}(\tilde{\Lambda}_{12}-W)^{-1}\\
&e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)
\end{aligned}
\tag{B-33}
$$

The case where there is no aquifer dilution, $W=0$, (B-33) becomes

$$
\begin{aligned}
&\vec{N}_3(t)=0 && t\le t_r\\
&\vec{N}_3(t)=e^{-\Lambda(t-t_r)}\vec{N}_1(t_r)-\tilde{\Lambda}_{12}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r) && t>t_r\\
&+\tilde{\Lambda}_{23}(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23})^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r)
\end{aligned}
\tag{B-34}
$$

$\vec{N}_1(t)$, $\vec{N}_2(t)$ and $\vec{N}_3(t)$ are the atom counts of the short chain in the surface-soil layer, unsaturated-soil layer and GW aquifer, respectively. The atom counts are converted to activities as

$$\vec{A}_1(t) = \vec{\lambda}\vec{N}_1(t),\ \vec{A}_2(t) = \vec{\lambda}\vec{N}_2(t),\ \vec{A}_3(t) = \vec{\lambda}\vec{N}_3(t) \tag{B-35}$$

where

$\vec{A}_1(t)$ .... short chain activities in surface-soil layer (pCi/Ci)
$\vec{A}_2(t)$ .... short chain activities in unsaturated-soil layer (pCi/Ci)
$\vec{A}_3(t)$ .... short chain activities in GW aquifer (pCi/Ci)
$\vec{\lambda}$ .... short chain decay constants (1/y)

The short chain activities in the surface-soil layer are converted to soil concentrations as

$$\vec{C}_{wz}(t) = \vec{A}_1(t) / V_1 \tag{B-36}$$

where

$\vec{C}_{wz}(t)$ .... short chain concentrations in surface-soil layer (pCi/m^3/Ci)
V_1 .... volume of surface-soil layer, A×H (m^3)

The short chain concentrations in the waste zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium). The full chain concentrations for each parent radionuclide are used to compute inadvertent intruder maximum dose factors for screening.

The short chain activities in the GW aquifer are converted to concentrations as

$$\vec{C}_{az}(t) = \frac{\vec{A}_3(t)}{I \times A \times 1\ \text{yr}} \tag{B-37}$$

where

$\vec{C}_{az}(t)$ .... short chain concentrations in aquifer zone (pCi/m^3/Ci)
A .... cross-sectional or projected area of soil layer (m^2)
I .... infiltration rate of clean water, (m/y)

The short chain concentrations in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium) for each GW screening scenario. The maximum full chain concentrations for each parent radionuclide over all GW screening scenarios are used to compute GW pathways maximum dose factors for screening.

PorflowPS Screening Model

The PorflowPS model consists of fluxes from a PORFLOW 1D vadose zone transport model to a modified aquifer soil layer with radioactive decay, branching and aquifer dilution.

The ordinary differential equation form of the radionuclide balance in the aquifer model, (A-19), is

$$\frac{dN_j}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_i - \lambda_j N_j - w_d N_j + f_j(t) \tag{B-38}$$

Recasting (B-38) in vector-matrix form as

$$\dot{\vec{N}}(t) + (\Lambda + W)\vec{N}(t) = \vec{F}(t), \quad \vec{N}(0) = \vec{0} \tag{B-39}$$

where

$\vec{N}(t)$ .... atom count of short chain in the GW aquifer, gmol
Λ .... radioactive decay and regeneration matrix
W .... rate constant for aquifer dilution matrix (1/y)
$\vec{F}(t)$ .... flux to the watertable (PORFLOW), gmol/yr

Setting $G = -(\Lambda + W)$, we use the formula for the derivative of e^{-Gt} and the chain rule for differentiation, observe that

$$\begin{aligned}\frac{d}{dt}\left\{e^{-Gt}\vec{N}(t)\right\} &= e^{-Gt}\dot{\vec{N}}(t) - Ge^{-Gt}\vec{N}(t) \\ &= e^{-Gt}\left[\dot{\vec{N}}(t) - G\vec{N}(t)\right],\end{aligned}$$

making use of the fact the e^{-Gt} and G commute. Hence if we pre-multiply (B-39) by e^{-Gt} (and rearrange), we can write

$$\frac{d}{dt}\left(e^{-Gt}\vec{N}(t)\right) = e^{-Gt}\vec{F}(t)$$

and so

$$e^{-Gt}\vec{N}(t) - \vec{N}(0) = \int_0^t e^{-Gs}\vec{F}(s)ds$$

Applying the initial condition in (B-39) and rearranging

$$\vec{N}(t) = \int_0^t e^{G(t-s)}\vec{F}(s)ds \tag{B-40}$$

The solution of (B-40) that incorporates a delayed start of leaching, t_r, is given by the following set of equations

$$\begin{aligned}\vec{N}(t) &= 0 && t \le t_r \\ \vec{N}(t) &= \int_{t_r}^t e^{G(t-s)}\vec{F}(s)ds && t > t_r\end{aligned} \tag{B-41}$$

since $\vec{F}(t_r \le t) = \vec{0}$.

Boole's rule is the quadrature rule used to integrate the particular solution of the nonhomogeneous flux term in (B-41). The numerical integration over $[t_r, t]$ is split into smaller subintervals to maintain accuracy by applying Boole's rule over a 1-year time subinterval and summing up the results to the end of the simulation. This composite rule applied to Boole's rule approximates the integral in (B-41) as

$$\vec{N}(t)=\int_{t_r}^{t} e^{G(t-s)}\vec{F}(s)ds \approx \vec{N}(t_r)+\sum_j \frac{2h}{45}\left(7\vec{f}_0+32\vec{f}_1+12\vec{f}_2+32\vec{f}_3+7\vec{f}_4\right) \quad \text{(B-42)}$$

$$\vec{f}_i = e^{G(t_j-s_i)}\left[\vec{F}(t_{j-1})+i\frac{\vec{F}(t_j)-\vec{F}(t_{j-1})}{4}\right] \quad \text{(B-42a)}$$

$$s_i = t_{j-1}+i\frac{t_j-t_{j-1}}{4} \quad \text{(B-42b)}$$

$$h=\frac{t_j-t_{j-1}}{4} \quad \text{(B-42b)}$$

where

i .... equally spaced quadrature points, $0 \le i \le 4$
j .... 1-year time interval index
$\vec{f}_i$ .... integrand evaluated at quadrature point i
t_j .... simulation time at j index, yr

The exponentials are evaluated using matrix exponential routines. Matrix multiplication intrinsic routines are used compute the integrand at each quadrature point.

$\vec{N}(t)$ are the atom counts, in gmol, of the short chain in the GW aquifer. The atom counts in gmol are converted to activities as

$$A_j(t)=10^{12}\,\frac{\text{pCi}}{\text{Ci}}\,\frac{A_{mj}N_j(t)}{A_{mp}(1\text{ gmol})} \quad \text{(B-35)}$$

where

$\vec{A}_j(t)$ .... activity of short chain radionuclide j in GW aquifer (pCi/Ci)
A_{mj} .... molar activity of short chain radionuclide j, Ci/gmol
A_{mp} .... molar activity of short chain parent radionuclide, Ci/gmol

The short chain activities in the GW aquifer are converted to concentrations as

$$\vec{C}_{az}(t)=\frac{\vec{A}(t)}{I\times A_F\times 1\,y} \quad \text{(B-37)}$$

where

$\vec{C}_{az}(t)$ .... short chain concentrations in aquifer zone (pCi/m³/Ci)
A_F .... cross-sectional or projected area of soil layer (m^2)
I .... infiltration rate of clean water, (m/y)

The short-chain concentrations in the aquifer zone are expanded into full chain concentrations where the concentration of a radionuclide with a half-life less than 1 year is set to the concentration of their short chain precursor (secular equilibrium) for each GW screening scenario. The maximum full chain concentrations for each parent radionuclide over all GW screening scenarios are used to compute GW pathways maximum dose factors for screening.

Appendix C. Projected 2065 ELLWF Closure Inventories

This appendix provides details associated with the creation of an upper bound inventory estimate for every parent radionuclide that has been listed in WITS as of March 2020. During the first pass at GW and II screening (see, Aleman and Hamm 2020), 2040 projected inventories were obtained from a closure analyses effort by Sink (2016). In this report we have updated the closure analysis by projecting closure inventories out to 2065 to be consistent with the current expectation of SIC. Details of this updated and extended closure analysis are provided in this appendix. To account for uncertainties the upper bound inventory estimates for the radionuclides listed in WITS are then scaled up by:

$$I_{DU,i}^{UB} = \eta_{mult} \times I_{DU,i}^{proj} \tag{C-1}$$

where

$I_{DU,i}^{UB}$ Upper bound inventory estimate for radionuclide i in a disposal unit DU (Ci)

$I_{DU,i}^{proj}$ projected closure inventory estimate for radionuclide i in a disposal unit DU (Ci)

η_{mult} multiplier used to account for projection uncertainties (set to 10)

These scaled up closure inventories are then employed as input into the Tier-1 and Tier-2 analysis efforts.

C.1 Special versus Generic Waste Form Aspects

Prior to listing the maximum projected 2065 closure inventory estimates for the various types of DUs within E-Area, a closer look is provided of the current existing inventories. A WITS inventory query was performed in March 2020. Table C-1 below lists the unique radionuclides contained within that query where the following items apply:

- Special waste forms within WITS are listed as unique radionuclides followed by specific letters (e.g., H-3T is H-3 associated with the special waste form called TPBAR). As of March 2020, there are 112 unique radionuclides that have been designated as existing within special waste forms. Note that for a special waste form some sort of engineered barrier and/or special absorption value (i.e., K_d) is employed. Generic waste does not take credit for any engineered barriers and assumes the absorption value (i.e., K_d) for clayey materials;
- Currently there are 21 special waste forms in E-Area DUs;
- These 112 special waste form radionuclides are a subset of the 177 radionuclides currently found in WITS. Table C-2 below includes the locations of these unique radionuclides (but excludes their special waste form designations);
- Inventories only exist within 18 DUs as of March 2020;
- Only a subset of the total 177 radionuclides found in WITS show up in any given DU;
- The entry P-33 doesn't show up in any DU thus far but has been added to this list since it's a member of the Naval Reactor program's waste stream earmarked to enter NCRDA-26E. P-33 is not a fission product but comes from neutron activation processes;

- DU naming convention provided in the table is consistent with the naming employed in the PA2008. Also, NRCDA-7E and NRCDA-26E are referred to as NR0 and NR1, respectively;
- DUs containing a given radionuclide are shown using the symbols W, X, Y, and Z. These symbols indicate how common the radionuclide is within E-Area (i.e., X – present in all 18 DUs, W – 1 to 3 DUs, Y – 4 to 10 DUs, and Z – 11 to 17 DUs).
- Of the 18 DUs shown 7 of them are closed (i.e., ST01, ST02, ST03, ST04, ST05, ET01, and NRCDA-7E) while the remaining 11 are currently open and active.

Table C-1. List of unique radionuclides by disposal unit within the WITS database as of March 2020.

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
1	Ac-225		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
2	Ac-227					Y	Y		Y	Y		Y	Y					Y	
3	Ac-228	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z			Z
4	Ag-108				Y	Y				Y	Y	Y			Y	Y		Y	
5	Ag-108m				Y	Y				Y	Y	Y			Y			Y	
6	Ag-109m			Y	Y	Y	Y		Y	Y	Y	Y	Y					Y	
7	Ag-110				Y		Y			Y			Y		Y			Y	
8	Ag-110m				Y		Y			Y	Y		Y		Y	Y		Y	
9	Al-26									W	W								
10	Am-241	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11	Am-242				Y	Y				Y	Y	Y	Y					Y	
12	Am-242m	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
13	Am-243	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	Ar-37															W			
15	Ar-39					W				W					W				
16	At-217		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
17	Ba-133	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z			Z	
18	Ba-137m	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
19	Ba-140																	W	
20	Be-7										W								
21	Be-10			Y						Y			Y					Y	
22	Bi-207										W								
23	Bi-210	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z	Z			
24	Bi-211						Y			Y	Y	Y			Y	Y			Y
25	Bi-212	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
26	Bi-213		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
27	Bi-214	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
28	Bk-247								Y	Y		Y	Y						
29	Bk-249																	W	
30	C-14	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
31	Ca-41									W					W				
32	Ca-45									Y			Y				Y	Y	
33	Cd-109		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z			Z	Z
34	Cd-113			Y		Y			Y		Y	Y							
35	Cd-113m		Y		Y	Y			Y	Y	Y	Y			Y	Y		Y	
36	Cd-115m									W								W	
37	Ce-139		Y			Y			Y		Y	Y	Y		Y				
38	Ce-141	W								W								W	
39	Ce-144	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
40	Cf-249	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
41	**Cf-250**	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z				
42	**Cf-251**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
43	**Cf-252**	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z				Z
44	**Cl-36**	Z	Z		Z	Z			Z	Z	Z	Z			Z	Z	Z	Z	
45	**Cm-242**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
46	**Cm-243**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
47	**Cm-244**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
48	**Cm-245**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
49	**Cm-246**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
50	**Cm-247**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
51	**Cm-248**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
52	**Co-57**		Z	Z		Z	Z		Z	Z	Z	Z	Z	Z	Z	Z			
53	**Co-58**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
54	**Co-60**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
55	**Cr-51**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
56	**Cs-134**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
57	**Cs-135**	Z			Z	Z				Z	Z	Z		Z	Z		Z	Z	Z
58	**Cs-137**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
59	**Eu-152**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
60	**Eu-154**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
61	**Eu-155**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
62	**Fe-55**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
63	**Fe-59**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
64	**Fr-221**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
65	**H-3**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
66	**Hf-175**										Y		Y			Y	Y	Y	
67	**Hf-181**	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z
68	**Hg-203**		Y	Y		Y	Y		Y	Y	Y	Y	Y		Y				
69	**Ho-166m**									W									
70	**I-129**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
71	**In-113m**			Z		Z	Z		Z	Z	Z	Z	Z		Z	Z	Z	Z	
72	**In-114**																	W	
73	**In-114m**																	W	
74	**Ir-192**			Y			Y			Y		Y						Y	
75	**Ir-192m**									W								W	
76	**K-40**	Z	Z	Z	Z	Z			Z	Z	Z	Z	Z	Z	Z	Z			Z
77	**Kr-85**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
78	**La-140**																	W	
79	**Mn-54**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
80	**Mo-93**	Z				Z			Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
81	**Na-22**		Y	Y			Y		Y	Y	Y	Y			Y				Y
82	**Nb-93m**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
83	**Nb-94**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
84	**Nb-95**	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
85	**Nb-95m**	Z	Z				Z			Z	Z	Z	Z		Z	Z	Z	Z	
86	**Ni-59**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
87	**Ni-63**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
88	**Np-237**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
89	**Np-239**			Z	Z	Z		Z	Z	Z	Z	Z	Z		Z	Z		Z	
90	**P-33**																		
91	**Pa-231**					Y			Y	Y		Y	Y					Y	
92	**Pa-233**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z			Z
93	**Pa-234**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
94	**Pa-234m**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
95	**Pb-205**									W								W	
96	**Pb-209**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
97	**Pb-210**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z			
98	**Pb-212**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
99	**Pb-214**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
100	**Pd-107**	Y				Y				Y				Y				Y	Y
101	**Pm-146**								W	W		W							
102	**Pm-147**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
103	**Po-210**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z	Z		Z	
104	**Po-212**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z
105	**Po-213**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
106	**Po-214**	Z			Z	Z	Z		Z	Z	Z	Z	Z		Z	Z		Z	
107	**Po-216**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z
108	**Po-218**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z	Z		Z	
109	**Pr-144**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
110	**Pr-144m**	Z	Z	Z	Z		Z		Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
111	**Pt-193**								Y	Y					Y	Y		Y	
112	**Pu-238**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
113	**Pu-239**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
114	**Pu-240**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
115	**Pu-241**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
116	**Pu-242**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
117	**Pu-244**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
118	**Ra-224**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z
119	**Ra-225**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z	Z		Z	
120	**Ra-226**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z			Z
121	**Ra-228**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z			Z
122	**Rb-86**										W								
123	**Rb-87**	Y				Y				Y			Y	Y					Y
124	**Rh-103m**						Y			Y	Y		Y		Y	Y		Y	
125	**Rh-106**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
126	**Rn-220**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
127	**Rn-222**	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z	Z		Z	
128	**Ru-103**						Y			Y	Y		Y		Y	Y		Y	
129	**Ru-106**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
130	**S-35**	Y								Y	Y		Y				Y	Y	
131	**Sb-124**					Y				Y			Y					Y	
132	**Sb-125**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
133	**Sb-126**	Y		Y	Y				Y		Y	Y		Y				Y	Y
134	**Sb-126m**	Z	Z	Z	Z	Z	Z		Z		Z	Z		Z				Z	Z
135	**Sc-46**									Y	Y		Y				Y	Y	
136	**Se-75**									Y	Y	Y	Y	Y				Y	
137	**Se-79**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
138	**Sm-151**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
139	**Sn-113**		Z	Z		Z	Z		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	
140	**Sn-119m**				Z	Z			Z	Z	Z	Z	Z		Z	Z	Z	Z	
141	**Sn-121**				Y	Y			Y	Y	Y	Y	Y		Y	Y		Y	
142	**Sn-121m**				Y	Y			Y	Y	Y	Y	Y		Y	Y		Y	
143	**Sn-123**									Y			Y			Y	Y	Y	
144	**Sn-126**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
145	**Sr-85**	Y	Y		Y		Y				Y	Y	Y	Y	Y				Y
146	**Sr-89**		Y	Y	Y				Y	Y	Y	Y			Y			Y	
147	**Sr-90**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
148	**Ta-182**	Y	Y		Y					Y	Y		Y			Y	Y	Y	Y
149	**Tc-99**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
150	**Te-123m**			Y					Y	Y		Y						Y	
151	**Te-125m**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
152	**Th-228**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
153	**Th-229**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
154	**Th-230**		Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z		Z	Z
155	**Th-231**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
156	**Th-232**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z
157	**Th-234**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z		Z	Z
158	**Tl-204**														W				
159	**Tl-208**	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z			Z
160	**Tl-209**		Z	Z	Z	Z	Z		Z	Z	Z	Z	Z		Z				
161	**Tm-170**										W	W							
162	**Tm-171**									W		W							
163	**U-232**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
164	**U-233**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
165	**U-234**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
166	**U-235**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
167	**U-236**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
168	**U-237**					Y			Y	Y			Y					Y	
169	**U-238**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
170	**W-181**					Y				Y			Y					Y	
171	**W-185**																	W	
172	**W-188**																	W	
173	**Y-90**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
174	**Y-91**			Y	Y					Y	Y	Y						Y	
175	**Zn-65**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
176	**Zr-93**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
177	**Zr-95**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

The majority of the unique radionuclides reside primarily within "generic" waste forms, while the remainder reside within what is termed "special" waste forms. These special waste forms have unique hydraulic and/or chemical properties that are considered within a PA (e.g., container hydraulic integrity, effective sorption properties of the waste form, etc.). Generic radionuclides take no special credit for hydraulic or chemical engineered barriers; instead, they assume the radionuclide is in imminent contact with neighboring soil and are in chemical equilibrium with it at all times.

Currently, within WITS there are 21 special waste forms present as listed in Table C-2.

Table C-2 below lists these special waste forms where the symbol W implies a unique waste form only showing up in one DU while the symbol X implies more than one DU.

Note that:

- There are two special waste forms listed (i.e., "F Area Carbon" and "H Area Carbon") that do not currently show up within WITS having inventory. PA2008 inventory limits were created for these two special waste forms; however, prior to their burial, due to their high inventory values, they were sent to off-site burial facilities; and
- All radionuclides present in the NR1 DU were modeled as a Naval Reactor welded cask special waste form in the PA2008. NR1 modeling was used to simulate the NR0 DU. In the new PA2022 both generic and one special waste form will be considered and both DU's will be explicitly modeled. These DUs contain inventories that are within bolted containers and welded casks. All inventories within the bolted containers will be handled as generic waste, while all inventories within the casks will be handled as a special waste form (i.e., the welded casks are hydraulically isolated from the environment for at least +750 years).

Table C-2. List of special waste forms by disposal unit within the WITS database as of March 2020.

Count	Special Waste Form	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG1	LAWV	ILV	NR0	NR1
1	232-F Concrete	W																	
2	285F Cooling Tower						W												
3	ETF Activated Carbon			X				X									X		
4	ETF GT-73		X	X	X							X							
5	F Area Carbon																		
6	F Area CG-8		X									X							
7	F Area Dowex 21K		X									X							
8	F Area Filtercake	X	X	X	X	X		X				X							
9	H Area Carbon																		
10	H Area CG-8		X		X							X							
11	H Area Dowex 21K											X							
12	H Area Filtercake	W																	
13	HWCTR										W								
14	IP2 Tritium Box																W		
15	K/L Basin Resin														X		X		
16	M Area Glass		W																
17	Mk 50A Targets					W													
18	NR Main Coolant Pumps	X	X	X	X	X		X	X		X								
19	Paducah Cask					W													
20	Reactor Heat Exchangers									W									
21	TPBAR																W		

C.2 Altered 2040 Projected Closure Inventories by Sink (2040)

Within the WITS database, discussed above, we find the following radionuclide totals:

- 177 generic radionuclides; and
- 112 special waste form radionuclides;

giving a total of 289 radionuclides. In preparation for updating the PA2008 SWM estimated (Sink, 2016) closure inventories for every radionuclide contained within the WITS database, their inventory estimates were projected out to the year 2040 where process knowledge and waste generator projections were employed. In 2016 E-Area closure was being estimated to be in the year 2040. The closure inventories presented in this section reflect WITS inventories as of March 2016 that are projected out to 2040 by Sink (2016) and do not incorporate additional increases associated with the updated closure date of 2065 that are included in the following section.

The original 2040 closure inventories provided by Sink (2016) were altered based on the following topics:

- With the exception noted in the next two sub-bulleted items, closure inventories for each unique radionuclide were generated where the generic and special waste form contributions to a particular radionuclide were summed up. For GW screening purposes, no credit is considered for potentially beneficial engineered barriers (except for facility barriers such as ILV, LAWV, and NRCDAS hydraulic isolation timing); thus, all sources of a particular radionuclide are lumped together;
    - Within the ILV, TPBAR contributions were neglected since its contents are considered to be immobile beyond the CP. The one exception being H-3 due to its large solid-phase diffusion coefficient within the walls of the shipping/burial cask;
    - In original screening (Aleman and Hamm 2020), for Ar-37 no inventory for any DU was provided. That was based on only source of Ar-37 being within the TPBARs and as stated above its release from the casks exceeds the CP. In this screening effort it remains in;
- Typo's in radionuclide naming were corrected; and

Numerous cross-checking between available sources were performed (e.g., Sink (2016) versus WITS inventories for closed DUs versus Naval Reactor program's closure estimates). Table C-3 below contains the estimated 2040 closure inventories for the 177 radionuclides that are tracked by WITS. For each unique radionuclide the inventory (i.e., activities in Ci) values provided have been grouped as follows:

- **All Units** – Summed over every DU;
- **All Trenches** – Summed over only the trench units (i.e., STs, ETs, and CIGs);
- **LAWV** – LAWV unit only;
- **ILV** – ILV unit only;
- **All NRCDAs** – Summed over both NRCDA units (i.e., NRCDA-7E and NRCDA-26E);
- **Max Trenches** – Maximum value taken over the trench units (i.e., STs, ETs, and CIGs); and
- **All NRCDAs** – Maximum value taken over both NRCDA units (i.e., NRCDA-7E and NRCDA-26E).

Table C-3. Estimated 2040 closure inventories for radionuclides by disposal type.

	Nuclide	All Units (Ci)	All Trenches (Ci)	LAWV (Ci)	ILV (Ci)	All NRCDAs (Ci)	Max Trenches (Ci)	Max NRCDA (Ci)
1	Ac-225	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
2	Ac-227	1.31E-03	1.31E-03			1.03E-12	3.54E-04	1.03E-12
3	Ac-228	4.72E-02	4.53E-02	1.84E-03	3.20E-05		1.20E-02	
4	Ag-108	1.50E+00	1.50E+00			1.15E-07	4.98E-01	1.15E-07
5	Ag-108m	1.83E+01	1.83E+01	2.49E-04	7.18E-05	1.32E-06	6.09E+00	1.32E-06
6	Ag-109m	4.47E-02	2.36E-02			2.11E-02	1.04E-02	2.11E-02
7	Ag-110	1.49E-04	5.20E-09	7.80E-07		1.48E-04	1.20E-09	1.48E-04
8	Ag-110m	4.94E-02	8.72E-06	7.97E-05	2.12E-05	4.92E-02	2.40E-06	4.92E-02
9	Al-26	4.97E-11	4.97E-11				4.97E-11	
10	Am-241	1.82E+01	1.52E+01	1.36E+00	1.18E+00	4.86E-01	1.87E+00	3.52E-01
11	Am-242	1.03E-03	4.29E-08			1.03E-03	1.20E-08	1.03E-03
12	Am-242m	2.55E+00	2.54E+00	1.51E-03	1.89E-03	2.30E-03	3.94E-01	2.29E-03
13	Am-243	5.16E-01	5.01E-01	6.48E-03	3.11E-03	5.19E-03	1.67E-01	2.78E-03
14	Ar-37							
15	Ar-39	1.07E-13	1.07E-13				1.07E-13	
16	At-217	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
17	Ba-133	2.21E-01	8.58E-04	2.18E-01		2.09E-03	3.28E-04	2.09E-03
18	Ba-137m	3.64E+03	2.92E+03	2.19E+02	4.93E+02	1.21E+01	1.96E+03	6.81E+00
19	Ba-140	4.90E-08				4.90E-08		4.90E-08
20	Be-10	3.46E-05	1.30E-05			2.16E-05	2.17E-06	2.16E-05
21	B-E7	4.37E-06	4.37E-06				4.37E-06	
22	Bi-207	7.82E-06	7.82E-06				7.82E-06	
23	Bi-210	9.06E-02	9.06E-02		1.09E-06		4.43E-02	
24	Bi-211	6.38E-04	5.75E-04	6.23E-05	5.65E-07		1.38E-04	
25	Bi-212	3.25E-01	3.11E-01	1.42E-02	2.29E-04	2.60E-08	1.10E-01	2.60E-08
26	Bi-213	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
27	Bi-214	1.46E+00	9.24E-02		1.37E+00	2.02E-13	4.43E-02	2.02E-13
28	Bk-247	3.77E-07	3.77E-07				3.99E-08	
29	Bk-249	2.07E-08				2.07E-08		2.07E-08
30	C-14	1.93E+03	7.61E+00	8.75E-01	1.69E+03	2.30E+02	6.32E+00	1.39E+02
31	Ca-41							
32	Ca-45	1.51E-02	2.00E-09			1.51E-02	1.67E-10	1.49E-02
33	Cd-109	6.11E-02	2.09E-02	7.82E-06		4.02E-02	1.04E-02	4.02E-02
34	Cd-113	1.47E-13	1.47E-13				4.90E-14	
35	Cd-113m	7.31E-01	7.18E-01	5.94E-05	1.50E-06	1.33E-02	2.96E-01	1.33E-02
36	Cd-115m	9.76E-04				9.76E-04		9.76E-04
37	Ce-139	1.28E-06	1.28E-06	8.50E-10			4.23E-07	
38	Ce-141	4.94E-03	1.59E-08			4.94E-03	1.59E-08	4.94E-03
39	Ce-144	1.71E+01	1.39E+00	3.92E+00	7.94E-01	1.09E+01	3.61E-01	5.81E+00
40	Cf-249	4.42E-01	4.39E-01	6.05E-06	2.82E-03	3.21E-10	9.32E-02	1.96E-10
41	Cf-250	3.95E-01	3.92E-01	2.13E-03			7.22E-02	
42	Cf-251	4.02E-01	4.01E-01	2.62E-05	1.63E-03	7.09E-12	8.47E-02	4.39E-12
43	Cf-252	8.83E-02	6.98E-02	1.85E-02			1.01E-02	
44	Cl-36	1.78E-02	1.98E-04	4.77E-03	1.33E-04	1.27E-02	7.00E-05	1.27E-02
45	Cm-242	6.74E+00	1.05E-03	1.72E-04	1.49E-04	6.73E+00	1.65E-04	5.22E+00
46	Cm-243	4.14E-02	1.89E-02	5.76E-04	1.98E-02	2.14E-03	4.05E-03	2.13E-03
47	Cm-244	4.16E+01	3.35E+01	6.52E+00	1.13E+00	4.49E-01	4.19E+00	2.56E-01
48	Cm-245	2.19E-02	9.68E-03	7.73E-03	4.42E-03	2.67E-05	1.46E-03	1.65E-05
49	Cm-246	1.90E-02	5.33E-03	1.36E-02	5.18E-05	1.29E-05	7.33E-04	9.00E-06
50	Cm-247	3.76E-02	1.12E-02	2.76E-11	2.64E-02	1.64E-11	3.18E-03	8.39E-12
51	Cm-248	1.83E-03	1.82E-03	8.50E-12	1.04E-05	4.50E-11	4.55E-04	2.61E-11
52	Co-57	9.84E+00	9.84E+00	5.13E-08	9.06E-05		4.66E+00	
53	Co-58	2.90E+04	2.49E+01	2.99E-01	6.59E+00	2.90E+04	5.04E+00	2.07E+04
54	Co-60	3.00E+05	1.28E+05	9.67E+01	1.50E+02	1.72E+05	1.27E+05	9.85E+04
55	Cr-51	7.58E+03	4.72E-01	8.45E-10	2.47E-02	7.58E+03	1.91E-01	7.47E+03
56	Cs-134	2.70E+01	1.14E+00	9.03E+00	1.66E+00	1.52E+01	2.02E-01	1.51E+01
57	Cs-135	9.23E-05	5.09E-06	1.52E-09		8.72E-05	4.48E-06	5.26E-05
58	Cs-137	4.90E+03	3.31E+03	9.47E+02	6.27E+02	1.25E+01	2.07E+03	7.22E+00

	Nuclide	All Units (Ci)	All Trenches (Ci)	LAWV (Ci)	ILV (Ci)	All NRCDAs (Ci)	Max Trenches (Ci)	Max NRCDA (Ci)
59	Eu-152	3.69E+01	2.95E+01	7.44E+00	2.70E-02	6.23E-04	8.86E+00	6.23E-04
60	Eu-154	7.62E+01	6.87E+01	6.57E+00	4.13E-01	5.83E-01	2.24E+01	5.16E-01
61	Eu-155	9.11E+00	8.88E+00	4.93E-02	2.83E-02	1.57E-01	1.83E+00	1.18E-01
62	Fe-55	1.57E+05	2.08E+02	3.89E+02	2.33E+02	1.56E+05	3.69E+01	9.03E+04
63	Fe-59	7.49E+03	6.66E-01	1.15E-08	8.23E-02	7.49E+03	2.07E-01	7.48E+03
64	Fr-221	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
65	H-3	2.63E+08	5.58E+03	1.91E+08	7.17E+07	1.80E+02	5.56E+03	1.34E+02
66	Hf-175	4.04E+00	2.96E-05		3.34E-05	4.04E+00	4.93E-06	4.04E+00
67	Hf-181	7.53E+03	2.57E-01	3.70E-09	2.96E-02	7.53E+03	8.19E-02	7.46E+03
68	Hg-203	3.10E-05	3.10E-05	1.99E-16			1.29E-05	
69	Ho-166m	7.31E-06	7.31E-06				6.65E-07	
70	I-129	1.75E-01	1.41E-01	5.73E-04	3.38E-02	3.47E-05	2.28E-02	1.99E-05
71	In-113m	5.97E+03	2.55E-05	7.13E-17	8.95E-06	5.97E+03	9.84E-06	4.87E+03
72	In-114	2.02E+00				2.02E+00		2.02E+00
73	In-114m	3.80E+00				3.80E+00		3.80E+00
74	Ir-192	4.27E+01	4.27E+01			1.30E-02	1.22E+01	1.30E-02
75	Ir-192m	1.10E-06	8.51E-07			2.47E-07	7.74E-08	2.47E-07
76	K-40	1.17E-02	9.28E-03	1.88E-06	2.40E-03		4.12E-03	
77	Kr-85	4.56E+01	1.03E+00	7.95E+00	3.63E+01	2.71E-01	1.55E-01	2.65E-01
78	La-140	5.65E-08				5.65E-08		5.65E-08
79	Mn-54	2.02E+03	4.01E+00	2.91E-01	1.04E+00	2.01E+03	9.98E-01	1.39E+03
80	Mo-93	2.24E+00	4.71E-02	8.38E-03	1.33E-03	2.18E+00	2.55E-02	1.43E+00
81	Na-22	1.97E-04	1.96E-04	1.33E-06			7.65E-05	
82	Nb-93m	7.57E+03	1.06E+00	7.93E+00	2.63E+00	7.56E+03	1.74E-01	7.46E+03
83	Nb-94	1.32E+01	1.32E-01	3.43E-01	9.70E-02	1.26E+01	1.13E-01	6.54E+00
84	Nb-95	1.57E+05	9.79E-01	3.85E-02	1.57E-01	1.57E+05	1.96E-01	1.31E+05
85	Nb-95m	1.43E+03	1.29E-03	2.22E-05	1.73E-04	1.43E+03	4.70E-04	1.31E+03
86	Ni-59	3.33E+03	3.78E+01	4.88E+00	1.70E+00	3.29E+03	3.69E+01	1.74E+03
87	Ni-63	3.85E+05	3.30E+03	6.95E+02	2.07E+02	3.81E+05	3.26E+03	2.01E+05
88	Np-237	2.94E-01	1.41E-01	1.41E-01	1.15E-02	7.24E-06	3.97E-02	4.03E-06
89	Np-239	4.92E+01	4.92E+01	5.64E-06	1.51E-07	1.26E-03	1.61E+01	1.26E-03
90	P-33	6.32E-03				6.32E-03		6.32E-03
91	Pa-231	3.68E-09	3.68E-09			2.24E-12	5.35E-10	2.24E-12
92	Pa-233	1.80E-01	9.37E-02	8.63E-02	2.59E-04		3.14E-02	
93	Pa-234	5.46E-01	3.15E-01	5.99E-05	2.31E-01	6.70E-11	1.45E-01	6.70E-11
94	Pa-234m	4.33E+01	4.02E+01	2.45E+00	6.60E-01	2.66E-06	1.19E+01	2.66E-06
95	Pb-205	5.68E-08				5.68E-08		5.68E-08
96	Pb-209	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
97	Pb-210	1.47E+00	9.66E-02		1.37E+00		4.43E-02	
98	Pb-212	3.37E-01	3.23E-01	1.43E-02	2.29E-04	2.60E-08	1.10E-01	2.60E-08
99	Pb-214	1.46E+00	9.31E-02		1.37E+00	2.02E-13	4.43E-02	2.02E-13
100	Pd-107	1.13E-05	7.32E-06			3.99E-06	6.76E-06	3.99E-06
101	Pm-146	5.57E-05	5.57E-05				6.14E-06	
102	Pm-147	5.14E+01	8.11E+00	2.94E+01	6.59E+00	7.28E+00	1.80E+00	4.23E+00
103	Po-210	9.69E-02	9.06E-02	5.03E-15	1.09E-06	6.24E-03	4.43E-02	6.24E-03
104	Po-212	1.91E-01	1.89E-01	2.47E-03	9.39E-07	1.66E-08	7.08E-02	1.66E-08
105	Po-213	6.22E-02	6.16E-02	5.58E-04			2.23E-02	
106	Po-214	1.38E+00	9.81E-03		1.37E+00	2.02E-13	3.96E-03	2.02E-13
107	Po-216	3.36E-01	3.22E-01	1.43E-02	2.29E-04	2.60E-08	1.10E-01	2.60E-08
108	Po-218	1.47E+00	9.74E-02		1.37E+00	2.02E-13	4.43E-02	2.02E-13
109	Pr-144	1.07E+01	1.30E+00	3.76E+00	6.82E-01	4.95E+00	3.56E-01	4.73E+00
110	Pr-144m	7.87E-02	3.38E-03	3.31E-03	6.04E-03	6.60E-02	1.54E-03	6.60E-02
111	Pt-193	2.10E-03	4.42E-05	1.89E-03	5.07E-05	1.14E-04	5.28E-06	1.14E-04
112	Pu-238	2.07E+02	1.90E+02	9.70E+00	7.18E+00	5.37E-01	2.54E+01	2.69E-01
113	Pu-239	5.42E+01	4.87E+01	3.82E+00	1.40E+00	2.13E-01	8.31E+00	1.23E-01
114	Pu-240	1.51E+01	1.26E+01	1.02E+00	1.37E+00	1.73E-01	1.86E+00	1.11E-01
115	Pu-241	3.24E+02	2.31E+02	3.60E+01	7.58E+00	5.01E+01	2.97E+01	3.40E+01
116	Pu-242	5.45E-01	4.65E-01	5.40E-03	7.37E-02	7.38E-04	1.26E-01	4.07E-04
117	Pu-244	2.06E-02	4.64E-09	3.05E-15	2.06E-02	4.36E-11	1.71E-09	2.77E-11

	Nuclide	All Units (Ci)	All Trenches (Ci)	LAWV (Ci)	ILV (Ci)	All NRCDAs (Ci)	Max Trenches (Ci)	Max NRCDA (Ci)
118	Ra-224	3.36E-01	3.22E-01	1.43E-02	2.29E-04	2.60E-08	1.10E-01	2.60E-08
119	Ra-225	6.46E-02	6.40E-02	5.82E-04	3.82E-16		2.32E-02	
120	Ra-226	8.22E-01	5.45E-02	2.01E-07	7.67E-01	2.02E-13	4.39E-02	2.02E-13
121	Ra-228	4.42E-02	4.31E-02	1.08E-03	3.20E-05		1.20E-02	
122	Rb-86	4.65E-05	4.65E-05				4.65E-05	
123	Rb-87	1.39E-10	1.39E-10				2.40E-11	
124	Rh-103m	4.26E-02	4.84E-05	2.90E-03	1.22E-04	3.95E-02	7.89E-06	3.95E-02
125	Rh-106	7.62E+00	7.47E-01	1.41E-01	7.72E-02	6.65E+00	3.52E-01	6.65E+00
126	Rn-220	3.36E-01	3.22E-01	1.43E-02	2.29E-04	2.60E-08	1.10E-01	2.60E-08
127	Rn-222	1.47E+00	9.74E-02		1.37E+00	2.02E-13	4.43E-02	2.02E-13
128	Ru-103	5.18E-02	4.84E-05	2.90E-03	1.22E-04	4.87E-02	7.89E-06	4.87E-02
129	Ru-106	1.03E+01	9.86E-01	3.10E-01	1.95E-01	8.86E+00	3.54E-01	8.20E+00
130	S-35	1.91E-01	5.92E-03			1.85E-01	2.96E-03	1.82E-01
131	Sb-124	1.89E+00	1.19E-08			1.89E+00	1.13E-09	1.89E+00
132	Sb-125	6.12E+04	2.50E+00	7.22E+00	4.81E-01	6.11E+04	7.87E-01	4.07E+04
133	Sb-126	1.36E-05	1.13E-05			2.37E-06	1.08E-05	2.37E-06
134	Sb-126m	2.53E-03	2.51E-03			1.68E-05	1.19E-03	1.68E-05
135	Sc-46	5.99E-01	2.29E-21			5.99E-01	2.29E-21	5.96E-01
136	Se-75	3.30E-01	2.25E-03			3.27E-01	3.74E-04	3.27E-01
137	Se-79	3.32E-01	5.11E-02	2.79E-01	4.46E-04	1.44E-03	9.55E-03	1.22E-03
138	Sm-151	4.66E+00	4.45E+00	4.93E-04	6.89E-02	1.46E-01	1.29E+00	9.18E-02
139	Sn-113	5.97E+03	2.59E-05	3.21E-10	8.95E-06	5.97E+03	9.84E-06	4.87E+03
140	Sn-119m	1.16E+05	1.82E-04	7.77E-02	1.67E-04	1.16E+05	6.81E-05	8.08E+04
141	Sn-121	6.48E+00	2.30E-02	4.78E-02	1.23E-03	6.41E+00	9.40E-03	6.41E+00
142	Sn-121m	1.72E+01	2.98E-02	3.32E-02	6.29E-04	1.71E+01	1.22E-02	1.71E+01
143	Sn-123	2.65E+03	2.34E-11		1.05E-06	2.65E+03	1.95E-12	2.35E+03
144	Sn-126	5.08E-03	3.33E-03	6.88E-04	9.73E-04	9.20E-05	1.19E-03	8.34E-05
145	Sr-85	9.35E-03	7.52E-03	1.82E-03			1.54E-03	
146	Sr-89	7.53E-01	4.51E-07	2.58E-03		7.50E-01	1.69E-07	7.50E-01
147	Sr-90	1.61E+03	6.48E+02	7.66E+02	1.91E+02	8.81E+00	1.07E+02	5.39E+00
148	Ta-182	2.21E+04	2.72E-02		6.14E-05	2.21E+04	5.10E-03	1.76E+04
149	Tc-99	1.64E+00	6.38E-01	3.91E-01	2.72E-01	3.41E-01	9.21E-02	1.95E-01
150	Te-123m	6.09E+02	9.71E-05			6.09E+02	1.62E-05	6.09E+02
151	Te-125m	2.84E+04	1.20E-01	1.64E+00	7.85E-02	2.84E+04	2.00E-02	2.54E+04
152	Th-228	3.25E-01	3.11E-01	1.43E-02	2.29E-04	2.59E-08	1.10E-01	2.59E-08
153	Th-229	6.46E-02	6.40E-02	5.82E-04			2.32E-02	
154	Th-230	6.41E-02	6.39E-02	1.51E-04	3.25E-05	2.14E-11	4.66E-02	2.14E-11
155	Th-231	4.51E-01	4.33E-01	1.43E-02	3.46E-03	3.05E-08	1.14E-01	3.05E-08
156	Th-232	4.35E-02	4.24E-02	1.08E-03	8.79E-05	3.56E-08	1.20E-02	3.53E-08
157	Th-234	4.42E+01	4.05E+01	2.88E+00	8.91E-01	2.66E-06	1.19E+01	2.66E-06
158	Tl-204	5.20E-07		5.20E-07				
159	Tl-208	1.04E-01	1.02E-01	1.40E-03	2.05E-07		3.97E-02	
160	Tl-209	2.43E-03	2.40E-03	2.34E-05			8.59E-04	
161	Tm-170	1.01E-04	1.01E-04				1.65E-05	
162	Tm-171	5.27E-03	5.27E-03				8.71E-04	
163	U-232	3.51E-01	3.38E-01	1.28E-02	1.90E-04	9.55E-06	1.06E-01	4.77E-06
164	U-233	3.19E+01	3.06E+01	9.20E-01	3.69E-01	8.63E-06	8.28E+00	7.85E-06
165	U-234	2.60E+01	2.38E+01	1.61E+00	5.77E-01	1.74E-04	7.05E+00	1.71E-04
166	U-235	1.25E+00	1.18E+00	5.14E-02	1.82E-02	7.57E-06	6.98E-01	7.37E-06
167	U-236	5.84E-01	4.49E-01	1.27E-01	7.45E-03	7.01E-05	1.82E-01	6.58E-05
168	U-237	6.88E-05	1.33E-07			6.87E-05	1.41E-08	6.87E-05
169	U-238	4.96E+01	4.57E+01	2.48E+00	1.37E+00	1.88E-04	1.52E+01	1.65E-04
170	W-181	3.31E+00	3.95E-07			3.31E+00	6.46E-08	3.31E+00
171	W-185	9.57E+00				9.57E+00		9.57E+00
172	W-188	2.79E-02				2.79E-02		2.79E-02
173	Y-90	1.56E+03	6.09E+02	7.62E+02	1.82E+02	8.81E+00	8.94E+01	5.39E+00
174	Y-91	3.69E+00	1.39E-57			3.69E+00	4.64E-58	3.69E+00
175	Zn-65	2.97E+01	6.87E-01	2.63E-01	7.48E-01	2.80E+01	1.14E-01	1.67E+01
176	Zr-93	7.47E+03	1.90E-03	1.12E-02	3.61E-04	7.47E+03	1.02E-03	7.46E+03
177	Zr-95	7.37E+04	4.28E-01	1.66E-02	4.34E-02	7.37E+04	8.89E-02	6.16E+04

As Table C-3 indicates, for many of the unique radionuclides no entry is seen for some of the DU types listed. This is based on the historical WITS inventories and expected future/ongoing waste generator waste streams.

For GW screening purposes a "generic" DU is considered for each DU type:"

- **Trench;**
- **LAWV;**
- **ILV; and**
- **NRCDA** (represented by two models: a model for generic Naval Reactor waste (NRCDAG) and a model for special waste forms (NRCDAS). Note that NRCDA inventories are further broken apart for generic versus special waste form in Appendix H).

For DU types consisting of multiple units a decision is needed to employ either maximum or average inventory values. For screening purposes (i.e., for Tier-1 purposes) maximum inventory values were deemed more appropriate.

The estimated 2040 closure inventories presented in Table C-3 only reflect upper bound estimates based on available information obtained from waste generators, WITS historical inventories, and SWM subject matter experts. These estimates were not constrained with respect to any physical/radiological constraints such as:

- Near surface radiation levels (Rads/hr) associated with for example B-25 boxes; or
- Physical limits on the maximum amount of weight a B-25 box can contain.

Once these additional constraints are factored in potentially lower closure estimates are obtained for some or many of the radionuclides listed in Table C-3. These additional constraints are discussed in Appendix D and Appendix E and also apply to all 1,252 radionuclides. These potential inventory reductions are handled during Tier-1 and Tier-2 processing.

C.3 Composited 2065 Projected Closure Inventories

WITS inventories are provided on a DU by DU basis. Provides the current status of each E-Area DU along with its current operational status, and past, naming convention.

Table C-4. E-Area disposal unit naming convention and current operational status.

Unit (ID)	Disposal Unit (new name)	Disoposal Unit (prior name)	Unit Status
1	ST01		closed
2	ST02		closed
3	ST03		closed
4	ST04		closed
5	ST05		closed
6	ST06		opened
7	ST07		opened
8	ST08		opened
9	ST09		opened
10	ST10		opened
11	ST11		opened
12	ST14		opened
13	ST17		Future
14	ST18		Future
15	ST19		Future
16	ST20		Future
17	ST21		Future
18	ST22		Future
19	ST23	CIG1	opened
20	ST24	CIG2	Future
21	ET01		closed
22	ET02		opened
23	ET03	ST12	opened
24	ET04	ST13	Future
25	ET05	ST15	Future
26	ET06	ST16	Future
27	ET07	DU8A	Future
28	ET08	DU8B	Future
29	ET09	DU8C	Future
30	LAWV		opened
31	ILV		opened
32	NRCDA7E		closed
33	NRCDA26E		opened

As Table C-4 indicates, the E-Area DUs are in various operating states and consists of trenches (slit and engineered), vaults, and Naval Pads. WITS inventories are available for both closed and opened DUs. The 2065 projected closure inventories were arrived at differently for each DU within a given operational status:

- **Closed** – DU is no longer receiving new waste packages and therefore its inventories were fixed at their WITS values as of March 2020. Note that no account for radioactive decay (for parent or its progeny) was considered based on waste history. Projected inventory was set equal to the values listed in WITS;
- **Opened** – DU is currently in operations and is assumed to be receiving waste packages. Two methods of projections are available: (1) projected inventory based on a waste generator rates of contributions terminated either when current limits reached or (2) when the 2065 calendar year is reached; and
- **Future** – DU is scheduled to be in operation prior to the SIC. Closure inventories for these future DUs are set equal to exiting units that best represent their expected contents.

SWM releases, in monthly reports, the status of E-Area operations where for every existing DU its (1) disposed volume and (2) PA statuses are provided (see, Simmons 2020b).These quantities for the month of March 2020 are provided in Table C-5 and Table C-6.

Table C-5. Disposal volume status of E-Area for March 2020.

EAV Facility	Capacity Volume (m3)	Volume Status (m3)	Percent Filled	Volume Status (m3)	Percent Filled	Volume Remaining (m3)	Remarks
		(02/27/20)	(02/27/20)	(03/31/20)	(03/31/20)	(03/31/20)	
LAWV	30,600	9,784	32.0%	9,797	32.0%	20,803	
ILV	4,284	2,494	58.2%	2,496	58.3%	1,788	
ET01	35,660	35,660	100.0%	35,660	100.0%	0	Facility is closed.
ET02	35,500	27,911	78.6%	27,916	78.6%	7,584	
ET03	27,000	21,335	79.0%	21,812	80.8%	5,188	
ST01	14,264	14,264	100.0%	14,264	100.0%	0	Facility is closed.
ST02	15,560	15,560	100.0%	15,560	100.0%	0	Facility is closed.
ST03	16,953	16,953	100.0%	16,953	100.0%	0	Facility is closed.
ST04	19,193	19,193	100.0%	19,193	100.0%	0	Facility is closed.
ST05	28,125	28,125	100.0%	28,125	100.0%	0	Facility is closed.
ST06	23,000	20,848	90.6%	20,848	90.6%	2,152	Remaining trench space is within ET02 ramp boundary and is on hold.
ST07	15,900	10,555	66.4%	10,555	66.4%	5,345	Remaining trench space is within ET02 ramp boundary and is on hold.
ST08	16,275	15,461	95.0%	15,461	95.0%	814	
ST09	21,000	19,617	93.4%	19,617	93.4%	1,383	
ST14	19,500	15,469	79.3%	15,618	80.1%	3,882	
NRC-7E	701	701	100.0%	701	100.0%	0	Facility is closed.
NRC-26E	6,000	689	11.5%	703	11.7%	5,297	
CIG1	6,500	1,834	28.2%	1,834	28.2%	4,666	

numbers being used in projection
number not used since Sink projection assumed
facility closed and not requiring projections

Table C-6. PA status of E-Area for March 2020.

EAV Facility	PA SOF Limit	Highest PA Limit Group SOF% Status (02/27/20)	Highest PA Limit Group SOF% Status (03/31/20)	Highest PA Group	Remarks
LAWV	95.0%	13.7%	13.7%	BG	
ILV	95.0%	9.6%	9.6%	BG2	
ET01	95.0%	91.3%	91.3%	BG2	Facility is closed.
ET02	95% (75% for BG2 and AP2)	95.3%	95.4%	BG2	Intermin measures were put into place during 7/18 that reduced the PA SOF for BG2 and AP2 from 95% to 75%.
ET03	95.0%	63.7%	64.9%	BG2	
ST01	95.0%	89.9%	89.9%	BG2	Facility is closed.
ST02	95.0%	91.1%	91.1%	BG2	Facility is closed.
ST03	90.0%	99.3%	99.3%	BG2	Facility is closed.
ST04	95.0%	99.5%	99.5%	BG2	Facility is closed.
ST05	100.0%	100.0%	100.0%	BG2	Facility is closed. Acceptable for closure with high PA inventory, using Special Analysis SRNL-STI-2008-00520.
ST06	95.0%	86.6%	86.6%	BG2	
ST07	95.0%	58.4%	58.4%	BG2	
ST08	95.0%	93.3%	93.3%	BG1	
ST09	95.0%	88.8%	88.8%	BG3	
ST14	95% (65% for BG2 and AP2)	97.5%	98.1%	BG2	Intermin measures were put into place during 7/18 that reduced the PA SOF for BG2 and AP2 from 95% to 65%.
NRC-7E	95.0%	3.3%	3.3%	BG	Facility is closed.
NRC-26E	95.0%	2.7%	2.8%	BG	
CIG1	95.0%	46.8%	46.8%	BG2	

numbers being used in projection
number not used since Sink projection assumed
facility closed and not requiring projections

For "**opened**" DUs the projected inventory is computed based on the DU reaching its administrative limit (i.e., 95% SOF except for ET02, ST05, and ST14 as shown in Table C-6). Here the projection is being made based on the following assumptions:

- Compositional changes from the March 2020 WITS inventories is small (e.g. the Ci fractions remain constant over time): and
- The disposed volume limit is not reached prior to hitting the DU SOF administrative limit.

To use this strategy the following equation was employed for every parent radionuclide within each DU:

$$I_{DU,i}^{proj} = \left[\left(\frac{S_{DU}^{Admin}}{S_{DU}^{IM}}\right)\left(\frac{1}{SOF}\right)\right] \times I_{DU,i}^{WITS} \tag{C-2}$$

where

$I_{DU,i}^{proj}$ projected inventory estimate for radionuclide i in a disposal unit DU (Ci)

$I_{DU,i}^{WITS}$ WITS inventory for radionuclide i in a disposal unit DU for a specified month (Ci)

S_{DU}^{Admin} Administrative SOF limit for disposal unit DU (-)

S_{DU}^{IM} Interim Measures SOF limit for disposal unit DU (-)

SOF SOF for disposal unit DU (-)

C.3.1 2065 Projected Trench Closure Inventories

By way of an example, for the parent radionuclide Am-225 within the DU ST14 the following factors apply for the WITS information provided in March 2020:

- Administration Limit – 95%
- Interim Measures Limit – 65%
- DU SOF – 98.1% (end of March)

The projected Am-225 closure inventory (in Ci), based on its status as of March 2020, becomes:

$$5.98\text{x}10^{-11} = \left[\left(\frac{95.0}{65.0}\right)\left(\frac{1}{0.981}\right)\right] \times 4.01\text{x}10^{-11}\ (\text{Ci}) = [1.490] \times 4.01\text{x}10^{-11}\ (\text{Ci}) \tag{C-3a}$$

Following this same approach, the projected Am-225 closure inventory (in Ci), based on its status as of March 2016 (Sink 2016a), yielded:

$$7.43\text{x}10^{-11}\ (\text{Ci}) \tag{C-3b}$$

These differences are most likely due to compositional changes from March 2016 to March 2020. However, Sink (2016) may have factored other aspects in (one a nuclide by nuclide basis) but no documentation was provided. Thus, to allow for compositional changes (and other potential aspects) the final 2065 projected closure inventories are set to the maximum of these two estimates:

$$I_{DU,i}^{proj} = \mathrm{Max}\left[I_{DU,i}^{proj-2016}, I_{DU,i}^{proj-2020} \right] \tag{C-4}$$

Applying the above approach and making use of Eq. (C-4) (i.e., using the projected closure inventories for March 2016 and March 2020), the "composited" 2065 closure inventories were computed. These inventory values for each existing trench DU are listed in Table C-7, along with the maximum value over all existing trenches.

Table C-7. Composited 2065 closure inventories for radionuclides by existing trench disposal type.

Projected	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max
Nuclide	**ST01**	**ST02**	**ST03**	**ST04**	**ST05**	**ST06**	**ST07**	**ST08**	**ST09**	**ST14**	**ST23**	**ET01**	**ET02**	**ET03**	**Max**
Ac-225	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Ac-227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-05	4.01E-04	0.00E+00	2.47E-07	2.59E-10	0.00E+00	0.00E+00	1.96E-10	2.06E-07	4.01E-04
Ac-228	3.06E-03	2.37E-06	8.84E-04	2.79E-04	3.69E-05	1.25E-02	7.19E-05	3.31E-06	1.67E-04	7.03E-07	5.01E-08	4.86E-03	4.28E-03	1.97E-04	1.25E-02
Ag-108	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-10	5.71E-06	0.00E+00	0.00E+00	0.00E+00	4.98E-01	0.00E+00	1.41E-08	4.09E-09	0.00E+00	4.98E-01
Ag-108m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-09	6.51E-05	0.00E+00	0.00E+00	0.00E+00	6.09E+00	0.00E+00	1.51E-07	4.40E-08	0.00E+00	6.09E+00
Ag-109m	0.00E+00	0.00E+00	0.00E+00	3.50E-05	1.04E-02	2.77E-06	8.89E-06	0.00E+00	2.72E-07	7.06E-06	0.00E+00	4.20E-05	4.13E-06	1.51E-06	1.04E-02
Ag-110	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-12	0.00E+00	1.29E-20	0.00E+00	0.00E+00	2.05E-09	0.00E+00	0.00E+00	0.00E+00	3.67E-10	2.05E-09
Ag-110m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-10	0.00E+00	9.71E-19	0.00E+00	0.00E+00	5.79E-04	0.00E+00	2.40E-06	0.00E+00	2.76E-08	5.79E-04
Al-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-12	0.00E+00	4.97E-11	0.00E+00	0.00E+00	4.97E-11
Am-241	3.79E-02	1.59E-01	4.04E-01	2.97E-01	6.57E-01	7.72E-01	1.01E+00	5.16E-01	1.12E+00	5.88E-01	1.53E-01	6.56E-01	2.12E+00	5.51E-01	2.12E+00
Am-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-11	8.52E-10	0.00E+00	0.00E+00	0.00E+00	1.77E-08	0.00E+00	1.20E-08	1.08E-10	3.59E-16	1.77E-08
Am-242m	7.36E-03	3.11E-02	3.38E-03	1.55E-03	4.81E-02	4.09E-01	4.19E-04	3.83E-01	1.59E-02	1.18E-04	1.07E-06	5.31E-03	2.71E-01	1.95E-01	4.09E-01
Am-243	6.13E-05	1.69E-03	2.39E-03	1.58E-03	1.16E-02	1.74E-01	2.99E-03	4.55E-02	4.18E-04	4.73E-03	1.61E-03	2.00E-03	3.82E-02	8.05E-03	1.74E-01
Ar-37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ar-39	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-18	0.00E+00	0.00E+00	0.00E+00	8.79E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.79E-10
At-217	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Ba-133	0.00E+00	8.29E-06	4.99E-07	3.03E-05	8.36E-07	7.86E-08	2.35E-05	0.00E+00	4.39E-06	3.28E-04	0.00E+00	5.02E-06	3.10E-05	4.84E-06	3.28E-04
Ba-137m	5.26E+00	2.03E+01	1.64E+01	3.39E+01	2.09E+01	2.68E+01	4.43E+01	3.40E+01	4.91E+01	1.30E+02	4.19E+03	3.28E+01	7.13E+01	1.00E+02	4.19E+03
Ba-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Be-10	0.00E+00	0.00E+00	0.00E+00	4.78E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.17E-06	0.00E+00	0.00E+00	0.00E+00	9.65E-11	2.17E-06
Be-7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.37E-06	0.00E+00	0.00E+00	4.37E-06
Bi-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.82E-06	0.00E+00	0.00E+00	7.82E-06
Bi-210	0.00E+00	1.30E-06	2.25E-05	1.01E-05	1.12E-07	4.60E-02	2.74E-06	0.00E+00	4.20E-11	5.94E-07	0.00E+00	9.76E-04	2.98E-05	2.03E-05	4.60E-02
Bi-211	2.47E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-04	0.00E+00	0.00E+00	1.94E-13	0.00E+00	4.67E-07	7.32E-07	0.00E+00	1.57E-04
Bi-212	2.40E-03	1.42E-06	1.36E-03	6.54E-03	1.08E-03	1.97E-02	1.64E-03	3.31E-06	1.03E-03	7.04E-07	5.18E-10	3.24E-02	1.10E-01	2.00E-04	1.10E-01
Bi-213	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Bi-214	7.04E-05	6.49E-06	7.31E-07	2.01E-05	1.12E-07	4.60E-02	2.75E-06	0.00E+00	8.37E-09	5.96E-07	2.97E-10	3.97E-03	3.75E-05	2.03E-05	4.60E-02
Bk-247	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.79E-09	7.86E-09	0.00E+00	0.00E+00	3.11E-08	3.99E-08	3.99E-08
Bk-249	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	6.11E-02	1.22E-01	2.43E-02	6.13E-02	4.13E-02	9.09E-03	6.31E-02	2.07E-02	9.80E-01	7.81E+00	2.62E-01	1.31E-01	9.50E-02	3.57E-02	7.81E+00
Ca-41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-09
Ca-45	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.98E-07	0.00E+00	0.00E+00	0.00E+00	3.00E-09	4.98E-07
Cd-109	2.47E-04	0.00E+00	1.19E-05	3.61E-05	1.04E-02	3.18E-06	9.73E-06	0.00E+00	5.82E-06	7.74E-06	4.74E-08	5.52E-05	4.24E-06	1.08E-04	1.04E-02
Cd-113	0.00E+00	0.00E+00	0.00E+00	7.97E-20	0.00E+00	5.09E-14	0.00E+00	0.00E+00	9.05E-20	0.00E+00	0.00E+00	1.59E-19	1.06E-19	0.00E+00	5.09E-14
Cd-113m	0.00E+00	0.00E+00	2.24E-09	0.00E+00	7.58E-13	4.15E-06	0.00E+00	0.00E+00	9.73E-08	2.96E-01	0.00E+00	9.18E-14	1.25E-11	0.00E+00	2.96E-01
Cd-115m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.24E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.24E-11
Ce-139	0.00E+00	0.00E+00	4.23E-07	0.00E+00	0.00E+00	1.98E-09	0.00E+00	0.00E+00	3.39E-10	0.00E+00	0.00E+00	5.63E-11	1.89E-10	6.38E-10	4.23E-07
Ce-141	0.00E+00	1.59E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.63E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E-08
Ce-144	2.88E-03	1.89E-02	1.41E-01	4.84E-02	3.61E-01	4.87E-07	4.44E-03	1.62E-04	6.92E-03	2.32E-01	2.61E-01	5.23E-02	9.17E-02	1.38E-01	3.61E-01
Cf-249	6.66E-06	6.23E-04	3.32E-04	1.26E-04	1.16E-02	9.69E-02	4.92E-04	9.03E-02	2.90E-04	9.49E-07	1.88E-04	8.12E-06	5.75E-02	5.28E-06	9.69E-02
Cf-250	0.00E+00	3.50E-02	1.55E-02	2.70E-04	3.62E-02	7.50E-02	2.16E-02	8.69E-03	9.43E-03	0.00E+00	3.87E-06	1.40E-04	4.19E-04	0.00E+00	7.50E-02

Projected	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max
Nuclide	**ST01**	**ST02**	**ST03**	**ST04**	**ST05**	**ST06**	**ST07**	**ST08**	**ST09**	**ST14**	**ST23**	**ET01**	**ET02**	**ET03**	**Max**
Cf-251	6.59E-05	6.68E-04	3.78E-04	1.67E-04	1.10E-02	8.80E-02	4.07E-04	8.21E-02	8.80E-05	7.62E-07	1.90E-04	5.74E-05	5.24E-02	6.80E-06	8.80E-02
Cf-252	1.43E-06	4.90E-03	2.34E-03	6.78E-05	5.06E-03	1.05E-02	3.02E-03	1.22E-03	1.69E-04	0.00E+00	2.04E-04	6.64E-04	9.38E-03	6.10E-08	1.05E-02
Cl-36	0.00E+00	1.05E-05	2.10E-06	0.00E+00	2.26E-06	1.90E-12	0.00E+00	0.00E+00	2.30E-06	6.27E-07	0.00E+00	7.00E-05	1.59E-08	0.00E+00	7.00E-05
Cm-242	6.06E-05	1.65E-04	2.60E-05	3.62E-05	5.29E-05	1.61E-09	8.55E-05	1.09E-05	1.08E-06	1.12E-04	1.60E-06	5.42E-05	7.48E-06	2.97E-05	1.65E-04
Cm-243	6.92E-06	3.90E-06	8.19E-04	1.30E-04	2.37E-03	4.21E-03	4.14E-04	1.79E-03	4.06E-05	1.33E-05	3.20E-04	2.19E-04	9.45E-04	2.48E-04	4.21E-03
Cm-244	3.84E-02	1.11E-01	3.27E-01	5.42E-01	1.42E+00	3.67E+00	2.55E-01	3.22E+00	3.85E-01	2.41E+00	4.20E-01	5.32E-01	4.35E+00	1.52E+00	4.35E+00
Cm-245	2.74E-07	2.92E-06	1.93E-04	2.40E-04	4.87E-04	1.37E-03	2.00E-04	1.56E-03	2.76E-05	1.53E-05	3.30E-05	2.93E-04	1.25E-03	1.20E-05	1.56E-03
Cm-246	1.53E-06	2.19E-05	9.14E-05	2.23E-04	7.33E-04	5.38E-04	2.41E-04	2.08E-05	3.70E-05	1.55E-05	1.87E-04	4.65E-04	6.15E-04	1.27E-05	7.33E-04
Cm-247	1.43E-06	2.48E-09	4.97E-05	5.95E-04	1.78E-04	1.37E-03	4.43E-04	3.41E-03	5.40E-06	8.25E-07	1.87E-04	6.81E-11	5.67E-04	4.49E-06	3.41E-03
Cm-248	1.43E-06	2.58E-05	6.09E-05	1.94E-07	3.53E-04	4.73E-04	5.59E-05	2.52E-05	1.18E-05	6.01E-15	1.87E-04	9.44E-15	5.01E-07	6.10E-08	4.73E-04
Co-57	0.00E+00	0.00E+00	2.46E-03	1.93E-09	0.00E+00	4.35E-09	7.14E-08	0.00E+00	1.64E-07	1.76E-06	1.37E-10	4.66E+00	6.77E-08	6.52E-06	4.66E+00
Co-58	2.88E-01	5.04E+00	5.00E-01	3.80E-01	6.34E-01	4.60E-06	4.11E+00	6.47E-01	1.89E-02	2.17E+00	1.61E-08	1.12E+00	1.39E-02	2.14E-01	5.04E+00
Co-60	4.69E+00	1.96E+01	1.18E+00	3.03E+00	1.27E+05	1.95E-01	5.00E+00	1.99E-01	1.97E+00	3.75E+02	3.61E-01	1.18E+01	8.93E-01	1.90E+00	1.27E+05
Cr-51	7.11E-05	1.23E-02	2.31E-03	9.27E-04	7.94E-03	2.77E-09	2.16E-01	3.64E-02	1.16E-04	8.27E-03	0.00E+00	8.57E-03	3.39E-03	1.11E-04	2.16E-01
Cs-134	4.19E-04	2.99E-04	1.97E-01	1.93E-02	7.80E-02	1.57E-04	3.65E-03	4.24E-03	1.05E-02	1.68E-01	8.98E-02	1.04E-01	2.08E-01	9.98E-02	2.08E-01
Cs-135	7.09E-08	1.18E-10	0.00E+00	0.00E+00	8.84E-14	6.84E-08	0.00E+00	0.00E+00	0.00E+00	1.13E-07	9.58E-06	1.33E-11	1.45E-12	0.00E+00	9.58E-06
Cs-137	7.09E+00	2.22E+01	1.77E+01	3.65E+01	2.94E+01	3.11E+01	6.00E+01	3.68E+01	7.00E+01	1.38E+02	4.42E+03	5.32E+01	1.00E+02	1.06E+02	4.42E+03
Eu-152	2.96E-04	8.08E-03	1.11E-02	1.13E-01	9.08E-05	2.57E-03	1.70E-01	9.95E-03	6.96E+00	1.14E-03	1.94E-01	1.95E-01	8.87E+00	1.77E-01	8.87E+00
Eu-154	1.00E-03	3.98E-02	8.05E-02	3.13E-01	2.24E+01	7.66E+00	8.51E-02	2.59E+00	2.22E+00	4.93E-05	1.10E-01	1.63E-01	3.56E+00	7.08E-02	2.24E+01
Eu-155	2.04E-05	8.90E-01	3.88E-01	6.82E-03	9.30E-01	1.91E+00	5.50E-01	2.21E-01	1.44E-01	1.83E-04	1.04E-02	2.39E-03	1.22E-01	1.55E-03	1.91E+00
Fe-55	7.80E+00	3.37E+01	2.08E+00	4.36E+00	1.29E+01	5.65E-04	3.92E+00	3.56E-01	7.77E-02	1.51E+01	6.47E-01	3.69E+01	7.95E-01	3.31E+00	3.69E+01
Fe-59	1.58E-03	3.60E-02	1.11E-02	5.52E-03	1.00E-02	3.35E-07	2.34E-01	3.88E-02	4.79E-04	4.34E-02	0.00E+00	3.08E-02	6.83E-04	1.02E-03	2.34E-01
Fr-221	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
H-3	4.72E+00	1.07E+00	1.13E+00	8.55E+00	4.02E-01	2.27E-01	8.59E-01	2.90E-01	2.08E+02	4.00E-01	1.15E+04	2.21E+00	6.50E-01	4.60E-01	1.15E+04
Hf-175	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-06	0.00E+00	5.13E-13	4.93E-06
Hf-181	4.65E-04	1.16E-02	3.88E-03	1.87E-03	2.65E-03	0.00E+00	9.26E-02	1.55E-02	1.70E-04	1.50E-02	0.00E+00	9.79E-03	2.93E-04	3.38E-04	9.26E-02
Hg-203	0.00E+00	0.00E+00	8.54E-07	9.21E-18	0.00E+00	3.88E-11	8.99E-13	0.00E+00	1.06E-13	7.89E-11	0.00E+00	1.29E-05	1.53E-17	1.12E-11	1.29E-05
Ho-166m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-07
I-129	1.02E-04	5.03E-03	1.65E-02	1.39E-04	6.61E-05	8.37E-05	6.47E-03	9.68E-05	2.85E-05	2.50E-05	7.98E-04	2.35E-03	7.91E-05	7.26E-05	1.65E-02
In-113m	0.00E+00	0.00E+00	0.00E+00	3.52E-08	0.00E+00	1.82E-09	1.11E-05	0.00E+00	2.56E-10	3.43E-09	0.00E+00	1.44E-06	4.30E-09	7.95E-08	1.11E-05
In-114	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
In-114m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ir-192	0.00E+00	0.00E+00	0.00E+00	2.69E-08	0.00E+00	0.00E+00	2.22E-07	0.00E+00	0.00E+00	7.74E-08	0.00E+00	0.00E+00	1.22E+01	0.00E+00	1.22E+01
Ir-192m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.74E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.74E-08
K-40	4.12E-03	3.21E-06	5.31E-06	6.55E-06	2.89E-04	4.95E-08	0.00E+00	0.00E+00	1.58E-05	5.46E-06	2.88E-09	1.37E-04	5.76E-05	1.38E-04	4.12E-03
Kr-85	7.76E-05	2.18E-03	4.63E-03	9.88E-03	2.60E-02	8.71E-04	9.20E-02	7.10E-03	1.18E-02	1.05E-03	7.41E-02	1.30E-01	1.75E-01	8.41E-02	1.75E-01
La-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-54	1.94E-01	9.98E-01	5.47E-02	1.42E-01	1.54E-01	1.94E-08	1.57E-01	1.73E-02	1.97E-03	3.43E-01	4.12E-04	2.63E-01	2.89E-03	9.03E-02	9.98E-01
Mo-93	1.15E-05	3.40E-07	0.00E+00	0.00E+00	0.00E+00	1.18E-03	0.00E+00	0.00E+00	8.57E-03	2.52E-02	0.00E+00	2.08E-03	1.60E-03	9.41E-09	2.52E-02
Na-22	7.92E-07	0.00E+00	2.59E-07	2.00E-06	0.00E+00	0.00E+00	2.86E-11	0.00E+00	6.56E-06	4.47E-07	0.00E+00	3.46E-07	7.65E-05	0.00E+00	7.65E-05
Nb-93m	7.45E-02	1.62E-01	1.39E-02	4.86E-02	4.77E-02	3.25E-05	3.39E-02	2.60E-03	1.32E-02	1.02E-01	0.00E+00	8.12E-02	2.24E-02	4.90E-03	1.62E-01
Nb-94	1.08E-03	2.26E-03	6.64E-04	9.76E-04	8.70E-04	2.39E-06	4.70E-04	3.47E-05	1.90E-04	1.64E-01	2.95E-04	3.23E-03	1.76E-03	4.79E-04	1.64E-01
Nb-95	9.92E-03	9.14E-02	2.34E-02	1.52E-02	2.57E-02	0.00E+00	2.21E-01	3.53E-02	2.13E-03	9.47E-02	4.79E-03	5.27E-02	2.27E-03	3.02E-03	2.21E-01

Projected	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max
Nuclide	**ST01**	**ST02**	**ST03**	**ST04**	**ST05**	**ST06**	**ST07**	**ST08**	**ST09**	**ST14**	**ST23**	**ET01**	**ET02**	**ET03**	**Max**
Nb-95m	0.00E+00	3.00E-10	3.86E-06	0.00E+00	0.00E+00	0.00E+00	7.90E-07	0.00E+00	0.00E+00	7.52E-05	0.00E+00	1.09E-05	4.70E-04	8.98E-12	4.70E-04
Ni-59	2.25E-02	3.65E-02	1.41E-02	1.93E-02	1.13E-02	2.38E-02	1.83E-01	4.93E-02	1.80E-02	5.48E+01	4.07E-03	1.17E-01	8.11E-02	8.71E-03	5.48E+01
Ni-63	1.58E+00	6.51E+00	5.70E-01	1.28E+00	2.72E+00	6.74E-02	8.64E-01	5.97E-02	9.49E-02	4.84E+03	4.13E-01	7.45E+00	1.32E+00	8.09E-01	4.84E+03
Np-237	1.19E-03	2.07E-03	1.87E-02	7.58E-03	5.55E-03	4.60E-03	8.10E-03	4.69E-04	7.26E-03	9.43E-03	2.73E-03	7.69E-03	4.28E-02	1.27E-02	4.28E-02
Np-239	0.00E+00	0.00E+00	0.00E+00	1.38E-01	1.61E+01	5.51E+00	0.00E+00	1.85E+00	1.03E-06	1.13E-09	0.00E+00	5.87E-05	6.89E-04	4.54E-05	1.61E+01
P-33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa-231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.25E-10	0.00E+00	0.00E+00	1.89E-12	5.35E-10	0.00E+00	0.00E+00	1.96E-10	2.06E-07	2.06E-07
Pa-233	7.67E-06	1.06E-05	3.51E-03	3.32E-03	4.25E-04	2.49E-03	3.76E-03	2.81E-05	5.23E-03	1.69E-03	2.97E-04	1.52E-03	3.14E-02	1.64E-05	3.14E-02
Pa-234	3.98E-03	1.41E-02	3.14E-03	1.08E-02	4.26E-09	1.22E-05	1.84E-04	1.14E-08	2.05E-05	1.25E-05	1.17E-06	1.45E-01	9.23E-04	5.42E-06	1.45E-01
Pa-234m	1.41E-01	1.19E+01	1.44E+00	3.55E-01	2.27E-01	7.99E-01	6.88E-02	4.05E-01	4.28E-01	1.08E-02	1.79E-01	2.35E-01	5.12E-01	3.98E+00	1.19E+01
Pb-205	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-14
Pb-209	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Pb-210	0.00E+00	0.00E+00	2.25E-05	1.01E-05	3.56E-04	4.60E-02	2.74E-06	0.00E+00	4.20E-11	5.94E-07	1.85E-11	3.60E-03	2.98E-05	2.10E-05	4.60E-02
Pb-212	2.62E-03	1.85E-06	1.35E-03	6.55E-03	1.08E-03	1.97E-02	1.80E-03	3.31E-06	1.03E-03	7.22E-07	4.98E-10	3.22E-02	1.10E-01	2.00E-04	1.10E-01
Pb-214	7.42E-05	6.49E-06	2.31E-05	1.95E-05	3.56E-04	4.60E-02	2.74E-06	0.00E+00	8.56E-09	5.95E-07	3.07E-10	3.97E-03	3.75E-05	2.03E-05	4.60E-02
Pd-107	1.10E-07	1.83E-10	0.00E+00	0.00E+00	0.00E+00	1.90E-08	0.00E+00	0.00E+00	0.00E+00	3.14E-08	1.44E-05	0.00E+00	0.00E+00	0.00E+00	1.44E-05
Pm-146	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.08E-06	1.63E-06	0.00E+00	0.00E+00	6.14E-06	0.00E+00	6.14E-06
Pm-147	5.92E-02	8.84E-02	7.46E-01	3.46E-01	1.80E+00	2.90E-02	1.73E-01	1.60E-02	1.91E-02	6.48E-01	3.19E-01	5.22E-01	7.24E-01	3.86E-01	1.80E+00
Po-210	0.00E+00	1.30E-06	2.25E-05	1.01E-05	1.12E-07	4.60E-02	2.74E-06	1.97E-06	4.20E-11	5.94E-07	0.00E+00	9.82E-04	2.96E-05	2.03E-05	4.60E-02
Po-212	1.50E-03	0.00E+00	3.29E-04	4.18E-03	6.94E-04	4.83E-03	1.05E-03	2.11E-06	6.59E-04	1.60E-08	0.00E+00	1.92E-02	7.08E-02	1.28E-04	7.08E-02
Po-213	0.00E+00	0.00E+00	9.78E-05	1.21E-03	2.14E-04	1.37E-03	3.20E-04	0.00E+00	1.79E-04	7.17E-11	0.00E+00	5.21E-03	2.23E-02	5.06E-07	2.23E-02
Po-214	0.00E+00	6.49E-06	0.00E+00	0.00E+00	3.56E-04	1.46E-08	2.74E-06	0.00E+00	4.20E-11	5.94E-07	0.00E+00	3.96E-03	3.75E-05	2.03E-05	3.96E-03
Po-216	2.34E-03	0.00E+00	1.34E-03	6.54E-03	1.07E-03	1.97E-02	1.80E-03	3.31E-06	1.03E-03	7.02E-07	0.00E+00	3.24E-02	1.10E-01	2.00E-04	1.10E-01
Po-218	0.00E+00	6.49E-06	2.25E-05	2.02E-05	3.56E-04	4.60E-02	2.74E-06	0.00E+00	4.20E-11	5.94E-07	0.00E+00	3.96E-03	3.75E-05	2.03E-05	4.60E-02
Pr-144	3.09E-03	1.81E-02	1.15E-01	4.50E-02	3.56E-01	4.87E-07	4.44E-03	1.62E-04	6.92E-03	2.32E-01	2.61E-01	3.61E-02	9.10E-02	1.38E-01	3.56E-01
Pr-144m	7.99E-07	9.08E-07	1.54E-03	4.35E-06	1.52E-06	0.00E+00	4.25E-05	0.00E+00	6.85E-09	1.16E-05	1.42E-06	7.98E-05	2.47E-05	0.00E+00	1.54E-03
Pt-193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.28E-06	4.93E-06	0.00E+00	0.00E+00	0.00E+00	1.30E-10	5.28E-06
Pu-238	3.31E-01	6.51E-01	3.94E+00	3.25E+00	2.54E+01	2.50E+01	9.25E+00	3.18E+00	9.11E+00	5.59E+00	5.41E-01	3.33E+00	1.28E+01	6.01E+00	2.54E+01
Pu-239	2.57E-02	1.98E-01	9.83E-01	1.01E+00	1.70E+00	1.14E+00	3.79E+00	1.40E+00	2.90E+00	8.17E-01	6.50E-01	1.45E+00	8.60E+00	2.69E+00	8.60E+00
Pu-240	7.30E-03	7.68E-02	2.74E-01	2.64E-01	4.76E-01	3.14E-01	8.68E-01	3.68E-01	6.68E-01	2.13E-01	6.25E-02	3.84E-01	1.95E+00	9.22E-01	1.95E+00
Pu-241	2.24E-01	2.24E+00	8.85E+00	6.26E+00	8.49E+00	6.24E+00	2.33E+01	4.58E+00	1.75E+01	5.89E+00	1.98E+00	8.95E+00	3.09E+01	7.06E+00	3.09E+01
Pu-242	1.11E-04	1.03E-03	7.64E-03	1.98E-02	5.05E-03	1.57E-02	3.37E-02	1.35E-01	7.10E-03	2.54E-03	2.90E-04	1.19E-02	3.63E-02	1.69E-03	1.35E-01
Pu-244	2.35E-15	5.10E-15	3.78E-16	1.79E-15	1.49E-15	4.05E-20	1.93E-09	7.80E-17	8.15E-17	2.84E-15	0.00E+00	4.69E-15	9.12E-10	1.81E-16	1.93E-09
Ra-224	2.34E-03	0.00E+00	1.34E-03	6.54E-03	1.07E-03	1.97E-02	1.80E-03	3.31E-06	1.03E-03	7.02E-07	0.00E+00	3.24E-02	1.10E-01	2.00E-04	1.10E-01
Ra-225	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.43E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Ra-226	3.18E-03	6.49E-06	2.25E-05	2.82E-05	3.58E-04	4.61E-02	2.75E-06	0.00E+00	6.64E-05	1.24E-04	1.67E-11	4.02E-03	1.12E-04	5.92E-05	4.61E-02
Ra-228	2.34E-03	0.00E+00	5.44E-05	2.78E-04	3.69E-05	1.25E-02	4.41E-05	3.31E-06	1.67E-04	7.02E-07	0.00E+00	4.31E-03	4.28E-03	1.97E-04	1.25E-02
Rb-86	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E-05	0.00E+00	0.00E+00	4.65E-05
Rb-87	8.59E-14	1.42E-16	0.00E+00	0.00E+00	0.00E+00	1.46E-11	0.00E+00	0.00E+00	0.00E+00	2.40E-11	1.12E-11	0.00E+00	0.00E+00	1.73E-05	1.73E-05
Rh-103m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.92E-06	0.00E+00	0.00E+00	2.25E-11	0.00E+00	1.70E-07	0.00E+00	1.29E-07	8.92E-06
Rh-106	6.77E-05	1.93E-04	1.87E-02	6.36E-04	3.52E-01	5.10E-07	4.37E-04	0.00E+00	6.60E-04	9.90E-04	2.09E-02	1.09E-02	2.11E-03	2.43E-05	3.52E-01
Rn-220	2.34E-03	0.00E+00	1.34E-03	6.54E-03	1.07E-03	1.97E-02	1.80E-03	3.31E-06	1.03E-03	7.02E-07	0.00E+00	3.24E-02	1.10E-01	2.00E-04	1.10E-01
Rn-222	0.00E+00	6.49E-06	2.25E-05	2.02E-05	3.56E-04	4.60E-02	2.74E-06	0.00E+00	4.11E-11	5.94E-07	0.00E+00	3.96E-03	3.75E-05	2.03E-05	4.60E-02

Projected	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max
Nuclide	**ST01**	**ST02**	**ST03**	**ST04**	**ST05**	**ST06**	**ST07**	**ST08**	**ST09**	**ST14**	**ST23**	**ET01**	**ET02**	**ET03**	**Max**
Ru-103	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.92E-06	0.00E+00	0.00E+00	2.25E-11	0.00E+00	1.70E-07	0.00E+00	1.29E-07	8.92E-06
Ru-106	2.34E-03	1.32E-02	5.68E-02	2.96E-03	3.54E-01	3.36E-15	2.06E-03	1.69E-04	9.44E-02	2.10E-03	2.10E-02	2.24E-02	2.14E-03	1.50E-04	3.54E-01
S-35	0.00E+00	2.96E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-07	0.00E+00	3.59E-21	0.00E+00	6.22E-09	2.96E-03
Sb-124	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.93E-10	0.00E+00	0.00E+00	0.00E+00	1.58E-10	0.00E+00	0.00E+00	0.00E+00	1.89E-08	1.89E-08
Sb-125	4.63E-02	1.35E-01	5.11E-02	1.77E-01	7.87E-01	1.87E-06	2.19E-02	2.35E-03	1.87E-02	6.13E-02	1.46E-02	1.13E-01	3.62E-03	2.62E-03	7.87E-01
Sb-126	1.76E-07	2.92E-10	0.00E+00	2.85E-09	1.63E-14	0.00E+00	0.00E+00	0.00E+00	1.11E-08	0.00E+00	2.30E-05	9.73E-09	1.30E-08	0.00E+00	2.30E-05
Sb-126m	1.76E-07	2.92E-10	6.50E-08	2.03E-08	3.13E-05	1.24E-03	8.14E-06	0.00E+00	3.71E-19	0.00E+00	2.67E-05	1.01E-05	6.52E-06	0.00E+00	1.24E-03
Sc-46	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.51E-07	0.00E+00	2.29E-21	0.00E+00	6.26E-09	2.51E-07
Se-75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.19E-08	0.00E+00	3.74E-04	1.45E-04	2.69E-10	3.74E-04
Se-79	3.21E-04	6.23E-04	6.33E-03	7.78E-04	3.97E-04	9.92E-03	1.50E-03	1.36E-05	1.33E-05	2.99E-06	4.78E-04	9.28E-03	1.14E-04	1.10E-07	9.92E-03
Sm-151	1.32E-04	2.12E-07	4.32E-03	3.21E-06	1.29E+00	1.22E+00	2.92E-02	1.22E-04	4.44E-04	9.02E-04	1.62E-02	1.60E-04	1.97E-03	5.51E-03	1.29E+00
Sn-113	0.00E+00	0.00E+00	7.25E-07	3.52E-08	0.00E+00	1.82E-09	1.11E-05	0.00E+00	2.56E-10	3.43E-09	6.41E-13	1.44E-06	2.07E-07	7.95E-08	1.11E-05
Sn-119m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-12	2.80E-20	0.00E+00	0.00E+00	6.81E-05	8.00E-12	0.00E+00	6.34E-07	6.17E-06	1.90E-07	6.81E-05
Sn-121	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-15	3.70E-07	0.00E+00	0.00E+00	6.16E-05	9.40E-03	0.00E+00	7.19E-16	1.98E-13	4.36E-10	9.40E-03
Sn-121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E-15	4.93E-07	0.00E+00	0.00E+00	7.89E-05	1.22E-02	0.00E+00	9.21E-16	2.29E-06	5.63E-10	1.22E-02
Sn-123	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-13	0.00E+00	0.00E+00	0.00E+00	1.01E-10	1.01E-10
Sn-126	1.83E-04	2.14E-06	2.03E-04	2.66E-05	3.24E-05	1.24E-03	1.41E-05	7.35E-07	1.15E-09	4.61E-04	9.24E-05	6.39E-05	4.30E-04	5.03E-09	1.24E-03
Sr-85	9.23E-06	2.47E-04	1.25E-03	0.00E+00	1.37E-07	0.00E+00	8.21E-07	0.00E+00	0.00E+00	0.00E+00	1.01E-04	1.54E-03	3.37E-05	1.81E-04	1.54E-03
Sr-89	0.00E+00	0.00E+00	1.69E-07	3.32E-70	4.05E-74	0.00E+00	0.00E+00	0.00E+00	1.85E-80	9.71E-11	0.00E+00	1.02E-69	2.65E-65	0.00E+00	1.69E-07
Sr-90	3.25E+00	4.70E+00	3.14E+01	1.73E+01	4.88E+01	4.00E+01	1.00E+01	3.94E+00	1.48E+01	5.73E+01	1.89E+01	2.52E+01	1.44E+02	2.34E+01	1.44E+02
Ta-182	1.59E-07	5.10E-03	9.43E-06	0.00E+00	5.10E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E-06	0.00E+00	1.56E-06	0.00E+00	7.47E-06	5.10E-03
Tc-99	5.32E-03	2.02E-02	3.86E-02	5.12E-02	4.72E-02	2.55E-02	2.00E-02	5.24E-03	3.10E-02	3.68E-02	3.76E-02	3.93E-02	9.03E-02	2.95E-02	9.03E-02
Te-123m	0.00E+00	0.00E+00	0.00E+00	1.62E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.97E-15	3.79E-13	0.00E+00	0.00E+00	2.11E-11	0.00E+00	1.62E-05
Te-125m	8.85E-03	2.00E-02	2.85E-03	5.20E-03	6.18E-03	5.43E-08	4.64E-03	1.02E-03	1.13E-04	1.38E-02	6.50E-04	5.20E-03	5.51E-04	5.97E-04	2.00E-02
Th-228	2.34E-03	3.10E-06	1.34E-03	6.54E-03	1.07E-03	1.97E-02	1.80E-03	3.31E-06	1.03E-03	7.02E-07	3.04E-11	3.24E-02	1.10E-01	2.00E-04	1.10E-01
Th-229	0.00E+00	0.00E+00	1.02E-04	1.26E-03	2.22E-04	1.42E-03	3.33E-04	0.00E+00	1.86E-04	7.44E-11	0.00E+00	5.42E-03	2.32E-02	5.18E-07	2.32E-02
Th-230	2.87E-04	0.00E+00	4.10E-05	2.76E-04	3.93E-04	4.63E-02	4.37E-05	3.31E-06	2.03E-04	6.17E-07	0.00E+00	6.75E-03	4.87E-03	1.85E-04	4.63E-02
Th-231	1.74E-03	5.63E-03	3.60E-02	1.14E-01	3.51E-02	2.70E-02	1.15E-03	9.11E-03	2.69E-03	7.21E-04	1.61E-04	6.40E-03	6.36E-03	1.22E-03	1.14E-01
Th-232	2.34E-03	3.53E-06	5.44E-05	2.94E-04	3.69E-05	1.25E-02	2.26E-04	1.63E-05	1.68E-04	9.75E-07	0.00E+00	4.52E-03	4.28E-03	1.98E-04	1.25E-02
Th-234	1.45E-01	1.19E+01	1.45E+00	3.66E-01	2.27E-01	7.99E-01	6.88E-02	4.05E-01	4.28E-01	1.08E-02	1.79E-01	3.80E-01	5.12E-01	3.98E+00	1.19E+01
Tl-204	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-208	8.57E-04	1.09E-07	1.85E-04	2.35E-03	3.86E-04	2.71E-03	5.95E-04	1.19E-06	3.68E-04	9.01E-09	1.49E-08	1.08E-02	3.97E-02	7.19E-05	3.97E-02
Tl-209	0.00E+00	0.00E+00	4.08E-06	5.09E-05	8.72E-06	5.79E-05	1.28E-05	0.00E+00	7.15E-06	2.60E-12	0.00E+00	2.08E-04	8.59E-04	1.16E-08	8.59E-04
Tm-170	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.61E-07	1.65E-05	0.00E+00	1.65E-05
Tm-171	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.81E-06	0.00E+00	0.00E+00	8.71E-04	0.00E+00	8.71E-04
U-232	1.18E-06	1.68E-07	3.90E-02	7.82E-03	1.03E-03	7.49E-03	1.78E-03	4.65E-08	9.08E-04	3.22E-05	6.99E-08	2.78E-02	1.06E-01	4.43E-05	1.06E-01
U-233	6.22E-03	2.72E-02	1.12E-01	4.47E-01	2.03E+00	5.29E-01	1.55E-01	1.87E-01	2.48E-01	6.88E-03	3.45E-02	2.08E+00	8.28E+00	2.06E+00	8.28E+00
U-234	7.69E-02	3.16E+00	1.75E+00	4.25E+00	1.82E+00	3.02E-01	1.42E-01	2.00E-01	2.19E-01	4.85E-02	8.30E-02	4.33E-01	6.60E-01	1.09E+00	4.25E+00
U-235	6.15E-03	2.19E-01	5.83E-02	1.18E-01	4.31E-01	2.90E-02	5.65E-03	9.22E-03	6.50E-03	3.00E-03	2.06E-03	1.51E-02	1.13E-02	5.16E-03	4.31E-01
U-236	3.27E-03	1.53E-01	3.93E-02	2.58E-02	2.57E-02	1.05E-02	4.27E-03	4.61E-04	2.47E-03	5.78E-04	2.11E-03	2.61E-02	2.38E-02	6.01E-05	1.53E-01
U-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.52E-09	0.00E+00	0.00E+00	2.02E-09	1.41E-08	0.00E+00	0.00E+00	0.00E+00	9.06E-08	9.06E-08
U-238	1.49E-01	1.19E+01	1.45E+00	3.75E-01	3.28E+00	8.05E-01	9.40E-02	4.08E-01	4.28E-01	1.10E-02	2.98E-01	4.71E+00	5.56E-01	3.98E+00	1.19E+01
W-181	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.71E-08	0.00E+00	0.00E+00	0.00E+00	1.99E-09	0.00E+00	0.00E+00	0.00E+00	1.72E-08	6.71E-08

Projected Nuclide	Max ST01	Max ST02	Max ST03	Max ST04	Max ST05	Max ST06	Max ST07	Max ST08	Max ST09	Max ST14	Max ST23	Max ET01	Max ET02	Max ET03	Max Max
W-185	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
W-188	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y-90	3.19E+00	4.61E+00	3.04E+01	1.72E+01	4.89E+01	3.15E+01	1.01E+01	3.98E+00	1.39E+01	5.73E+01	1.85E+01	2.49E+01	1.44E+02	2.34E+01	1.44E+02
Y-91	0.00E+00	0.00E+00	0.00E+00	5.81E-63	7.10E-67	0.00E+00	0.00E+00	0.00E+00	2.58E-71	1.93E-10	0.00E+00	1.78E-62	4.64E-58	0.00E+00	1.93E-10
Zn-65	4.78E-02	1.33E-02	1.51E-02	4.41E-02	2.67E-02	1.88E-06	7.36E-02	8.49E-03	8.47E-04	1.40E-01	3.55E-07	4.37E-02	9.14E-04	5.75E-03	1.40E-01
Zr-93	2.71E-05	2.26E-05	2.02E-06	8.00E-06	6.63E-06	7.96E-07	3.29E-05	3.47E-07	2.97E-05	1.46E-04	2.17E-03	2.02E-05	4.84E-05	1.21E-04	2.17E-03
Zr-95	4.54E-03	4.23E-02	1.08E-02	6.91E-03	1.18E-02	5.91E-11	1.00E-01	1.61E-02	1.02E-03	4.33E-02	3.03E-03	2.17E-02	1.03E-03	1.37E-03	1.00E-01

C.3.2 2065 Projected Vault Closure Inventories

For projecting inventories associated with the vaults (i.e., LAWV and ILV) the situation where a facility becomes volumetrically full prior to filling based on activity was included in the analyses. Based on the SWM monthly status reports projections of DU volume and SOF were performed assuming linear relationships between these variables and calendar year. A summary of these predictions is shown in Figure C-1.

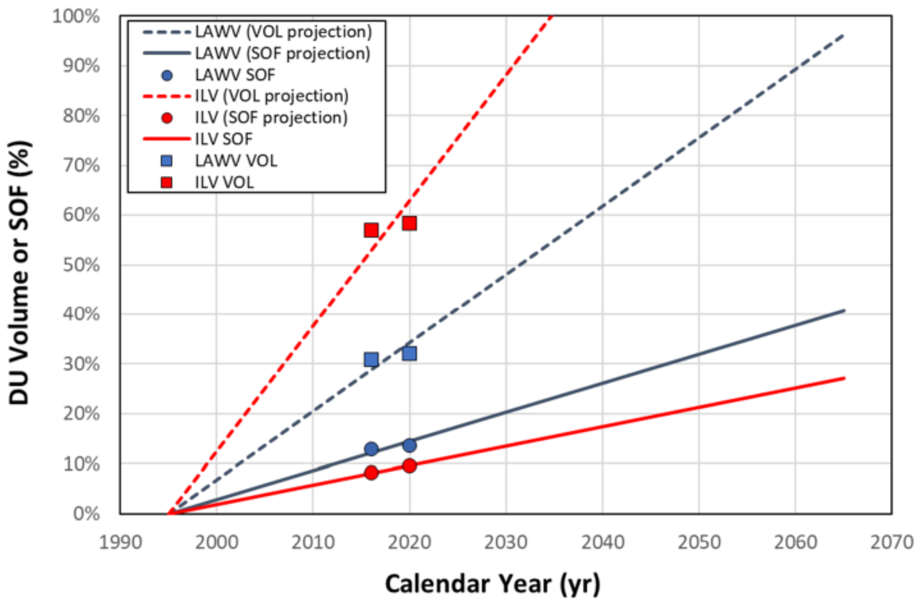


Figure C-1. Projections of total volume and SOF versus calendar year for the E-Area vaults.

The data points were computed from two SWM monthly reports (i.e., March 2016 and March 2020). The lines represent the linear projections passing through these points (i.e., dashed lines being volume projections while solid lines being SOF projections).

As shown in Figure C-1:

- the ILV is projected to be volumetrically full prior to reaching a SOF limit. It becomes volumetrically filled by the year ~2033.3 with an estimated SOF of ~14.8%; while
- the LAWV is projected to still be unlimited by 2065 with a SOF of ~40.7% and a volume% of ~96.1%.

LAWV Details

For the LAWV, based on the March 2020 data provided in Table C-6, we have the settings:

- Administration Limit – 95%
- Interim Measures Limit – 95%
- DU SOF – 13.7% (end of March)
- Max SOF at 2065 – 40.7%

The projected closure inventories for the LAWV, based on its status as of March 2020, becomes:

$$I_{LAWV,i}^{proj-2020} = \left[(0.407)\left(\frac{95.0}{95.0}\right)\left(\frac{1}{0.137}\right)\right] \times I_{LAWV,i}^{WITS} = [2.971] \times I_{LAWV,i}^{WITS} \quad \text{(C-5)}$$

and again, the max of both projections is employed:

$$I_{LAWV,i}^{proj} = \text{Max}\left[I_{LAWV,i}^{proj-2016}, I_{LAWV,i}^{proj-2020}\right] \quad \text{(C-6)}$$

ILV Details

For the ILV, based on the March 2020 data provided in Table C-6, we have the settings:

- Administration Limit – 95%
- Interim Measures Limit – 95%
- DU SOF – 9.6% (end of March)
- Max SOF at 2065 – 14.8%

The projected closure inventories for the ILV, based on its status as of March 2020, becomes:

$$I_{ILV,i}^{proj-2020} = \left[(0.148)\left(\frac{95.0}{95.0}\right)\left(\frac{1}{0.096}\right)\right] \times I_{ILV,i}^{WITS} = [1.542] \times I_{ILV,i}^{WITS} \quad \text{(C-7)}$$

and again, the max of both projections is employed:

$$I_{ILV,i}^{proj} = \text{Max}\left[I_{ILV,i}^{proj-2016}, I_{ILV,i}^{proj-2020}\right] \quad \text{(C-8)}$$

The maximum 2065 projected inventories for the vaults (i.e., LAWV and ILV), along with the values for the Naval pads (i.e., NRCDAG and NRCDAG) are listed in Table C-8.

Naval Pad Details

For the Naval Pads, the details are provided in Appendix H. Very different logic applies to the Naval Pads, and as such, their discussion was placed in a separate appendix. The projected inventories listed in Table C-8 correspond to those values listed in Table H-5. The only difference between the two separate listings is that Appendix H only lists parent radionuclides associated with the Naval Pads versus the entire WITS list of radionuclides

Table C-8. Composited 2065 closure inventories for radionuclides by existing vault and Naval pad disposal types.

Projected Nuclide	Max LAWV	Max ILV	Max NRC-S	Max NRC-G
Ac-225	5.82E-04	0.00E+00	0.00E+00	0.00E+00
Ac-227	0.00E+00	0.00E+00	0.00E+00	1.03E-12
Ac-228	1.84E-03	3.20E-05	0.00E+00	0.00E+00
Ag-108	5.53E-07	0.00E+00	1.15E-07	1.89E-10
Ag-108m	2.49E-04	7.18E-05	1.32E-06	2.17E-09
Ag-109m	0.00E+00	0.00E+00	2.11E-02	0.00E+00
Ag-110	7.80E-07	0.00E+00	1.48E-04	4.17E-09
Ag-110m	7.97E-05	2.12E-05	4.92E-02	3.07E-07
Al-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am-241	1.36E+00	1.18E+00	3.52E-01	4.98E-04
Am-242	0.00E+00	0.00E+00	1.03E-03	0.00E+00

Projected Nuclide	Max LAWV	Max ILV	Max NRC-S	Max NRC-G
Am-242m	1.51E-03	1.89E-03	2.29E-03	2.61E-06
Am-243	6.48E-03	3.11E-03	2.78E-03	2.41E-03
Ar-37	0.00E+00	2.54E-07	0.00E+00	0.00E+00
Ar-39	2.92E-05	7.35E+00	0.00E+00	0.00E+00
At-217	5.82E-04	0.00E+00	0.00E+00	0.00E+00
Ba-133	2.18E-01	0.00E+00	2.09E-03	0.00E+00
Ba-137m	2.24E+02	4.93E+02	6.73E+00	8.36E-02
Ba-140	0.00E+00	0.00E+00	4.90E-08	0.00E+00
Be-10	0.00E+00	0.00E+00	2.16E-05	5.07E-12
Be-7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-210	9.30E-02	1.09E-06	0.00E+00	0.00E+00
Bi-211	6.23E-05	5.65E-07	0.00E+00	0.00E+00
Bi-212	1.42E-02	2.29E-04	2.60E-08	0.00E+00
Bi-213	5.82E-04	0.00E+00	0.00E+00	0.00E+00
Bi-214	1.17E-01	1.37E+00	0.00E+00	2.02E-13
Bk-247	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bk-249	0.00E+00	0.00E+00	2.07E-08	0.00E+00
C-14	8.75E-01	1.69E+03	1.39E+02	1.43E+00
Ca-41	4.25E-05	0.00E+00	0.00E+00	0.00E+00
Ca-45	0.00E+00	0.00E+00	1.49E-02	2.49E-07
Cd-109	7.82E-06	0.00E+00	4.02E-02	0.00E+00
Cd-113	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd-113m	8.12E-05	1.50E-06	1.33E-02	0.00E+00
Cd-115m	0.00E+00	0.00E+00	9.76E-04	0.00E+00
Ce-139	8.50E-10	0.00E+00	0.00E+00	0.00E+00
Ce-141	0.00E+00	0.00E+00	4.94E-03	0.00E+00
Ce-144	6.21E+00	7.94E-01	5.80E+00	5.05E-03
Cf-249	6.05E-06	2.82E-03	1.95E-10	9.70E-13
Cf-250	2.13E-03	0.00E+00	0.00E+00	0.00E+00
Cf-251	2.62E-05	1.63E-03	4.35E-12	2.62E-14
Cf-252	1.85E-02	0.00E+00	0.00E+00	0.00E+00
Cl-36	5.47E-03	1.33E-04	1.27E-02	6.77E-08
Cm-242	2.06E-04	1.49E-04	5.22E+00	9.48E-01
Cm-243	5.90E-04	1.98E-02	2.13E-03	3.24E-06
Cm-244	6.52E+00	1.13E+00	2.55E-01	1.92E-01
Cm-245	7.73E-03	4.42E-03	1.64E-05	1.01E-07
Cm-246	1.36E-02	5.18E-05	8.98E-06	3.06E-06
Cm-247	2.76E-11	2.64E-02	8.33E-12	3.93E-14
Cm-248	8.50E-12	1.04E-05	2.59E-11	1.89E-11
Co-57	5.13E-08	9.06E-05	0.00E+00	0.00E+00
Co-58	2.99E-01	6.59E+00	2.07E+04	2.07E+04
Co-60	1.51E+02	1.50E+02	9.85E+04	9.85E+04
Cr-51	3.45E-06	2.47E-02	7.47E+03	7.47E+03
Cs-134	1.16E+01	1.66E+00	1.51E+01	5.33E-02
Cs-135	1.52E-09	0.00E+00	5.26E-05	5.14E-07
Cs-137	9.47E+02	6.27E+02	7.14E+00	5.60E-02
Eu-152	7.44E+00	2.70E-02	6.23E-04	0.00E+00
Eu-154	6.57E+00	4.13E-01	5.16E-01	3.18E-04
Eu-155	6.53E-02	2.83E-02	1.18E-01	5.97E-06
Fe-55	4.57E+02	2.33E+02	9.03E+04	2.46E+02
Fe-59	6.93E-08	8.23E-02	7.48E+03	1.90E+00
Fr-221	5.82E-04	0.00E+00	0.00E+00	0.00E+00
H-3	1.91E+08	7.17E+07	1.34E+02	3.24E-01
Hf-175	0.00E+00	3.34E-05	7.46E+03	7.46E+03
Hf-181	3.70E-09	2.96E-02	6.58E+01	6.58E-01
Hg-203	1.99E-16	0.00E+00	0.00E+00	0.00E+00
Ho-166m	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-129	5.73E-04	3.37E-02	1.48E-05	1.48E-05
In-113m	7.13E-17	2.59E+01	4.87E+03	4.87E+03
In-114	0.00E+00	0.00E+00	2.02E+00	0.00E+00

Projected Nuclide	Max LAWV	Max ILV	Max NRC-S	Max NRC-G
In-114m	0.00E+00	0.00E+00	3.80E+00	0.00E+00
Ir-192	0.00E+00	0.00E+00	1.30E-02	0.00E+00
Ir-192m	0.00E+00	0.00E+00	2.47E-07	0.00E+00
K-40	1.88E-06	7.51E-03	0.00E+00	0.00E+00
Kr-85	8.24E+00	3.63E+01	2.61E-01	5.71E-03
La-140	0.00E+00	0.00E+00	5.65E-08	0.00E+00
Mn-54	3.21E-01	1.04E+00	1.39E+03	1.39E+03
Mo-93	9.29E-03	1.33E-03	1.43E+00	1.43E+00
Na-22	1.33E-06	0.00E+00	0.00E+00	0.00E+00
Nb-93m	7.93E+00	2.63E+00	7.46E+03	7.46E+03
Nb-94	3.43E-01	9.70E-02	6.54E+00	6.54E+00
Nb-95	8.37E-02	1.57E-01	1.31E+05	1.72E+02
Nb-95m	2.22E-05	1.73E-04	1.31E+03	8.30E-01
Ni-59	4.88E+00	1.70E+00	1.73E+03	8.23E-01
Ni-63	7.88E+02	2.07E+02	2.01E+05	1.53E+02
Np-237	1.41E-01	2.15E-02	4.03E-06	4.79E-09
Np-239	5.64E-06	1.51E-07	1.26E-03	0.00E+00
P-33	0.00E+00	0.00E+00	6.32E-03	0.00E+00
Pa-231	0.00E+00	0.00E+00	0.00E+00	2.24E-12
Pa-233	8.63E-02	2.59E-04	0.00E+00	0.00E+00
Pa-234	5.99E-05	2.31E-01	0.00E+00	6.70E-11
Pa-234m	2.45E+00	6.60E-01	2.61E-06	5.16E-08
Pb-205	0.00E+00	0.00E+00	5.68E-08	0.00E+00
Pb-209	5.82E-04	0.00E+00	0.00E+00	0.00E+00
Pb-210	9.30E-02	1.37E+00	0.00E+00	0.00E+00
Pb-212	1.43E-02	2.29E-04	2.60E-08	0.00E+00
Pb-214	1.17E-01	1.37E+00	0.00E+00	2.02E-13
Pd-107	0.00E+00	0.00E+00	3.99E-06	0.00E+00
Pm-146	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pm-147	3.32E+01	6.59E+00	4.23E+00	3.05E+00
Po-210	9.30E-02	1.09E-06	6.24E-03	0.00E+00
Po-212	2.47E-03	9.39E-07	1.66E-08	0.00E+00
Po-213	5.58E-04	0.00E+00	0.00E+00	0.00E+00
Po-214	1.17E-01	1.37E+00	0.00E+00	2.02E-13
Po-216	1.43E-02	2.29E-04	2.60E-08	0.00E+00
Po-218	1.17E-01	1.37E+00	0.00E+00	2.02E-13
Pr-144	6.06E+00	6.82E-01	4.73E+00	2.20E-01
Pr-144m	3.31E-03	6.04E-03	6.60E-02	0.00E+00
Pt-193	1.89E-03	5.07E-05	1.14E-04	0.00E+00
Pu-238	9.70E+00	7.18E+00	2.69E-01	1.18E-02
Pu-239	4.81E+00	1.40E+00	1.23E-01	1.23E-01
Pu-240	1.02E+00	1.37E+00	1.11E-01	1.82E-03
Pu-241	3.60E+01	7.58E+00	3.40E+01	1.37E-02
Pu-242	5.40E-03	7.37E-02	4.07E-04	3.00E-06
Pu-244	5.12E-15	2.06E-02	2.77E-11	2.77E-11
Ra-224	1.43E-02	2.29E-04	2.60E-08	0.00E+00
Ra-225	5.82E-04	3.82E-16	0.00E+00	0.00E+00
Ra-226	1.17E-01	1.18E+00	0.00E+00	2.02E-13
Ra-228	1.08E-03	3.20E-05	0.00E+00	0.00E+00
Rb-86	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rb-87	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rh-103m	2.90E-03	1.22E-04	3.95E-02	0.00E+00
Rh-106	3.70E-01	7.72E-02	6.65E+00	4.85E-03
Rn-220	1.43E-02	2.29E-04	2.60E-08	0.00E+00
Rn-222	1.17E-01	1.37E+00	0.00E+00	2.02E-13
Ru-103	2.90E-03	1.22E-04	4.87E-02	0.00E+00
Ru-106	5.20E-01	1.95E-01	8.19E+00	6.60E-01
S-35	0.00E+00	0.00E+00	1.82E-01	2.68E-03
Sb-124	0.00E+00	0.00E+00	1.89E+00	6.23E-07
Sb-125	1.77E+01	4.81E-01	4.07E+04	4.07E+04
Sb-126	0.00E+00	0.00E+00	2.37E-06	0.00E+00

Projected Nuclide	Max LAWV	Max ILV	Max NRC-S	Max NRC-G
Sb-126m	0.00E+00	0.00E+00	1.68E-05	0.00E+00
Sc-46	0.00E+00	0.00E+00	5.96E-01	3.26E-03
Se-75	0.00E+00	0.00E+00	3.27E-01	3.15E-11
Se-79	2.79E-01	4.46E-04	1.22E-03	1.96E-07
Sm-151	5.63E-04	6.89E-02	9.18E-02	8.11E-06
Sn-113	3.21E-10	8.95E-06	4.87E+03	1.75E-08
Sn-119m	4.76E-01	1.67E-04	8.09E+04	1.68E-07
Sn-121	7.01E-02	1.23E-03	6.41E+00	1.94E-10
Sn-121m	6.51E-02	6.29E-04	1.71E+01	2.50E-10
Sn-123	0.00E+00	1.05E-06	2.35E+03	2.36E-11
Sn-126	6.88E-04	9.73E-04	8.25E-05	5.89E-07
Sr-85	1.82E-03	0.00E+00	0.00E+00	0.00E+00
Sr-89	2.58E-03	0.00E+00	7.50E-01	1.20E-13
Sr-90	7.66E+02	1.91E+02	5.39E+00	5.57E-02
Ta-182	0.00E+00	6.14E-05	1.76E+04	5.54E-02
Tc-99	3.91E-01	2.72E-01	1.93E-01	1.44E-03
Te-123m	0.00E+00	0.00E+00	6.09E+02	0.00E+00
Te-125m	4.27E+00	7.85E-02	2.54E+04	2.82E-01
Th-228	1.43E-02	2.29E-04	2.59E-08	0.00E+00
Th-229	5.82E-04	0.00E+00	0.00E+00	0.00E+00
Th-230	1.51E-04	3.25E-05	0.00E+00	2.14E-11
Th-231	1.43E-02	3.46E-03	2.81E-08	2.41E-09
Th-232	1.08E-03	8.79E-05	3.52E-08	1.24E-10
Th-234	2.88E+00	8.91E-01	2.61E-06	5.16E-08
Tl-204	5.20E-07	0.00E+00	0.00E+00	0.00E+00
Tl-208	1.40E-03	2.05E-07	0.00E+00	0.00E+00
Tl-209	2.34E-05	0.00E+00	0.00E+00	0.00E+00
Tm-170	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tm-171	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	1.28E-02	1.90E-04	4.77E-06	1.95E-06
U-233	9.20E-01	3.69E-01	7.84E-06	7.94E-09
U-234	1.61E+00	5.77E-01	2.56E-05	1.45E-04
U-235	5.14E-02	1.82E-02	6.94E-07	6.67E-06
U-236	1.27E-01	7.45E-03	6.58E-05	3.23E-11
U-237	0.00E+00	0.00E+00	6.87E-05	0.00E+00
U-238	2.48E+00	1.37E+00	2.32E-05	1.43E-04
W-181	0.00E+00	0.00E+00	3.31E+00	0.00E+00
W-185	0.00E+00	0.00E+00	9.57E+00	0.00E+00
W-188	0.00E+00	0.00E+00	2.79E-02	0.00E+00
Y-90	7.62E+02	1.82E+02	5.39E+00	5.55E-02
Y-91	0.00E+00	0.00E+00	3.69E+00	4.34E-13
Zn-65	2.63E-01	7.48E-01	1.13E+01	4.05E+00
Zr-93	1.63E-02	3.61E-04	7.46E+03	2.62E-04
Zr-95	5.03E-02	6.68E-02	6.16E+04	1.82E+00

Appendix D. Gamma-Ray Factors Limiting Trenches and LAWV Inventories

During disposal operations at the ELLWF disposal units, worker protection from a radiological perspective is maintained by limiting the amount of surface radiation exposure that workers can receive. Radiation levels (i.e., mRads/hr or mR/hr) are monitored outside of specific waste packages. For example, B-25 boxes are routinely disposed of in STs, ETs, and the LAWV. Based on conservative assumptions, for gamma-ray emitting radionuclides inventory limits have been computed and are discussed in this appendix.

D.1 Radiation Package Protection Limits

For worker protection, procedures are in place (Manual 1S, 5.1.1) that define specific Rad limits for each DU type such as (i.e., the following bullets were directly extracted from Manual 1S, 5.1.1):

- **ET** – Drive-in excavated trench primarily for containerized B-25, B-12, SeaLand, and other stackable containers or components. This DU is restricted to wastes radiating less than or equal to 200 mR/hr at 5 cm from the unshielded final disposal container;
- **ST** – Excavated rows of trenches where waste containers are placed by crane, or where loose waste is dumped at grade and pushed into trench by dozer. This disposal unit waste is comprised of approved containers and/or radiologically contaminated soil, decontamination and decommissioning debris, rubble, wood, animal carcasses, spent metal components, equipment and other non-prohibited waste. Per conversation with SWE, this DU is restricted to wastes radiating less than or equal to 300 mR/hr at 5 cm from the unshielded final disposal container;
- **CIG** – Is a trench similar to a Slit Trench; for disposal of radiologically contaminated equipment and other containerized non-prohibited waste that is encapsulated in grout. This disposal unit is primarily for waste that exceeds Slit Trench radiological disposal limits but demonstrated to be a cost-effective alternative to LAWV or ILV disposal. This DU is restricted to wastes radiating less than or equal to 300 mR/hr at 5 cm from the unshielded final disposal container;
- **LAWV** – Above grade concrete vault is for disposal of stackable LLW containers that exceeds trench radionuclide disposal limits; restricted to waste radiating less than or equal to 100 mR/hr at 30 cm from the unshielded final disposal container;
- **ILV** – no direct worker contact; and
- **NRCDA** – no direct worker contact.

Based on the above operating constraints, upper level inventory bounds for gamma-ray emitting radionuclides can be computed and employed to limit potential closure inventory values.

D.2 Gamma-Ray Factors

For a typical B-25, box Verst (2020) computed gamma-ray factors (mRad/hr-Ci) based on the following assumptions:

- Inside dimensions set to 6.0 ft long by 3.83 ft wide by 3.917 ft high;
- B-25 boxes can be either 12 or 14 gauge thick. To be conservative, use of 12-gauge walls were chosen (i.e., 0.1046 inches thick);
- Average density of B-25 metal walls = 8.0 g/ml;

- Median density of SRS Uncompacted B-25 Boxes = 0.1357 g/ml and uniformly distributed throughout the entire box. This number was computed based on available SWM measurements taken for 3767 B-25 boxes (Phifer and Wilhite 2001);
- 1S Manual, Chapter 5 (SRNS 2014) indicates that each of the four sides of a B-25 box are to be measured. Detector locations to be at the vertical midpoint at 5 and at 30 cm from outer wall; and
- Due to symmetry there are two unique locations. The location associated with the midpoint on the B-25's long side (i.e., the 6 ft long wall) was chosen.

Verst (2020) ran SCALE calculations to compute gamma-ray factors for all available radionuclides in the SCALE database (i.e., 1277 radionuclides). Not all of the 1,252 radionuclides being employed in the GW screening were available, but the majority of gamma-ray emitting ones were. Verst (2020) ran two sets of cases:

- Detector at 5 cm from wall surface (reflects the trench requirements); and
- Detector at 30 cm from wall surface (reflects the LAWV requirements).

D.3 Maximum Number of B-25 Boxes per DU Type

The maximum number of B-25 boxes that can fit into a given DU generally requires use of a packing algorithm. Instead, an upper bound estimate can be quickly achieved by computing the ratio of the total waste volume of a DU versus the waste volume of an individual B-25 box. Based on the geometry for a standard B-25 box the inside free volume of a box is ~90.0 ft^3. Given the uncompacted height of a DU's waste zone and the aerial extent of its waste zone footprint (see Hamm 2019, for current DU footprint sizes), total available waste zone volumes for every DU within E-Area can be estimated. The coordinates and footprint areas provided in Hamm (2019), along with uncompacted waste zones heights, are used to compute total waste zone volumes for each DU type (i.e., Trenches and LAWV). The resulting numbers are listed in Table D-1.

Table D-1. Maximum number of B-25 boxes and radiation limits by disposal unit type.

Disposal Unit Type	Nominal DU Volume ft^3	Total E-Area Volume by DU Type, ft^3	Number of DUs	Avg Generic DU volume (ft3)	Max number of B-25 per generic DU
ET	1,700,000	14,052,800	9	1,561,422	17,347
ST & CIG	1,040,000	30,861,390	20	1,543,069	17,143
LAWV	1,100,000	1,100,000	1	1,100,000	12,221

D.4 Trench and LAWV Inventory Limits

The application of a near-surface radiation constraint on packages to be buried only applies to trench and LAWV operations. The following parameter settings were used for computing inventory limits based on the above computed gamma-ray factors (see Table D-2):

- For trenches (i.e., STs, ETs, and CIGs) – 300 mRad/hr limit based on a 5 cm detector distance from the B-25 walls (conservatively larger radiation limit used for the generic trench model) and 17,143 B-25 boxes; and
- For LAWV – 100 mRad/hr limit based on a 30 cm detector distance from the B-25 walls and 12,221 B-25 boxes.

Table D-2. Maximum number of B-25 boxes and radiation limits by disposal unit type.

Disposal Unit Type	Max Number of B-25 Boxes	Rad Limit per B-25 Box (mR/hr-box)	Max Rad Limit per DU Type (R/hr)
ET	17,347	200	3,469.4
ST & CIG	17,143	300	5,142.9
LAWV	12,221	100	1,222.1

As shown in Table D-2, the maximum radiation trench limit is for ST & CIG trenches versus ET trenches. For the generic trench screening model this maximum value was chosen. The value shown in Table D-2 for the LAWV was chosen for the LAWV screening model.

As such, for each screening DU model (i.e., generic Trench and LAWV), inventory limits based on gamma-ray factors can be computed for each gamma-ray emitting radionuclide, by the following equation:

$$I_{DU,i}^{gam} = \frac{R_{DU} N_{DU}}{F_i^{gam}} \tag{D-1}$$

where

$I_{DU,i}^{gam}$ .... Gamma-ray emitting radionuclide i inventory limit based on gamma-ray factors for a specific DU type (Ci)

R_{DU} .... Rad limit for specific DU type (mRad/hr)

N_{DU} .... Maximum number of B-25 boxes within a specific DU type (-)

F_i^{gam} .... Gamma-ray factor for radionuclide i (mRad/hr-Ci)

These limits are considered to be "very" conservative based on the assumptions that:

- The entire radiation source is assumed to be coming from a single radionuclide (i.e., within a given B-25 for every B-25 box within the DU); and
- Maximum number of B-25 boxes within a DU not accounting for spacing (i.e., physical packing limitations are not being considered).

Based on Eq. (D-1) 2,554 gamma-ray factors were computed (i.e., 2x1277 – SCALE entries; two units, Trench and LAWV, for 1277 radionuclides) and are not being listed in this report. These computed factors are maintained within an Excel Spreadsheet that was placed in a key secure PA2022 folder.

Appendix E. Container Weight Limiting Trenches and LAWV Inventories

During disposal operations at the E-Area Low-Level-Waste disposal units, packages such as B-25 boxes historically have had a total waste weight (i.e., weight of waste contents excluding metal box weight) that varied significantly. A B-25 box has the nominal geometry (Phifer and Wilhite, 2001) as listed in Table E-1. The nominal inside free volume is 90.0 ft^3.

Table E-1. Nominal dimensions of a B-25 box.

	Length (ft)	Width (ft)	Height (ft)
Inside Dimensions	6.000	3.830	3.917
Outside Dimensions	6.078	3.911	4.323

To compute the typical weight of waste content contained within a B-25 box, density data provided by Phifer and Wilhite (2001) was employed. A large number of B-25 boxes have been weighed and the resulting data, as reported in terms of uncompacted densities by Phifer and Wilhite (2001), are summarized in Table E-2.

Table E-2. Measured weight of waste contained within B-25 boxes.

ET / LAWV Container Category	Number of Boxes in Sample	Average Density (g/ml)	Standard Deviation (g/ml)	Minimum Density (g/ml)	Maximum Density (g/ml)	Median Density (g/ml)	Average Weight (g)
SRS Uncompacted B-25 Boxes	3767	1.673E-01	1.291E-01	3.024E-03	1.183E+00	1.357E-01	4.264E+05

Given the average waste density and the nominal inside volume of a typical B-25 box, the average weight (g) of waste content is also provided in Table E-2. As the data in Table E-2 indicates, an approximately 77% variation in waste weight was observed (i.e., at the one-sigma level). The average value is chosen here since a large number of B-25 boxes (as shown in Table E-3) is required to fill up any given DU and as stated below other conservative assumptions are considered.

Table E-3. Maximum number of B-25 boxes that can be buried within a DU by DU type.

DU Type	Max Number of B-25 Boxes
Engineered Trench	17,347
Slit Trench	17,143
CIG Trench (current loading)	4,549
LAW Vault	12,221

By making the conservative assumptions that:

- every package entering a given DU contains the maximum amount of a specific radionuclide (i.e., an upper bound estimate of the weight fraction within a B-25 box corresponding to a specific radionuclide is imposed); and
- the maximum number of B-25 boxes are placed within a this given DU; then

an upper limit on the amount of a specific radionuclide that can exist within a given DU can be estimated. Radionuclide weight limits imposed on all DUs that routinely accept B-25 boxes (i.e., trenches and LAWV) have been computed for the original list of 1,252 radionuclides. Details on the weight limits are discussed below.

E.1 Package Weight Limits

For each GW screening DU model (i.e., generic Trench and LAWV), inventory limits based on weight can be computed for each radionuclide of interest, by the following equations:

$$I_{DU,i}^{wt} = A_{sp,i} W_{DU,i} \tag{E-1}$$

given

$$W_{DU,i} = X_i W_{DU} \tag{E-2a}$$

$$W_{DU} = N_{DU} W_{B25} \tag{E-2b}$$

where

$I_{DU,i}^{wt}$ .... Weight-based inventory limit for radionuclide i for a specific DU type (Ci)
$A_{sp,i}$ .... Specific activity for radionuclide i (Ci/g)
N_{DU} .... Maximum number of B-25 boxes within a specific DU type (-)
W_{DU} .... Total weight of waste only within a given DU type (g)
$W_{DU,i}$ .... Total weight of radionuclide i within a given DU type (g)
W_{B25} .... Total allowed weight of waste only within a B-25 box (g)
X_i .... Weight fraction of radionuclide i within a B-25 box (-)

In the above equations the weight fraction assumed for radionuclide i within a given B-25 box (X_i) must be established. To estimate this weight-fraction a series of runs were made where assumed values were employed to compute inventory limits by Eq. (E-1) for each of the 1,252 radionuclides for both the trench and LAWV models. These limits were then compared to the 177-radionuclide list given by Sink's (2016) 2040 projection inventory limits (note that for the trench the maximum value taken from all of the trenches was employed). The results from this study were then used to create a histogram plot as shown in Figure E-1.

As Figure E-1 indicates, over 99% of Sink's 2040 inventory projections have weight fractions less than 0.01%. There is little difference between the trench results and the LAWV results. Therefore, the recommended weight fraction for all 1,252 radionuclides and both DU types is set to 0.01%.

Based on Eq. (E-1) and using the weight faction of 0.01% 1,252 weight-based inventories were computed for the trench and the LAWV GW screening models. The total number of B-25 boxes used for each DU type have been highlighted in orange in Table E-3. The maximum number of B-25 boxes for a ST was chosen to represent the trench value. It is conservative with respect to ETs, and the CIG value shown only applies to the existing CIG components since no new CIG components are planned.

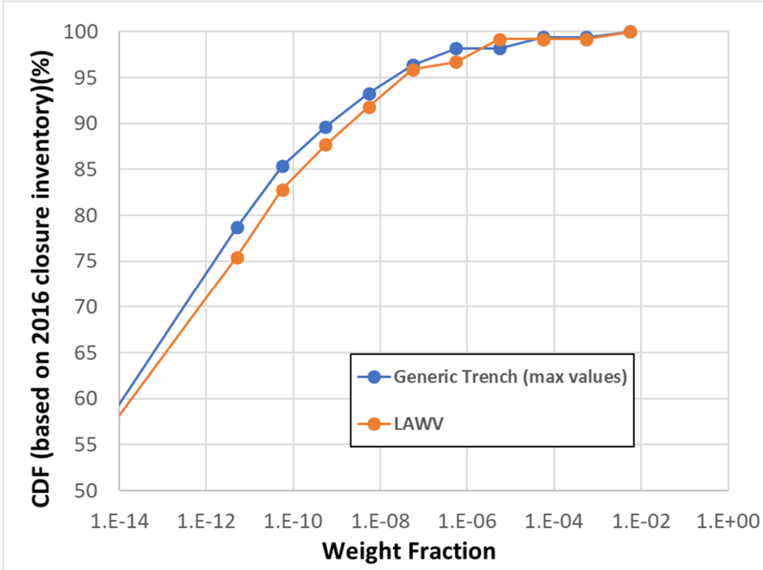


Figure E-1. Histogram plot of weight-based inventory limit versus Sink (2016) 2040 projection.

These computed factors (2x1,252) are maintained within an Excel Spreadsheet that was placed in a key secure PA2022 folder.

Appendix F. Minimum Travel Times from Waste Zone to 100-m POA

Within the methodology employed to perform a NCRP "like" GW screening analysis (NCRP, 1996), a range of "bake" times are used. For each bake time the initially buried waste inventory for a particular parent nuclide is allowed to decay, building up its progeny within its decay chains, while no leaching out of the waste zone is considered. Also, the NCRP methodology assumes a constant infiltration rate applies over all time periods. To account for the actual time variation of infiltration rates (due to how surface conditions are changing: uncovered versus covered and then cover degradation), a range of different fixed values of infiltration rates are considered.

For each E-Area DU there is a minimum amount of time required for GW transport to take place from leaving the waste zone and then reaching the downstream 100-m POA. This minimum amount of time can be estimated based on the transport of a non-diffusing conservative tracer (i.e., non-absorbing and non-decaying species). These minimum travel times are made up of two contributions:

- Transport time through the vadose zone (VZ) (i.e., from bottom of WZ to surface of water table); and
- Transport time through the aquifer (i.e., from surface of water table to the 100-m POA).

The various aspects associated with computing these minimum transport times is provided below.

F.1 Vadose Zone Minimum Transport Times

Within the VZ, beneath most E-Area DUs, there is both sand and clay layers present. The pore velocities through these material layers can be expressed as:

$$u_{Sand} = \frac{U_{Darcy}}{\alpha_{Sand}} = \frac{I}{(\phi S_w)_{Sand}} \tag{F-1a}$$

$$u_{Clay} = \frac{U_{Darcy}}{\alpha_{Clay}} = \frac{I}{(\phi S_w)_{Clay}} \tag{F-1b}$$

where

u_i .... Pore velocity of GW through material i (cm/yr)
U_{Darcy} .... VZ Darcy velocity (cm/yr)
I .... Surface Infiltration (cm/yr)
α_i .... Void fraction of material i within the VZ (-)
ϕ_i .... Porosity of material i (-)
$S_{w,i}$ .... Water saturation of material i within the VZ (-)

The total travel time through the VZ can be computed based on the above equations as:

$$\Delta t_{VZ} \equiv \Delta t_{Sand} + \Delta t_{Clay} = I\left[\left(\frac{\Delta z_{DU}}{\phi S_w}\right)_{Sand} + \left(\frac{\Delta z_{DU}}{\phi S_w}\right)_{Clay}\right] \tag{F-2}$$

where

. $\Delta z_{DU,i}$ . ... Vertical distance through material i within a specific DU (cm)

Δt_i .... Travel time through material i (yr)

Δt_{VZ} .... Travel time through VZ for a specific DU (yr)

A series of VZ PORFLOW runs were made where the infiltration rate was varied over the entire range expected during E-Area operations and to the end of POP. Average values of water saturation within both the Sandy and Clayey material were computed along with the corresponding pore velocities as shown in Table F-1. The infiltration rates listed in Table F-1 range from the lowest value presenting a covered DU up to the highest value that slightly exceeds the estimated average yearly uncovered value of 40 cm/yr. This uncovered infiltration rate is based on observed and predicted values as discussed in McDowell-Boyer et al. (2000, see Section C.1.1.1).

Table F-1. PORFLOW-based vadoze zone water saturation and pore velocity values.

Infiltration Rate (cm/yr)	Water Saturation (SANDY)	Water Saturation (CLAYEY)	Sand Pore Velocity (cm/yr)	Clay Pore Velocity (cm/yr)
0.0035	0.6360	0.7630	0.014	0.012
0.022	0.6124	0.7418	0.092	0.076
10.02	0.6333	0.7598	40.568	33.814
2.2	0.6600	0.7905	8.546	7.136
22	0.7226	0.8592	78.061	65.655
40.5	0.7700	0.9050	134.865	114.747

The vertical travel distances are DU specific (Bagwell and Bennett 2017) and are listed in Table F-2.

Table F-2. Travel distances through sand and clay on a disposal unit basis.

Disposal Unit (old naming)	Disposal Unit (new naming)	Avg Depth to WT (ft)	WZ to WT depth (ft)	Avg Sand Thickness (ft)	Avg Clay Thickness (ft)
ST08	**ST08**	75.80	55.80	44.61	11.20
ST09	**ST09**	78.05	58.05	44.23	13.83
ST10	**ST10**	77.06	57.06	42.88	14.19
ST11	**ST11**	75.42	55.42	42.95	12.47
ET04	**ET04**	75.18	55.18	43.73	11.46
ST01	**ST01**	76.32	56.32	43.63	12.68
ST02	**ST02**	76.59	56.59	45.31	11.29
ST03	**ST03**	72.93	52.93	45.23	7.70
ET03	**ET03**	72.14	52.14	45.01	7.13
ST04	**ST04**	68.61	48.61	42.90	5.70
CIG1	**ST23**	64.31	44.31	40.22	4.09
CIG2	**ST24**	61.14	41.14	39.21	1.93
ST05	**ST05**	59.73	39.73	37.85	1.88
ST06	**ST06**	58.25	38.25	35.17	3.08
ST07	**ST07**	55.46	35.46	32.84	2.62
ET01	**ET01**	57.64	37.64	20.88	16.76
ST14	**ST14**	55.04	35.04	19.57	15.46
ST15	**ET05**	50.80	30.80	20.61	10.19
ST16	**ET06**	46.12	26.12	15.56	10.57

Disposal Unit (old naming)	Disposal Unit (new naming)	Avg Depth to WT (ft)	WZ to WT depth (ft)	Avg Sand Thickness (ft)	Avg Clay Thickness (ft)
ST17	**ST17**	49.18	29.18	15.84	13.35
ST18	**ST18**	48.13	28.13	15.95	12.18
ST19	**ST19**	49.33	29.33	16.05	13.29
ST20	**ST20**	48.70	28.70	16.10	12.59
ST21	**ST21**	49.75	29.75	17.12	12.63
ST22	**ST22**	49.75	29.75	17.12	12.63
ET02	**ET02**	47.87	27.87	21.98	5.89
ET07	**ET07**	65.20	45.20	40.07	5.14
ET08	**ET08**	65.38	45.38	40.29	5.09
ET09	**ET09**	58.86	38.86	33.07	5.79
LAWV	**LAWV**	45.50	45.50	35.12	10.38
ILV	**ILV**	53.48	53.48	40.56	12.92
NR26E	**NR26E**	74.94	74.94	65.01	9.93
NR7E	**NR7E**	62.82	62.82	50.20	12.62

Given the above parameter settings travel time through the VZ for each DU over a range in infiltration rates were computed and are listed in Table F-3. The travel times through the aquifer are also provided in the last column. These travel times correspond to conditions where E-Area was uncovered and reflect the more conservative estimates.

Table F-3. Travel times through vadose zone and aquifer on a disposal unit basis for a range of infiltration rates.

I (cm/yr) =	0.0035	0.022	10.02	2.2	22	40.5	Uncovered
VZ Travel Time (yr)	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**Aq Travel Time (yr)**
ST08	125371	19249	44	207	23	13.1	5.7
ST09	131357	20176	46	217	24	13.7	5.8
ST10	129379	19874	45	214	23	13.5	5.7
ST11	125083	19210	44	206	23	13.0	7.1
ET04	124145	19062	43	205	22	12.9	12.1
ST01	127115	19522	44	210	23	13.2	7.4
ST02	127114	19516	44	210	23	13.2	8.1
ST03	117661	18055	41	194	21	12.3	8.0
ET03	115700	17752	40	191	21	12.1	5.1
ST04	107449	16482	37	177	19	11.2	8.7
ST23	97466	14947	34	161	18	10.2	8.6
ST24	89697	13749	31	148	16	9.4	8.8
ST05	86624	13278	30	143	16	9.1	9.8
ST06	83944	12872	29	139	15	8.8	11.6
ST07	77726	11917	27	128	14	8.1	10.8
ET01	88527	13626	31	146	16	9.2	15.8
ST14	82348	12674	29	136	15	8.5	12.5
ET05	70924	10904	25	117	13	7.4	14.5
ET06	60988	9383	21	101	11	6.3	14.4
ST17	68790	10589	24	113	12	7.1	14.7
ST18	66016	10160	23	109	12	6.8	15.8
ST19	69092	10635	24	114	12	7.2	16.9
ST20	67426	10377	23	111	12	7.0	19.9
ST21	69709	10727	24	115	13	7.2	25.7

I (cm/yr) =	0.0035	0.022	10.02	2.2	22	40.5	Uncovered
VZ Travel Time (yr)	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**VZ Travel Time (yr)**	**Aq Travel Time (yr)**
ST22	69709	10727	24	115	13	7.2	29.5
ET02	62743	9634	22	104	11	6.5	11.8
ET07	99859	15318	35	165	18	10.4	4.2
ET08	100222	15373	35	165	18	10.5	3.9
ET09	86435	13264	30	143	16	9.0	3.8
LAWV	102760	15782	36	170	19	10.7	13.6
ILV	121094	18600	42	200	22	12.6	10.8
NR26E	166159	25493	58	274	30	17.3	6.6
NR7E	141139	21670	49	233	25	14.7	7.0

F.2 Aquifer Minimum Transport Times

A GSA2018 PORFLOW-based aquifer flow model exists (Flach 2018) where four cutouts were created for computing aquifer travel times for each DU (i.e., includes all closed, open, or future units) within E-Area. Both uncovered and E-Area covered flow models were considered. No transport analyses are required. Only 3D streamtracing analysis was required and was performed within TecPlot. The four aquifer cutouts employed were:

- **Center** (CIG1, CIG2, ST01, ST02, ST03, ST04, ST05, ST06, ST07)
- **East1** (ET01, ET02, LAWV, ST14, ST15, ST16, ST17, ST18, ST19, ST20, ST21, ST22)
- **East2** (NRCDA-7E, NRCDA-26E)
- **West** (ET03, ET04, ET07, ET08, ET09, ILV, NRCDA26E, ST08, ST09, ST10, ST11)

The 3D streamtraces generated in TecPlot for each DU within these four cutouts are shown in Figure F-1 through Figure F-4.

Figure F-1. 3D streamtraces for DUs within the Center cutout.

Figure F-2. 3D streamtraces for DUs within the East1 cutout.

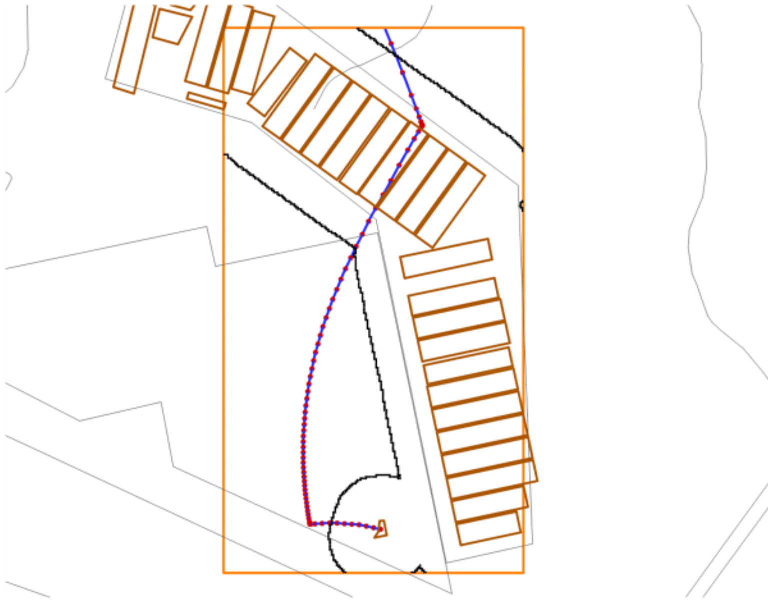


Figure F-3. 3D streamtraces for DUs within the East2 cutout.

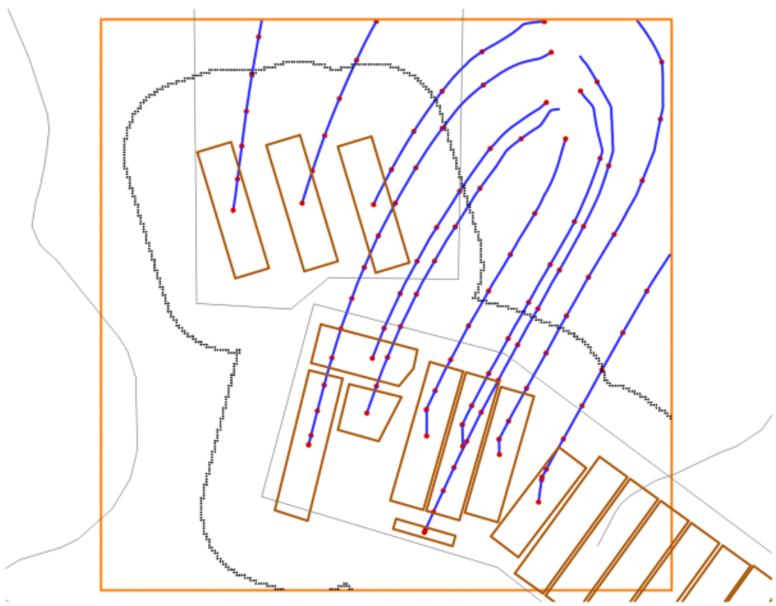


Figure F-4. 3D streamtraces for DUs within the West cutout.

The total travel time to the 100-m POA can be computed based on:

$$\Delta t_{Tot} = \Delta t_{VZ} + \Delta t_{Aq} \tag{F-3}$$

where

Δt_{Tot} .... Total travel time for a specific DU (yr)
Δt_{VZ} .... Travel time through VZ for a specific DU (yr)
Δt_{Aq} .... Travel time through Aquifer for a specific DU (yr)

The Aquifer travel times for each DU are listed in Table F-3. Based on Eq. (F-3) the total travel time (i.e., minimum time) from the bottom of a WZ to the 100-m POA is listed in Table F-4. The minimum values across all of the trench units is also heighted in orange in Table F-4 and for the NRCDA DUs in cyan.

Table F-4. Total travel times on a disposal unit basis for a range of infiltration rates.

I (cm/yr) =	0.0035	10.02	40.5
Disposal Unit (new naming)	**Total Travel Time (yr)**	**Total Travel Time (yr)**	**Total Travel Time (yr)**
ST08	125376	49	18.8
ST09	131363	51	19.5
ST10	129385	51	19.2
ST11	125090	51	20.1
ET04	124157	55	25.0
ST01	127123	52	20.6
ST02	127122	52	21.3
ST03	117669	49	20.3
ET03	115705	45	17.2
ST04	107458	46	19.9
ST23	97475	43	18.8
ST24	89705	40	18.2
ST05	86634	40	18.9
ST06	83955	41	20.4
ST07	77737	38	18.9
ET01	88543	47	25.0
ST14	82361	41	21.0
ET05	70939	39	21.9
ET06	61002	36	20.7
ST17	68805	39	21.8
ST18	66032	39	22.6
ST19	69109	41	24.1
ST20	67446	43	26.9
ST21	69735	50	32.9
ST22	69739	54	36.7
ET02	62755	34	18.3
ET07	99863	39	14.6
ET08	100226	39	14.4
ET09	86439	34	12.8
LAWV	102774	49	24.3
ILV	121105	53	23
NR26E	166165	64	24
NR7E	141146	56	22

For GW screening purposes only three of the six infiltration rates are being employed (i.e., 0.0035, 10.2, and 40.5 cm/yr). These three values cover the entire range and are based on:

- **0.0035 cm/yr** – represents an intact cover;
- **10.2 cm/yr** – represents an average value over the entire CP; and
- **40.5 cm/yr** – represents uncovered natural conditions.

The recommended values for each GW screening model are listed in Table F-5.

Table F-5. Recommended minimum total travel times for the Tier-1 screening models for a range of infiltration rates.

I (cm/yr) =	0.0035	10.02	40.5
Tier-1 GW Screening Model	**Total Travel Time (yr)**	**Total Travel Time (yr)**	**Total Travel Time (yr)**
Trench	61002	34	12.8
ILV	121105	53	23
LAWV	102774	49	24
NRCDA	141146	56	22

Appendix G. Aquifer Dilution Aspects

Contaminant transport for a specific DU travels essentially vertically downwards through the VZ and ends up reaching the top surface of the water table directly underneath this DU's footprint (note that only a slight downgradient drift of contaminant occurs within the capillary fringe or "transition" region). The contaminant flux (i.e., volumetric flowrate times its liquid-phase concentration) locally mixes with the aquifer and is then carried downstream towards the 100-m POA. During its travel its plume disperses resulting in a potentially significant reduction in concentration values. This reduction in concentration is referred to in this report as a Dilution Factor (DF). The equations required to compute the magnitude of aquifer dilution is provided within the next section, while the following section presents the application of these equations to every DU within E-Area.

G.1 Derivation of Equations and Results for Estimating Aquifer Dilution

Following the basic NCRP123 methodology, a simple 2-box modeling domain is considered as shown in Figure 1 (i.e., a 2D vertical slice through the DU). In the 2-box model the vadose zone is not addressed explicitly. Notation employed below is consistent with Appendix A and Appendix B.

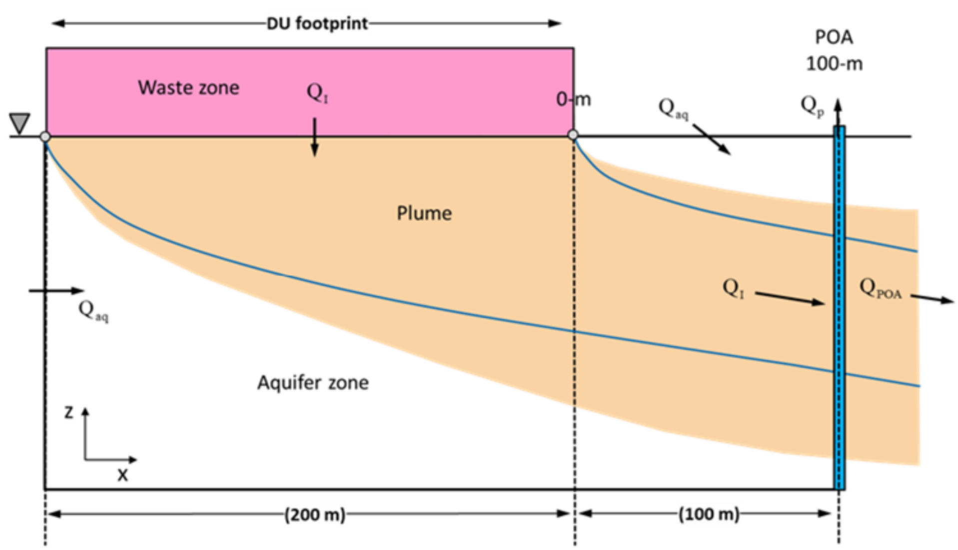


Figure G-1. Model domain (waste zone plus aquifer) for the basic NCRP123 2-box model.

Note that the flowrate entering the aquifer from the DU footprint represents a streamtube as shown in Figure G-1 by two blue streamlines emanating down (i.e., towards the ultimate drainage seepage face) from the two DU footprint edges. The orange shaded region represents the plume where lateral dispersion allows it to extend out beyond the streamtube. The aquifer flow associated with the dilution process (i.e., mixing) comes into the "aquifer volume associated with the dilution process" from two different sources (as shown in Figure G-1):

- Clean upstream aquifer water; and
- Clean rainwater downstream of the DU footprint up to the POA.

The various water sources being considered are shown in Figure G-1 with accompanying black arrows (i.e., volumetric flowrates Q with the subscripts I, aq, POA, and p).

The two total molar balance (i.e., transport) equations for box-1 (i.e., waste zone) and box-2 (i.e., aquifer zone) become:

(box-1) $$\frac{d(V_1 c_{e1,j})}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i V_1 c_{e1,i} - \lambda_j V_1 c_{e1,j} - Q_I c_{w1,j} \quad \text{(G-1)}$$

(box-2) $$\frac{d(V_2 c_{e2,j})}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i V_2 c_{e2,i} - \lambda_j V_2 c_{e2,j} + Q_I c_{w1,j} - \left[Q_{POA} + Q_p\right] c_{w2,j} \quad \text{(G-2)}$$

Applying the definitions as provided in Appendix A, Eqs. (G-1) and (G-22) can be further expressed as:

(box-1) $$\frac{d(N_{1,j})}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1,i} - \lambda_j N_{1,j} - L_{12,j} N_{1,j} \quad \text{(G-3)}$$

(box-2) $$\frac{d(N_{2,j})}{dt} = \sum_{i=1}^{j-1} b_{ji} N_{2,i} - \lambda_j N_{2,j} + L_{12,j} N_{1,j} - \left[\frac{Q_{POA} + Q_p}{\phi_2 R_{2,j} V_2}\right] N_{2,j} \quad \text{(G-4)}$$

As shown in Figure G-1, an overall aquifer water balance becomes:

$$\frac{d(\phi_2 V_2)}{dt} = Q_{aq} + Q_I - \left[Q_p + Q_{POA}\right] \quad \text{(G-5)}$$

where the aquifer is assumed to be fully saturated and

where

- V_2 - aquifer dilution volume associated with the dilution process (m^3)
- Q_{aq} - aquifer dilution flowrate associated with the dilution process (m^3/yr)
- - infiltration flowrate associated with the DU of interest (m^3/yr)
- Q_p - well pumping flowrate for a receptor located at the 100-m POA (m^3/yr)
- Q_{POA} - aquifer flowrate within plume beyond the 100-m POA curtain (m^3/yr)

Note that the aquifer volume being considered in Eq. (G-5) represents the steady-state tracer plume as shaded in orange in Figure G-1. Further, if we also assume that the potential for expansion/contraction of the aquifer (e.g., raising or lowering of the water table) are minimal then:

$$Q_{POA} + Q_p \approx Q_{aq} + Q_I \quad \text{(G-6)}$$

Making use of the above assumptions, Eq. (G-4) becomes:

(box-2) $$\frac{d(N_{2,j})}{dt} = \sum_{i=1}^{j-1} b_{ji} N_{2,i} - \lambda_j N_{2,j} + L_{12,j} N_{1,j} - \left[\frac{D_F Q_I}{\phi_2 R_{2,j} V_2}\right] N_{2,j} \quad \text{(G-7)}$$

given

$$D_F \equiv \left[\frac{Q_{aq} + Q_I}{Q_I}\right] \tag{G-8}$$

A simple steady-state tracer mass balance, consistent with the Figure G-1 nomenclature, can be expressed as:

$$Q_{aq} c_{aq} + Q_I \langle c \rangle_I = \left[Q_{POA} + Q_p\right] \langle c \rangle_{POA} \tag{G-9}$$

where

c_{aq} - assumed to be zero (i.e., clean upstream aquifer) (gmol/m^3)

$\langle c \rangle_I$ - average tracer concentration from DU at the surface of the water table (gmol/m^3)

$\langle c \rangle_{POA}$ - average tracer concentration at the 00-m POA (gmol/m^3)

Making use of Eq. (G-6), while assuming a clean upstream aquifer and the POA and pumping concentrations being approximately equivalent, yields:

$$D_F \approx \frac{\left[Q_I + Q_{aq}\right]}{Q_I} = \frac{\langle c \rangle_I}{\langle c \rangle_{POA}} \tag{G-10}$$

As Eq. (G-10) indicates, the dilution factor is related to both mixing volumes and steady-state tracer concentrations. Solution of the coupled set of Eqs. (G-3) and (G-7) are required. However, three parameters that are not explicitly defined are:

V_2 - aquifer dilution volume associated with the dilution process (m^3)

Q_{aq} - aquifer dilution flowrate associated with the dilution process (m^3/yr)

D_F - aquifer dilution factor associated with each DU of interest (-)

For each DU within E-Area (i.e., 33 in total), aquifer 3D PORFLOW steady-state tracer transport runs were made based on (as discussed within this appendix):

- A constant tracer source being applied at each DU individually;
- Source strength was set such that the peak tracer concentration at the 100-m POA yielded a concentration value of 1x10^{-8} gmol/L;
- Aquifer flow fields for a completely uncovered versus a final facility cover were considered where these flow fields were obtained from the GSA2018 PORFLOW flow model (Flach 2018); and
- Aquifer dilution factors and dilution volumes were computed for each DU.

The details associated with computing the aquifer dilution factor and the geometrical estimate of the aquifer dilution volume involved in the overall dilution process are provided within the following section.

The dilution factor can be computed from Eq. (G-10) based on PORFLOW estimated average tracer concentrations for each DU. The aquifer dilution flow rate can then be computed from Eq. (G-8) once a specific infiltration rate is specified using:

$$Q_{aq} = \left[1 - D_F\right] Q_I \tag{G-11}$$

Thus, all the parameter settings required in Eqs. (G-3) and (G-7) are available for each specific scenario case of interest.

Making use of the above assumptions, Eq. (G-7) can be rewritten as:

(box-2)
$$\frac{d(N_{2,j})}{dt} = \sum_{i=1}^{j-1} b_{ji} N_{2,i} - \lambda_j N_{2,j} + L_{12,j} N_{1,j} - \left[w_{d,j} \right] N_{2,j} \tag{G-12}$$

where

$$w_{d,j} = \left[\frac{D_F Q_I}{\phi_2 R_{2,j} V_2} \right] = \left[\frac{1}{\phi_2 R_{2,j}} \right] \left[\frac{D_F Q_I}{V_2} \right] = \left[\frac{\eta}{\phi_2 R_{2,j}} \right] \tag{G-13}$$

In Eq. (G-13) a dilution time constant has been defined as:

$$\eta = \left[\frac{D_F Q_I}{V_2} \right] \tag{G-14}$$

where

η - aquifer dilution time constant associated with each DU of interest (yr^{-1})

G.2 Aquifer Dilution Factor Results

Note that the naming convention for DUs have changed some since the PA2008 due to unit conversions and additional units added. To help eliminate confusion as to which DU is being addressed, both the old and new naming convention is tabulated in Table G-1.

Table G-1. New versus old naming convention for E-Area disposal units.

Aquifer Cutout	DU (Old Name)	DU (New Name)
Center	CIG1	ST23
Center	CIG2	ST24
Center	ST01	ST01
Center	ST02	ST02
Center	ST03	ST03
Center	ST04	ST04
Center	ST05	ST05
Center	ST06	ST06
Center	ST07	ST07

Aquifer Cutout	DU (Old Name)	DU (New Name)
East1	ET01	ET01
East1	ET02	ET02
East1	LAWV	LAWV
East1	ST14	ST14
East1	ST15	ET05
East1	ST16	ET06
East1	ST17	ST17
East1	ST18	ST18
East1	ST19	ST19
East1	ST20	ST20
East1	ST21(North)	ST21
East1	ST21(South)	ST22
East2	NRCDA7E	NRCDA7E

Aquifer Cutout	DU (Old Name)	DU (New Name)
West	DU8A	ET07
West	DU8B	ET08
West	DU8C	ET09
West	ET03	ET03
West	ET04	ET04
West	ILV	ILV
West	NRCDA26E	NRCDA26E
West	ST08	ST08
West	ST09	ST09
West	ST10	ST10
West	ST11	ST11

A GSA2018 PORFLOW-based aquifer flow model exists (Flach 2018) where four cutouts were created for computing these DF values for each DU (i.e., includes all closed, open, and future units) within E-Area. Both uncovered and E-Area covered flow models were considered (i.e., only small differences were observed between the two surface condition cases). PORFLOW-based aquifer steady-state tracer runs were performed for all DUs based on the following GSA aquifer flow cutouts:

- **Center** (ST23, ST24, ST01, ST02, ST03, ST04, ST05, ST06, ST07)

- **East1** (ET01, ET02, LAWV, ST14, ET05, ET06, ET07, ST18, ST19, ST20, ST21, ST22)
- **East2** (NRCDA-7E)
- **West** (ET07, ET08, ET09, ET03, ET04, ILV, NRCDA26E, ST08, ST09, ST10, ST11)

For each DU a uniform strength source term was applied (i.e., constant rate of gmol/yr) whose numerical value was set such that the "maximum" tracer concentration reaching the 100-m POA was 1×10^{-8} gmol/ft^3). For example, PORFLOW results are shown in Figure G-2 through Figure G-4 for the ET04, ILV, ST02, ST06, ET01, and ST18 DUs, respectively (these units illustrate the basic plume behavior throughout the entire E-Area).

In each figure tracer contours are provided at concentration levels of 1×10^{-6}, 1×10^{-7}, 1×10^{-8}, 1×10^{-9}, 1×10^{-10}, and 1×10^{-11} gmol/L. The 1×10^{-8} gmol/L contour represents the arbitrary concentration limit and the source strengths at the DU footprint were set such that this contour just touches the 100-m POA.

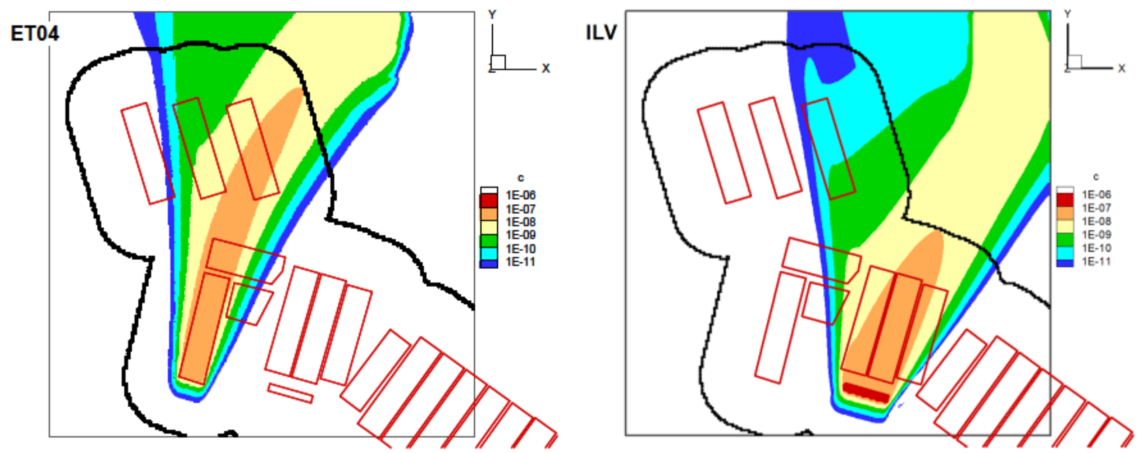


Figure G-2. PORFLOW-based steady-state tracer plumes for ET04 and ILV.

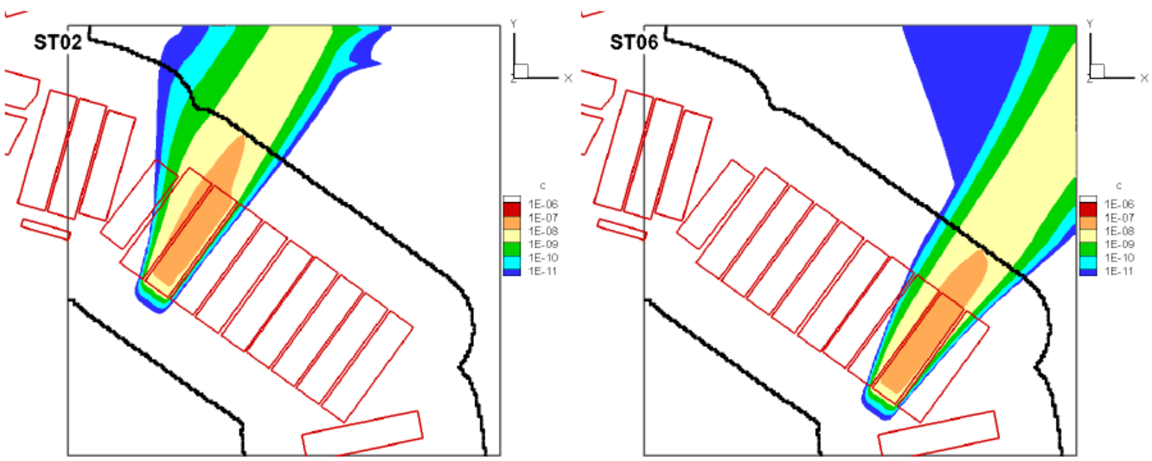


Figure G-3. PORFLOW-based steady-state tracer plumes for ST02 and ST06.

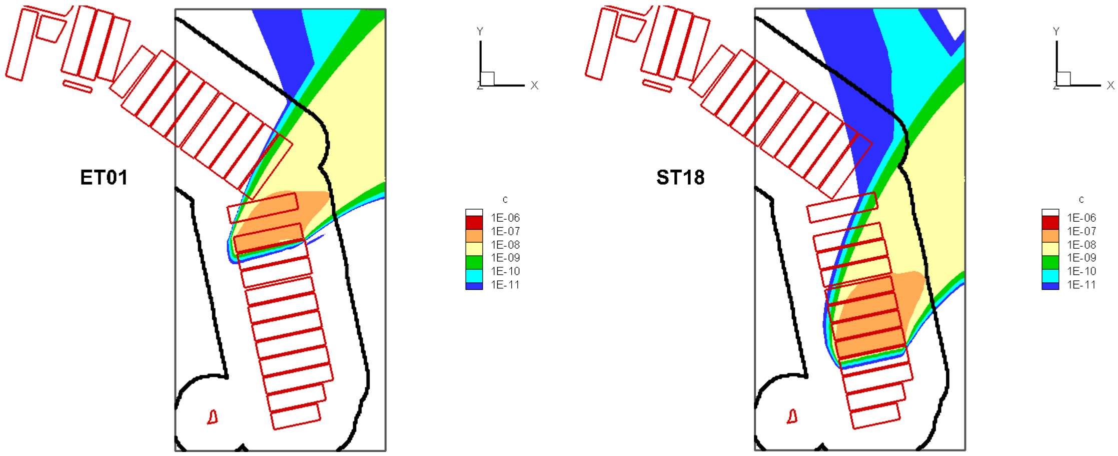


Figure G-4. PORFLOW-based steady-state tracer plumes for ET01 and ST18.

One-order in magnitude concentration contours are shown where the 1×10^{-8} value seats in between the orange and yellow regions. As these figures indicate, this concentration value just touches the 100-m POA. The contouring cutoff value was set to 1×10^{-12} (i.e., outer blue edge of the plume presented). Thus, these plumes span over a 10,000 factor in concentrations. The majority of tracer mass residing within these plumes is within the yellow-to-orange contour regions. Also note for ST06, ET01, and ST18 their plumes drop below the Green Clay confining unit and start traveling northwest within the Gordon Aquifer Unit.

Average concentrations associated with the surface of the water table just beneath each footprint were also computed. Dilution factors were then computed for each DU using the following expression:

$$DF_{DU} = \frac{\langle c \rangle_{DU}}{\langle c \rangle_{POA}} \qquad \text{(G-15)}$$

where

DF_{DU} - Dilution Factor for a specific DU (-)

$\langle c \rangle_{DU}$ - Average water table surface concentration within the given DU t ($gmol/ft^3$)

$\langle c \rangle_{POA}$ - Average aquifer concentration along the 100-m POA ($gmol/ft^3$)

Dilution Factors were computed using Eq. (G-15). A summary of these DF values for the uncovered case are listed in Table G-1.

Table G-1. Summary of dilution factor estimates for uncovered E-Area case.

Center	Uncovered
DU	DF (-)
ST01	165.8
ST02	161.2
ST03	153.8
ST04	116.1
ST23	130.1
ST24	114.7
ST05	116.1
ST06	112.7
ST07	110.7
ST11	195.0

East1	Uncovered
DU	DF (-)
ET01	68.4
ET02	71.9
LAWV	110.7
ST14	75.2
ET05	76.0
ET06	126.9
ST17	126.8
ST18	120.7
ST19	107.1
ST20	102.1
ST21	124.8
ST22	117.1

West	Uncovered
DU	DF (-)
ET07	145.5
ET08	109.8
ET09	94.6
ET03	121.4
ET04	176.8
ILV	1266.0
NRCDA26E	299.9
ST08	112.3
ST09	153.7
ST10	182.1

East2	Uncovered
DU	DF (-)
NRCDA7E	NA

For GW screening purposes the minimum value for all of the ST, ET, and CIG units was employed for the generic trench model (i.e., average value of 186 versus its minimum value of 107). In summary, the recommended DF values for GW screening purposes are listed in Table G-2.

Table G-2. Summary of dilution factor values for groundwater screening purposes.

DU	DF (min) (-)	DF (avg) (-)
Generic Trench	68.4	123.8
LAWV	110.7	na
ILV	1266.0	na
NRCDAG	299.9	na
NRCDAS	299.9	na

Note the vary large DF value for the ILV. This is a direct result of its footprint geometry with respect to its orientation to the aquifer flow direction. Also, note that dilution factors were employed for Tier-1 screening in the previous effort (Aleman and Hamm 2020). In this updated screening effort Tier-1 does not employ any aquifer dilution aspects. In this screening effort aquifer dilution is only being addressed within the Tier-2 screening efforts.

G.3 Aquifer Plume Volume Results

To compute aquifer dilution for each DU, an estimated plume volume residing from the DU footprint at the top surface of the water table downstream to the 100-m POA is required. To estimate the size of a plume requires some mass content cutoff value since in theory the volume could be infinite. Thus, the volume for each DU was computed from a PORFLOW-based steady-state tracer run where the following logic was applied:

- Cumulative fluid-phase only volume versus mass content was determined. Here the tracer mass content per PORFLOW cell was determined and them sorted from largest to smallest in value; and
- The estimated plume volume was then found from this cumulative curve based on a mass fraction cutoff value.

For all of the DUs a mass fraction cutoff value of 95% was employed. The cumulative plume volume curves for every DU are shown in Figure G-5 through Figure G-8 where the DU curves are grouped based on aquifer cutouts.

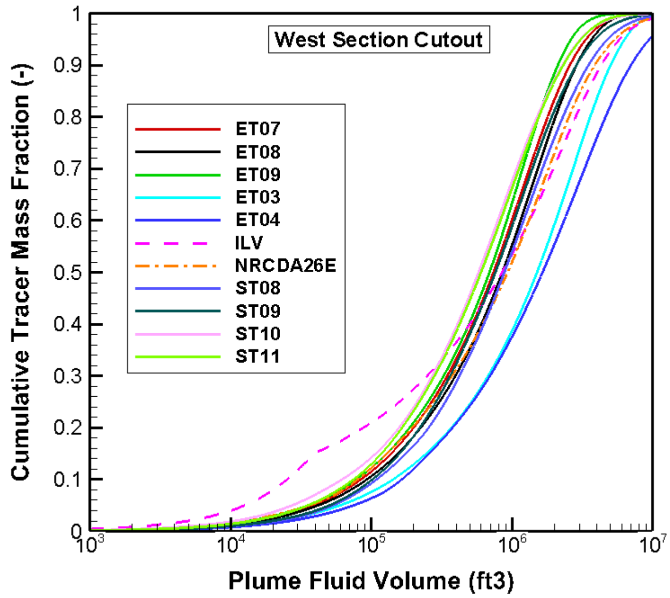


Figure G-5. Cumulative plume volume versus mass fraction for West cutout disposal units.

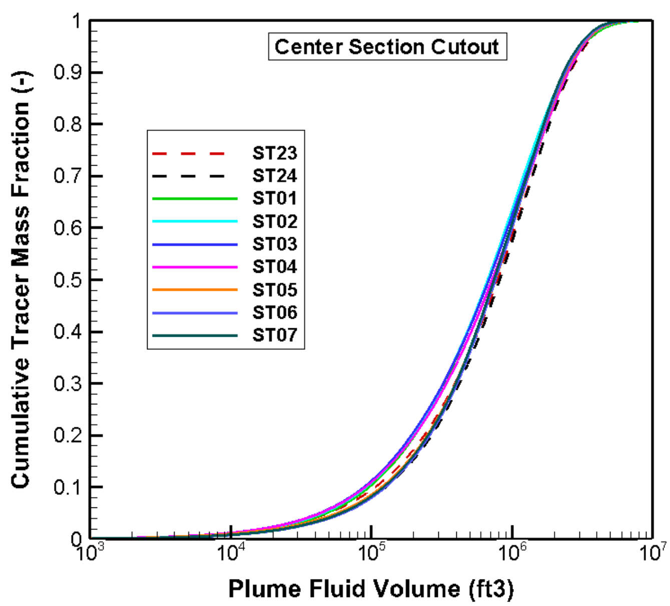


Figure G-6. Cumulative plume volume versus mass fraction for Center cutout disposal units.

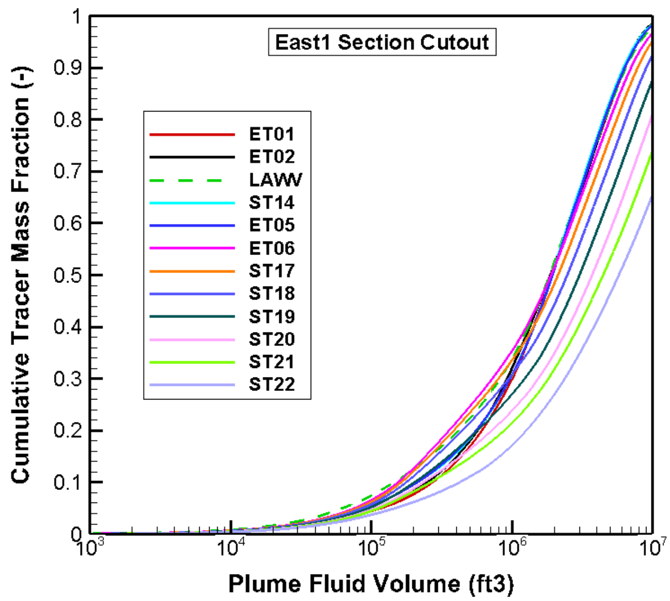


Figure G-7. Cumulative plume volume versus mass fraction for East1 cutout disposal units.

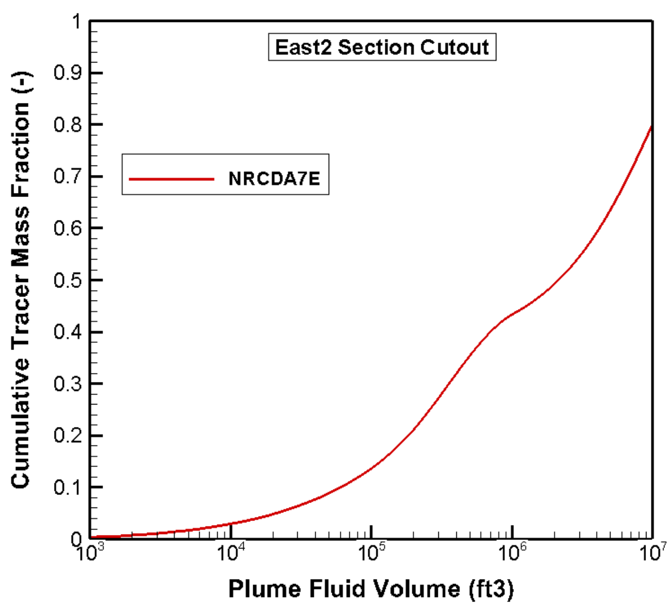


Figure G-8. Cumulative plume volume versus mass fraction for East2 cutout disposal unit.

Based on a mass fraction cutoff value of 95%, the resulting liquid-phase plume volume for each DU is listed in Table G-3. The average and minimum volumes are also listed in Table G-3.

Table G-3. Estimated liquid-phase tracer plume volumes per disposal unit.

Cutout	DU	Aquifer Volume (ft3)	Avg (ft3)	Min (ft3)
Center	ST23	3,311,351		
Center	ST24	3,266,923		
Center	ST01	3,174,074		
Center	ST02	3,106,675		
Center	ST03	3,110,123		
Center	ST04	3,185,535		
Center	ST05	3,099,731		
Center	ST06	3,060,259		
Center	ST07	2,977,409		
East1	ET01	7,869,064		
East1	ET02	7,722,393		
East1	ST14	7,737,084		
East1	ET05	7,916,524		
East1	ET06	8,917,310		
East1	ST17	9,896,290		
East1	ST18	11,360,454		
East1	ST19	13,744,310		
East1	ST20	17,084,245		
East1	ST21	21,761,624		
East1	ST22	29,492,424		
West	ET07	3,364,870		
West	ET08	3,690,322		
West	ET09	2,633,595		2,633,595
West	ET03	6,329,724		
West	ET04	9,492,799		
West	ST08	4,797,000		
West	ST09	3,893,117		
West	ST10	3,072,262		
West	ST11	3,101,001	7,316,155	
West	ILV	5,845,828	5,845,828	5,845,828
East1	LAWV	8,154,080	8,154,080	8,154,080
East2	NRCDA7E	19,864,083		
West	NRCDA26E	5,385,175	12,624,629	5,385,175

G.4 Rate Constant for Aquifer Dilution

In Eq. (G-12) the last term represents an effective aquifer dilution term whose units are yr^{-1} and behaves as a first-order loss term. Conservatively neglecting absorption aspects within the aquifer, the first-order rate constant becomes:

$$w_d = w_{d,j} = \left[\frac{D_F Q_I}{\phi_2 V_2} \right] \qquad \text{(G-16)}$$

where for PORFLOW aquifer analyses the following two parameter settings are fixed:

$$\phi_2 = 0.25 \qquad \text{(G-17a)}$$

and $$I = \frac{40.081}{100}\,(\text{m/yr}) \tag{G-17b}$$

The volumetric infiltration flowrates are computed by:

$$Q_I = I \times A_{DU} \tag{G-18}$$

A_{DU} - disposal unit footprint (m^2)

Q_I - infiltration flowrate associated with the DU of interest (m^3/yr)

Note that this rate first-order rate constant can also be expressed in terms of an effective half-like as well:

$$\tau_{wd} = \frac{\ln(2)}{w_d} \tag{G-19}$$

The rate constant values for aquifer dilution for each disposal unit, along with its corresponding key inputs, are listed in Table G-4 through Table G-6.

Table G-4. Rate constants for aquifer dilution for Center section disposal units.

DU	DF (-)	Flow Area (ft2/1000)	QI (m3/yr)	V2 (m3)	wp (yr-1)	half-life wp (yr)
ST23	130.11	103.01	4795.2	131070.2	19.0	0.036
ST24	114.70	102.97	4793.4	129311.7	17.0	0.041
ST01	165.83	103.47	4816.5	125636.5	25.4	0.027
ST02	161.18	103.37	4811.9	122968.7	25.2	0.027
ST03	153.84	103.00	4794.8	123105.2	24.0	0.029
ST04	152.38	103.00	4794.8	126090.1	23.2	0.030
ST05	116.12	102.97	4793.4	122693.8	18.1	0.038
ST06	112.66	103.01	4795.2	121131.5	17.8	0.039
ST07	110.67	102.97	4793.4	117852.1	18.0	0.038
ST11	194.98	80.26	3736.2	122744.1	23.7	0.029
				avg =	21.2	
				min =	17.0	

Table G-5. Rate constants for aquifer dilution for East1 section disposal units.

DU	DF (-)	Flow Area (ft2/1000)	QI (m3/yr)	V2 (m3)	wp (yr-1)	half-life wp (yr)
ET01	68.45	96.84	4508.2	311474.0	4.0	0.175
ET02	71.89	104.59	4869.0	305668.5	4.6	0.151
LAWV	110.70	89.96	4187.7	231390.1	8.0	0.086
ST14	75.23	102.99	4794.5	306250.0	4.7	0.147
ET05	75.99	102.99	4794.5	313352.6	4.7	0.149
ET06	126.92	101.70	4734.5	352965.8	6.8	0.102
ST17	126.81	101.70	4734.5	391715.9	6.1	0.113
ST18	120.71	101.70	4734.5	449670.6	5.1	0.136
ST19	107.12	101.70	4734.5	544028.5	3.7	0.186
ST20	102.11	101.70	4734.5	676230.2	2.9	0.242
ST21	124.76	84.78	3946.7	861370.6	2.3	0.303
ST22	117.13	70.65	3288.9	1167371.9	1.3	0.525
				avg =	4.5	
				min =	1.3	

Table G-6. Rate constants for aquifer dilution for West section disposal units.

DU	DF (-)	Flow Area (ft2/1000)	QI (m3/yr)	V2 (m3)	wp (yr-1)	half-life wp (yr)
ET07	145.45	96.00	4469.0	133188.6	19.5	0.036
ET08	109.82	96.00	4469.1	146070.7	13.4	0.052
ET09	94.58	96.00	4469.0	104243.2	16.2	0.043
ET03	121.42	80.85	3763.7	250543.7	7.3	0.095
ILV	1266.02	10.48	487.9	231390.1	10.7	0.065
ET04	176.81	103.30	4808.8	375744.9	9.1	0.077
NRCDA26E	299.87	47.69	2219.9	213156.5	12.5	0.055
ST08	112.30	102.98	4793.8	189875.3	11.3	0.061
ST09	153.75	102.98	4793.8	154097.7	19.1	0.036
ST10	182.05	93.56	4355.4	121606.6	26.1	0.027
				avg =	14.5	
				min =	7.3	

For GW screening purposes the minimum value for all of the ST and ET units was employed for the generic trench model (i.e., average value of 13.1 versus its minimum value of 1.3). In summary, the recommended values of rate constants for aquifer dilution for GW screening purposes are listed in Table G-7.

Table G-7. Summary of rate constant values for aquifer dilution for groundwater screening purposes.

DU	wp (min) (yr-1)	wp (avg) (yr-1)
Generic Trench	1.3	13.1
LAWV	8.0	na
ILV	10.7	na
NRCDAG	12.5	na
NRCDAS	12.5	na

Appendix H. NRCDA Inventories and Waste Age

The NRCDA DUs are unique within the E-Area facility since the wastes being buried within them all come from the decommissioning components taken from US nuclear Navy ships (i.e., both surface vessels and submarines). Details associated with the source terms and operational aspects of the NRCDA's can be found in Wohlwend and Butcher (2018). The details associated with estimated closure inventories for these DUs as provided by SWM (Simmons 2020a) are addressed, along with an estimated average age for the decommissioned reactor components of ~27 years.

Two DUs currently exist:

- **NRCDA-7E** – (also referred to as NR0) that is a closed unit; and
- **NRCDA-26E** – (also referred to as NR1) that is currently in operation.

The operational timelines for the two NRCDAs are listed in Table H-1.

Table H-1. Timelines for the NRCDA disposal units.

Disposal Unit	First Waste Package	Last Waste Package
NR0	1/1/1987	5/21/2004
NR1	2/6/1997	9/30/2065

The NR0 DU was closed to new burials as of 5/21/2004, while the newer NR1 DU is expected to remain operational to the SIC (i.e., 9/30/2065).

Closure inventories for these DUs are based on the following:

- For NR0 the current inventory values contained within WITS reflect its closure inventory values; and
- For NR1 closure inventory estimates, information obtained from Naval Reactor sources and from SWM SMEs projections to 2040 were employed (Sink 2016b).

H.1 Nuclear Navy Decommissioning Background

Since its inception in 1948, the U.S. Naval Reactor program has developed 27 different plant designs, installed them in 210 nuclear-powered ships, taken 526+ reactor cores into operation, and accumulated over 6,000+ reactor years of operation. The first nuclear-powered vessel went operational prior to 1950. Essentially, all of the Navy's submarines and all of its aircraft carriers are nuclear-powered with about 83 operating nuclear-powered ships: 72 submarines, 10 aircraft carriers and one research vessel.

In order to estimate the average age of decommissioned reactor components (thermal shields [TS], core barrels [CB], reactor heads [RH], etc.) key information and assumptions were extracted from the open literature (Google 2020). This information is listed in Table H-2.

Table H-2. Key reactor construction and decommissioning aspects.

Aspect	Value Assumed
Total # of Naval Reactors built	526
Total # of ships deployed in	210
Avg # reactors per ship	2.50
avg service life (yrs)	35
First Reactor built in	1950
First Decommissioned Reactor	1985
Current time Reactor built	2020
Time period of interest	70
Uniform rate of construction (yr^{-1})	7.51
Uniform rate of decommission (yr^{-1})	7.51
Average age of Decommissioned Reactors (yrs)	26.7

The first decommissioned reactor started in 1985 and is envisioned to continue well beyond the closure of E-Area. Historically, decommissioned naval reactor components were sent to two different sites: the Hanford site and the SRS. In Figure H-1 an overhead photo of the Naval Reactor Disposal Site at Hanford is shown.

Figure H-1. The Naval Reactor Disposal Site, Trench 94 200 Area East Hanford Site.

In Figure H-2 an overhead photo of NR1 at E-Area within the SRS is shown.

Figure H-2. The Naval Reactor Component Disposal Area (NRCDA-26E), Savannah River Site.

H.2 Average Age of Decommissioned Reactor Components

To potentially assist in the Tier-0 process (i.e., reduction in radionuclides considered in the Tier-1 process) for NRCDA DUs, the average age of decommissioned reactor components was estimated. The majority of solid low-level waste generated at SRS comes from various chemical processing steps associated with SRS reactor core materials and other SRS reactor support components. Outside of naval reactor waste, only a minor amount of waste comes from other off-site facilities such as ORNL and foreign sources. Since all SRS reactor operations ceased in 1989 and E-Area operations started in 1995, the average age of SRS waste was estimated to be ~23 years old by 1995. As time progresses the average age of the SRS waste increases with time. Therefore, a minimum average waste age can be computed and employed in a reasonably conservative fashion.

Decommissioning of Naval Reactors started in 1985 and wastes will be continually generated throughout the existence of E-Area (i.e., SIC in 2065). Given this, no single conservative age can be computed; however, an estimated overall average age may provide insight and is computed below.

This estimate assumes that a uniform rate of reactor decommissioning occurs that can be related to a uniform reactor construction assumption and a 35-year reactor life. The rate of reactor decommissioning can be expressed as:

$$R_d = m\left(t - T_o\right) \tag{H-1}$$

where

R_d .... Number of decommissioned reactors (#)
m .... Rate constant for the decommissioning of reactors (#/yr)
T_o .... Date of first reactor decommissioning (1985)
t .... Calendar time (year)

The rate constant is computed from Table H-2 as:

$$m = \frac{526}{2020-1950} = 7.51 \qquad \text{(H-2)}$$

To compute an average age of decommissioned reactors at some point in time (T), the following integral was developed:

$$\langle T \rangle = \frac{1}{R_d(T_o)T - T_o}\int_{T_o}^{T}(t - T_o)R_d dt = \frac{m}{3}(T - T_o)^2 \qquad \text{(H-3)}$$

where

$\langle T \rangle$ ....Average age of decommissioned reactors (yr)

As shown in Eq. (H-3), a simple expression is generated. The results of this analysis are provided in Table H-3. As Table H-3 indicates, ~27 years average age occurs at the SIC.

Table H-3. Average age of decommissioned reactors over the life expectancy of E-Area operations.

Key Time	Year	Number of Reactors Built	Number of Reactors Decommissioned	Composite Age of Decommissioned Reactors
	1985	264	0	0.0
	1986	272	8	0.3
(first burial in NR0)	1987	279	15	0.7
	1988	287	23	1.0
	1989	294	30	1.3
	1990	302	38	1.7
	1991	309	45	2.0
	1992	317	53	2.3
	1993	324	60	2.7
	1994	332	68	3.0
	1995	339	75	3.3
	1996	347	83	3.7
(first burial in NR1)	1997	354	90	4.0
	1998	362	98	4.3
	1999	369	105	4.7
	2000	377	113	5.0
	2001	384	120	5.3
	2002	392	128	5.7
	2003	399	135	6.0
(last burial in NR0)	2004	407	143	6.3
	2005	414	150	6.7
	2006	422	158	7.0
	2007	429	165	7.3
	2008	437	173	7.7
	2009	444	180	8.0
	2010	452	188	8.3
	2011	459	195	8.7
	2012	467	203	9.0
	2013	474	210	9.3
	2014	482	218	9.7
	2015	489	225	10.0
	2016	497	233	10.3
	2017	504	240	10.7
	2018	512	248	11.0

Key Time	Year	Number of Reactors Built	Number of Reactors Decommissioned	Composite Age of Decommissioned Reactors
	2019	519	255	11.3
	2020	527	263	11.7
	2021	535	271	12.0
	2022	542	278	12.3
	2023	550	286	12.7
	2024	557	293	13.0
	2025	565	301	13.3
	2026	572	308	13.7
	2027	580	316	14.0
	2028	587	323	14.3
	2029	595	331	14.7
	2030	602	338	15.0
	2031	610	346	15.3
	2032	617	353	15.7
	2033	625	361	16.0
	2034	632	368	16.3
	2035	640	376	16.7
	2036	647	383	17.0
	2037	655	391	17.3
	2038	662	398	17.7
	2039	670	406	18.0
	2040	677	413	18.3
	2041	685	421	18.7
	2042	692	428	19.0
	2043	700	436	19.3
	2044	707	443	19.7
	2045	715	451	20.0
	2046	722	458	20.3
	2047	730	466	20.7
	2048	737	473	21.0
	2049	745	481	21.3
	2050	752	488	21.7
	2051	760	496	22.0
	2052	767	503	22.3
	2053	775	511	22.7
	2054	782	518	23.0
	2055	790	526	23.3
	2056	798	534	23.7
	2057	805	541	24.0
	2058	813	549	24.3
	2059	820	556	24.7
	2060	828	564	25.0
	2061	835	571	25.3
	2062	843	579	25.7
	2063	850	586	26.0
	2064	858	594	26.3
(SIC and last burial in NR1)	2065	865	601	26.7

H.3 Decommissioned Reactor Component Waste Types

As discussed in Wohlwend and Butcher (2018) the waste packages being delivered by the Naval Reactor program for E-Area burial are of two different forms of contaminants:

- Neutron activation products that reside on the surface or embedded within the metal components. The main release mechanism for these components is surface corrosion. Key examples of components with this predominant type of contamination are reactor thermal shields and core barrels; and

- Loosely bound surface contamination (referred to as "crud" by the Naval Reactor program) whose release mechanisms are considered to be rapid. Key examples of components with this predominant type of contamination are shield blocks and reactor closure heads.

Because of the variety of naval reactor components and levels of contamination, a standard waste type has been selected to represent each form of contamination in the PA:

- **KAPL core barrel thermal shield (CB/TS) in a heavily shielded, welded cask** – These casks contain neutron activated metal components and are projected to hold 99.8% of the estimated NRCDA inventory at closure. The CB/TS cask is 18 feet tall and has a continuously welded closure. It is estimated to remain hydraulically isolated from surrounding environment for hundreds of years; and
- **Shear blocks in thinner-walled, bolted containers** – These boxes contain surface-contaminated reactor shielding blocks and are projected to hold 0.2% of the estimated NRCDA inventory at closure. The largest shear block box is 4.1 feet tall and sealed with a gasket that is bolted in place. It is conservatively assumed to become hydraulically connected with its surrounding environment immediately after being covered with soil at the first stage of closure).

Both forms of contamination are found buried in NR0 (closed) and NR1 (currently active) DUs. Based on the WITS inventory for NR0 the Curie fraction of its waste is +99.8% of the neutron activated product waste form. More recent Naval Reactor operations indicate this Curie fraction is higher for more recent and projected futures inventories. Thus, NR1 inventories are also +99.8% of the neutron activation product form.

Given the significant difference in each waste type release mechanism, containers hydraulic integrity, and contents; burial inventory limits for each waste type are planned for the new PA2022.

Thus, reactor component inventory from the Navy is broken up into two basic categories:

- **Generic** – all inventory identified as crud material; and
- **Special** – all inventory identified as neutron activation product.

H.4 NR0 and NR1 projected 2040 closure Inventories

Sink (2016) projected inventories out to 2040 for NR1, while the current WITS NR0 inventories reflect a permanently closed unit. Sink's NR1 2040 projection was made based on information provided by Bettis and KAPL (Sink 2016b) where inventories for both crud and activated metal components were broken out separately. The distribution of activity between these two forms of contamination associated with the inventories on NR0 are not available. However, KAPL inventories of a representative shipment were provided to SRS and employed in an earlier SA by Yu et al. (2002).

From Table 2.4-1 in Yu et al. (2002) upper-bound inventories of crud and activated metal components for 65 radionuclides were listed. From this data crud fractions (i.e., fraction of activity versus total) were computed. From Sink's 2016 closure projections crud fractions for 138 radionuclides were computed. A comparison of these computed crud fractions is provided in Table H-4 along with the maximum value selected for use in the NRCDA screening.

Table H-4. Computed crud fractions for NR0 and NR1 waste packages.

	NR1 2040 Forecast	Representative Sample Cask	Max Value
Isotope	Fraction Crud (%)	Fraction Crud (%)	Fraction Crud (%)
AC227	100.0000%	100.0000%	100.0000%
AG108	0.1639%	100.0000%	100.0000%
AG108M	0.1640%	100.0000%	100.0000%
AG109M	0.0000%	100.0000%	100.0000%
AG110	0.0028%	100.0000%	100.0000%
AG110M	0.0006%	100.0000%	100.0000%
AM241	0.3695%	0.0710%	0.3695%
AM242	0.0000%	100.0000%	100.0000%
AM242M	0.1140%	100.0000%	100.0000%
AM243	0.1415%	0.0908%	0.1415%
BA133	0.0000%	100.0000%	100.0000%
BA137M	0.8146%	0.5578%	0.8146%
BA140	0.0000%	100.0000%	100.0000%
BE10	0.0000%	100.0000%	100.0000%
BI212	0.0000%	100.0000%	100.0000%
BI214	100.0000%	100.0000%	100.0000%
BK249	0.0000%	100.0000%	100.0000%
C14	1.5840%	0.5386%	1.5840%
CA45	0.0000%	100.0000%	100.0000%
CD109	0.0000%	100.0000%	100.0000%
CD113M	0.0000%	100.0000%	100.0000%
CD115M	0.0000%	100.0000%	100.0000%
CE141	0.0000%	100.0000%	100.0000%
CE144	0.0870%	0.0000%	0.0870%
CF249	0.3348%	0.2943%	0.3348%
CF251	0.5982%	0.5504%	0.5982%
CL36	0.0000%	100.0000%	100.0000%
CM242	0.2661%	0.0672%	0.2661%
CM243	0.1520%	100.0000%	100.0000%
CM244	0.1872%	0.0872%	0.1872%
CM245	0.1991%	0.1792%	0.1991%
CM246	0.1455%	0.1857%	0.1857%
CM247	0.4701%	0.2764%	0.4701%
CM248	0.4779%	0.3723%	0.4779%
CO58	1.0822%	0.9176%	1.0822%
CO60	0.1805%	0.0717%	0.1805%
CR51	0.2880%	0.1507%	0.2880%
CS134	0.1458%	100.0000%	100.0000%
CS135	0.0000%	0.0000%	0.0000%
CS137	0.7782%	0.5578%	0.7782%
EU152	0.0000%	100.0000%	100.0000%
EU154	0.0000%	0.0000%	0.0000%
EU155	0.0000%	0.0000%	0.0000%
FE55	0.3761%	0.1518%	0.3761%
FE59	18.1738%	0.1520%	18.1738%
H3	0.0074%	0.0005%	0.0074%
HF175	0.0000%	100.0000%	100.0000%
HF181	0.9900%	0.0606%	0.9900%
I129	33.5379%	77.4536%	77.4536%
IN113M	0.0000%	0.0000%	0.0000%
IN114	0.0000%	100.0000%	100.0000%
IN114M	0.0000%	100.0000%	100.0000%
IR192	0.0000%	100.0000%	100.0000%
IR192M	0.0000%	100.0000%	100.0000%

	NR1 2040 Forecast	Representative Sample Cask	Max Value
Isotope	Fraction Crud (%)	Fraction Crud (%)	Fraction Crud (%)
KR85	0.9612%	100.0000%	100.0000%
LA140	0.0000%	100.0000%	100.0000%
MN54	1.4882%	0.4397%	1.4882%
MO93	0.0000%	0.0000%	0.0000%
NB93M	2.0276%	47.4401%	47.4401%
NB94	0.4729%	0.2244%	0.4729%
NB95	0.0156%	0.0077%	0.0156%
NB95M	0.0000%	0.0001%	0.0001%
NI59	0.0250%	0.0140%	0.0250%
NI63	0.0215%	0.0121%	0.0215%
NP237	0.1233%	0.2414%	0.2414%
NP239	0.0000%	100.0000%	100.0000%
P33	0.0000%	100.0000%	100.0000%
PA231	100.0000%	100.0000%	100.0000%
PA234	100.0000%	100.0000%	100.0000%
PA234M	1.9387%	100.0000%	100.0000%
PB205	0.0000%	100.0000%	100.0000%
PB212	0.0000%	100.0000%	100.0000%
PB214	100.0000%	100.0000%	100.0000%
PD107	0.0000%	100.0000%	100.0000%
PM147	0.0162%	0.0000%	0.0162%
PO210	0.0000%	100.0000%	100.0000%
PO212	0.0000%	100.0000%	100.0000%
PO214	100.0000%	100.0000%	100.0000%
PO216	0.0000%	100.0000%	100.0000%
PO218	100.0000%	100.0000%	100.0000%
PR144	0.1068%	100.0000%	100.0000%
PR144M	0.0000%	100.0000%	100.0000%
PT193	0.0000%	100.0000%	100.0000%
PU238	0.1314%	0.0680%	0.1314%
PU239	0.0634%	0.0235%	0.0634%
PU240	0.0530%	0.0165%	0.0530%
PU241	0.0850%	0.0214%	0.0850%
PU242	0.1188%	0.0538%	0.1188%
PU244	0.3731%	0.1186%	0.3731%
RA224	0.0000%	100.0000%	100.0000%
RA226	100.0000%	100.0000%	100.0000%
RH103M	0.0000%	100.0000%	100.0000%
RH106	0.0729%	0.0000%	0.0729%
RN220	0.0000%	100.0000%	100.0000%
RN222	100.0000%	100.0000%	100.0000%
RU103	0.0000%	100.0000%	100.0000%
RU106	0.0763%	100.0000%	100.0000%
S35	0.0000%	100.0000%	100.0000%
SB124	0.0000%	100.0000%	100.0000%
SB125	0.0060%	0.0017%	0.0060%
SB126	0.0000%	100.0000%	100.0000%
SB126M	0.0000%	100.0000%	100.0000%
SC46	0.0000%	100.0000%	100.0000%
SE75	0.0000%	100.0000%	100.0000%
SE79	0.0923%	0.0089%	0.0923%
SM151	0.0000%	0.0000%	0.0000%
SN113	0.0000%	0.0000%	0.0000%
SN119M	0.0000%	0.0000%	0.0000%
SN121	0.0000%	100.0000%	100.0000%
SN121M	0.0000%	100.0000%	100.0000%

	NR1 2040 Forecast	Representative Sample Cask	Max Value
Isotope	Fraction Crud (%)	Fraction Crud (%)	Fraction Crud (%)
SN123	0.0000%	0.0000%	0.0000%
SN126	0.7093%	4.3814%	4.3814%
SR89	0.0000%	100.0000%	100.0000%
SR90	1.6409%	0.5473%	1.6409%
TA182	0.0012%	0.0000%	0.0012%
TC99	0.7385%	0.5086%	0.7385%
TE123M	0.0000%	100.0000%	100.0000%
TE125M	0.0096%	0.0007%	0.0096%
TH228	0.0000%	100.0000%	100.0000%
TH230	100.0000%	100.0000%	100.0000%
TH231	7.8930%	100.0000%	100.0000%
TH232	0.3528%	99.9968%	99.9968%
TH234	1.9387%	100.0000%	100.0000%
U232	40.9905%	98.1485%	98.1485%
U233	0.1011%	100.0000%	100.0000%
U234	84.9713%	0.0000%	84.9713%
U235	90.5838%	0.0000%	90.5838%
U236	0.0000%	0.0000%	0.0000%
U237	0.0000%	100.0000%	100.0000%
U238	86.6865%	0.0000%	86.6865%
W181	0.0000%	100.0000%	100.0000%
W185	0.0000%	100.0000%	100.0000%
W188	0.0000%	100.0000%	100.0000%
Y90	1.6339%	0.5473%	1.6339%
Y91	0.0000%	100.0000%	100.0000%
ZN65	27.6045%	100.0000%	100.0000%
ZR93	0.0022%	0.0000%	0.0022%
ZR95	0.0151%	0.0075%	0.0151%

Note that total activities within both NR0 and NR1 are primarily from activated metal components (i.e., over +99.8%). Also, based on operational changes by the Navy less crud activity will be contained within future waste packages.

Estimated closure inventories for both crud and activated metal components are required for both the NRCDAG and NRCDAS screening models. These estimated inventories are based on the following:

- **NR0 crud components** – inventory computed using the maximum crud fraction values provided in Table H-4 and the total inventory activities provided in WITS for NR0;
- **NR0 activated components** – inventory (“slightly” conservative) set to the total activity provided in WITS for NR0;
- **NR1 crud components** – set to the crud values provided the Naval Reactor program and projected to 2040 by Sink (2016); and
- **NR1 activated components** – set to the activated values provided the Naval Reactor program and projected to 2040 by Sink (2016).

Based on the above four inventory groups, the inventory values for use in the GW screening models become:

- **NRCDAG** – Maximum inventory values for crud within either NR0 or NR1; and
- **NRCDAS** – Maximum inventory values for activated metal within either NR0 or NR1.

Table H-5 contains the 138 radionuclide 2040 inventory projections for use in the NRCDAG and NRCDAS GW screening models.

Table H-5. 2040 Projected Closure Inventories for NRCDAG and NRCDAS.

138 List Nuclide	NRCDAS Max Act. (Ci)	NRCDAG Max Act. (Ci)
Ac-227	0.0000E+00	1.0320E-12
Ag-108	1.1500E-07	1.8880E-10
Ag-108m	1.3200E-06	2.1680E-09
Ag-109m	2.1100E-02	0.0000E+00
Ag-110	1.4800E-04	4.1680E-09
Ag-110m	4.9247E-02	3.0720E-07
Am-241	3.5193E-01	4.9793E-04
Am-242	1.0344E-03	0.0000E+00
Am-242m	2.2891E-03	2.6134E-06
Am-243	2.7760E-03	2.4067E-03
Ba-133	2.0900E-03	0.0000E+00
Ba-137m	6.7251E+00	8.3649E-02
Ba-140	4.9000E-08	0.0000E+00
Be-10	2.1600E-05	5.0720E-12
Bi-212	2.6000E-08	0.0000E+00
Bi-214	0.0000E+00	2.0240E-13
Bk-249	2.0700E-08	0.0000E+00
C-14	1.3851E+02	1.4349E+00
Ca-45	1.4920E-02	2.4878E-07
Cd-109	4.0224E-02	0.0000E+00
Cd-113m	1.3280E-02	0.0000E+00
Cd-115m	9.7600E-04	0.0000E+00
Ce-141	4.9400E-03	0.0000E+00
Ce-144	5.8027E+00	5.0500E-03
Cf-249	1.9513E-10	9.7007E-13
Cf-251	4.3537E-12	2.6199E-14
Cl-36	1.2702E-02	6.7692E-08
Cm-242	5.2157E+00	9.4790E-01
Cm-243	2.1262E-03	3.2362E-06
Cm-244	2.5542E-01	1.9242E-01
Cm-245	1.6422E-05	1.0134E-07
Cm-246	8.9802E-06	3.0555E-06
Cm-247	8.3291E-12	3.9340E-14
Cm-248	2.5920E-11	1.8866E-11
Co-58	2.0727E+04	2.0727E+04
Co-60	9.8477E+04	9.8477E+04
Cr-51	7.4654E+03	7.4654E+03
Cs-134	1.5113E+01	5.3302E-02
Cs-135	5.2634E-05	5.1401E-07
Cs-137	7.1351E+00	5.5964E-02
Eu-152	6.2335E-04	0.0000E+00
Eu-154	5.1611E-01	3.1784E-04
Eu-155	1.1838E-01	5.9653E-06
Fe-55	9.0297E+04	2.4622E+02
Fe-59	7.4754E+03	1.9008E+00
H-3	1.3421E+02	3.2392E-01
Hf-175	7.4645E+03	7.4645E+03
Hf-181	6.5841E+01	6.5836E-01
I-129	1.4808E-05	1.4808E-05
In-113m	4.8730E+03	4.8730E+03
In-114	2.0200E+00	0.0000E+00
In-114m	3.8000E+00	0.0000E+00
Ir-192	1.3040E-02	0.0000E+00
Ir-192m	2.4700E-07	0.0000E+00

138 List Nuclide	NRCDAS Max Act. (Ci)	NRCDAG Max Act. (Ci)
Kr-85	2.6129E-01	5.7072E-03
La-140	5.6500E-08	0.0000E+00
Mn-54	1.3907E+03	1.3907E+03
Mo-93	1.4301E+00	1.4301E+00
Nb-93m	7.4623E+03	7.4623E+03
Nb-94	6.5434E+00	6.5434E+00
Nb-95	1.3092E+05	1.7199E+02
Nb-95m	1.3090E+03	8.2963E-01
Ni-59	1.7346E+03	8.2349E-01
Ni-63	2.0068E+05	1.5288E+02
Np-237	4.0347E-06	4.7940E-09
Np-239	1.2590E-03	0.0000E+00
P-33	6.3200E-03	0.0000E+00
Pa-231	0.0000E+00	2.2400E-12
Pa-234	0.0000E+00	6.7040E-11
Pa-234m	2.6100E-06	5.1600E-08
Pb-205	5.6800E-08	0.0000E+00
Pb-212	2.6000E-08	0.0000E+00
Pb-214	0.0000E+00	2.0240E-13
Pd-107	3.9900E-06	0.0000E+00
Pm-147	4.2284E+00	3.0541E+00
Po-210	6.2400E-03	0.0000E+00
Po-212	1.6600E-08	0.0000E+00
Po-214	0.0000E+00	2.0160E-13
Po-216	2.6000E-08	0.0000E+00
Po-218	0.0000E+00	2.0240E-13
Pr-144	4.7252E+00	2.2023E-01
Pr-144m	6.6001E-02	0.0000E+00
Pt-193	1.1400E-04	0.0000E+00
Pu-238	2.6915E-01	1.1792E-02
Pu-239	1.2334E-01	1.2334E-01
Pu-240	1.1117E-01	1.8242E-03
Pu-241	3.4020E+01	1.3697E-02
Pu-242	4.0677E-04	3.0038E-06
Pu-244	2.7741E-11	2.7741E-11
Ra-224	2.6000E-08	0.0000E+00
Ra-226	0.0000E+00	2.0240E-13
Rh-103m	3.9510E-02	0.0000E+00
Rh-106	6.6485E+00	4.8500E-03
Rn-220	2.6000E-08	0.0000E+00
Rn-222	0.0000E+00	2.0240E-13
Ru-103	4.8680E-02	0.0000E+00
Ru-106	8.1903E+00	6.5995E-01
S-35	1.8240E-01	2.6786E-03
Sb-124	1.8930E+00	6.2320E-07
Sb-125	4.0703E+04	4.0703E+04
Sb-126	2.3700E-06	0.0000E+00
Sb-126m	1.6800E-05	0.0000E+00
Sc-46	5.9600E-01	3.2600E-03
Se-75	3.2740E-01	3.1520E-11
Se-79	1.2227E-03	1.9642E-07
Sm-151	9.1793E-02	8.1069E-06
Sn-113	4.8730E+03	1.7520E-08
Sn-119m	8.0850E+04	1.6800E-07
Sn-121	6.4100E+00	1.9440E-10
Sn-121m	1.7110E+01	2.5040E-10
Sn-123	2.3540E+03	2.3600E-11
Sn-126	8.2483E-05	5.8921E-07
Sr-89	7.5000E-01	1.2000E-13

138 List Nuclide	NRCDAS Max Act. (Ci)	NRCDAG Max Act. (Ci)
Sr-90	5.3854E+00	5.5708E-02
Ta-182	1.7603E+04	5.5350E-02
Tc-99	1.9294E-01	1.4354E-03
Te-123m	6.0938E+02	0.0000E+00
Te-125m	2.5411E+04	2.8185E-01
Th-228	2.5900E-08	0.0000E+00
Th-230	0.0000E+00	2.1360E-11
Th-231	2.8100E-08	2.4080E-09
Th-232	3.5156E-08	1.2448E-10
Th-234	2.6100E-06	5.1600E-08
U-232	4.7729E-06	1.9540E-06
U-233	7.8436E-06	7.9400E-09
U-234	2.5649E-05	1.4502E-04
U-235	6.9360E-07	6.6724E-06
U-236	6.5849E-05	3.2300E-11
U-237	6.8700E-05	0.0000E+00
U-238	2.3224E-05	1.4305E-04
W-181	3.3100E+00	0.0000E+00
W-185	9.5700E+00	0.0000E+00
W-188	2.7900E-02	0.0000E+00
Y-90	5.3854E+00	5.5468E-02
Y-91	3.6900E+00	4.3440E-13
Zn-65	1.1294E+01	4.0479E+00
Zr-93	7.4580E+03	2.6199E-04
Zr-95	6.1611E+04	1.8228E+00

Appendix I. Details/Results Associated with Tier-1 Radionuclide Lists

For each of the five DU types, a variety of screening models and initial radionuclide lists were used to ascertain their impact on the Tier-1 list of radionuclides passing through this level of GW and inadvertent intruder pathway screening. The models, nuclide lists and pathways considered were:

- **GW model** – the traditional GW NCRP model and the 3-Box model;
- **II model** – RadScreen inadvertent intruder model;
- **Initial nuclide list** –the full list of ICRP-07 1,252 radionuclides, Tier-0 list based on SRS waste (applicable to the Trench, ILV, and LAWV models), and Tier-0 list based on Naval Reactor waste (applicable to the NRCDA-G and NRCDA-S models).
- **Pathways** – GW and inadvertent intruder pathways

For each DU type three tables are provided below:

- The first table contains the Tier-1 radionuclide lists for each screening model, initial nuclide list and pathway.
- The second table contains the Tier-1 NCRP123 GW SOF histogram bins (row 2), counts (row 3) and running totals of radionuclides remaining (row 4). The range of histogram bins varies from < 1E-6 to > 1E+2. The screening criteria is a SOF equal to 1E-3 (0.1%). For example, the count in the SOF bin 1E-3 represents all radionuclides with a SOF • 1E-4 and < 1E-3. Any radionuclides in bins beyond 1E-3 failed Tier-1 screening.
- The third table contains the Tier-1 RadScreen II SOF histogram bins, counts and running totals of radionuclides remaining. This table reflects the second table as far as structure but applies only to the inadvertent intruder.

I.1 Generic Trench Model

Table I-1, Table I-2 and Table I-3 are the results for the generic trench model that apply to all ST, ET, and CIG units.

Table I-1. Tier-1 radionuclide listing for the Generic Trench disposal unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	348	163	276	138	128	88
	Ac-226		Ac-226		Ac-226	
	Ac-227	Ac-227				
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233		Ac-233			
	Ag-101					
	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m
	Ag-113		Ag-113			
	Ag-113m					
	Am-237		Am-237			
	Am-238		Am-238			
	Am-239		Am-239			
	Am-240		Am-240			
	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
	Am-242m	Am-242m	Am-242m	Am-242m	Am-242m	Am-242m
	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243
	Am-244		Am-244			
	Am-244m		Am-244m			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**348**	**163**	**276**	**138**	**128**	**88**
	Am-245	Am-245	Am-245	Am-245		
	Am-246		Am-246			
	Am-246m	Am-246m	Am-246m	Am-246m		
	Am-247					
	Ar-42		Ar-42		Ar-42	
	As-79					
	At-206		At-206			
	At-207		At-207		At-207	
	At-208		At-208			
	At-209		At-209		At-209	
	At-211		At-211		At-211	
	At-218	At-218				
	Au-193		Au-193			
	Au-193m		Au-193m			
	Au-195	Au-195				
	Ba-133	Ba-133	Ba-133	Ba-133		
	Ba-133m		Ba-133m			
	Be-10	Be-10	Be-10	Be-10		
	Bi-202		Bi-202		Bi-202	
	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m
	Bk-245		Bk-245		Bk-245	
	Bk-246		Bk-246			
	Bk-247	Bk-247				
	Bk-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250	Bk-250	Bk-250		
	Bk-251		Bk-251			
	C-14	C-14	C-14	C-14	C-14	C-14
	Cd-101					
	Cd-113m	Cd-113m	Cd-113m	Cd-113m		
	Ce-133		Ce-133			
	Ce-133m		Ce-133m			
	Ce-137					
	Ce-137m					
	Cf-244		Cf-244		Cf-244	
	Cf-246		Cf-246			
	Cf-247		Cf-247		Cf-247	
	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248
	Cf-249	Cf-249	Cf-249	Cf-249	Cf-249	Cf-249
	Cf-250	Cf-250	Cf-250	Cf-250		
	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251
	Cf-252	Cf-252				
	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253
	Cf-254		Cf-254		Cf-254	
	Cf-255		Cf-255		Cf-255	
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cl-39		Cl-39			
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241		Cm-241	
	Cm-242	Cm-242				
	Cm-243	Cm-243	Cm-243	Cm-243		
	Cm-244	Cm-244	Cm-244	Cm-244		
	Cm-245	Cm-245	Cm-245	Cm-245		
	Cm-246	Cm-246	Cm-246	Cm-246		
	Cm-247	Cm-247	Cm-247	Cm-247	Cm-247	Cm-247
	Cm-248	Cm-248	Cm-248	Cm-248	Cm-248	Cm-248
	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251		Cm-251			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**348**	**163**	**276**	**138**	**128**	**88**
	Co-55					
	Co-60	Co-60	Co-60	Co-60		
	Co-60m	Co-60m	Co-60m	Co-60m		
	Cs-134	Cs-134	Cs-134	Cs-134		
	Cs-134m		Cs-134m			
	Cs-135	Cs-135	Cs-135	Cs-135		
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-149					
	Dy-150		Dy-150			
	Dy-152		Dy-152			
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Dy-157					
	Er-154		Er-154			
	Er-163					
	Er-171					
	Es-249		Es-249		Es-249	
	Es-250		Es-250		Es-250	
	Es-250m		Es-250m		Es-250m	
	Es-251		Es-251		Es-251	
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Es-254m		Es-254m		Es-254m	
	Es-255		Es-255		Es-255	
	Es-256		Es-256			
	Eu-145					
	Eu-146					
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m		Eu-150m			
	Eu-152	Eu-152	Eu-152	Eu-152		
	Eu-152n		Eu-152n			
	Eu-154	Eu-154	Eu-154	Eu-154		
	Eu-154m		Eu-154m			
	Eu-155	Eu-155				
	Fe-53					
	Fe-55	Fe-55	Fe-55	Fe-55		
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-251		Fm-251		Fm-251	
	Fm-252		Fm-252		Fm-252	
	Fm-253		Fm-253		Fm-253	
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-255		Fm-255		Fm-255	
	Fm-256		Fm-256			
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	Fr-212		Fr-212			
	Fr-222		Fr-222			
	Fr-227		Fr-227			
	Gd-145					
	Gd-145m					
	Gd-146		Gd-146			
	Gd-148	Gd-148	Gd-148	Gd-148	Gd-148	Gd-148
	Gd-150	Gd-150	Gd-150	Gd-150	Gd-150	Gd-150
	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152
	Gd-153	Gd-153				
	Ge-68	Ge-68				
	H-3	H-3	H-3	H-3		
	Hf-172	Hf-172	Hf-172	Hf-172		
	Hf-173					
	Hf-174	Hf-174	Hf-174	Hf-174	Hf-174	Hf-174
	Hf-178m	Hf-178m	Hf-178m	Hf-178m	Hf-178m	Hf-178m
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**348**	**163**	**276**	**138**	**128**	**88**
	Hf-182m					
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-150					
	Ho-154		Ho-154			
	Ho-154m		Ho-154m			
	Ho-157					
	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163
	I-129	I-129	I-129	I-129	I-129	I-129
	I-135					
	In-109					
	In-109m					
	In-115	In-115	In-115	In-115	In-115	In-115
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40	K-40	K-40
	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81
	La-133		La-133			
	La-137	La-137	La-137	La-137	La-137	La-137
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-173	Lu-173				
	Lu-174	Lu-174	Lu-174	Lu-174		
	Lu-174m	Lu-174m	Lu-174m	Lu-174m		
	Lu-176	Lu-176	Lu-176	Lu-176	Lu-176	Lu-176
	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53
	Mn-54	Mn-54				
	Mo-91m					
	Mo-93	Mo-93	Mo-93	Mo-93		
	Mo-93m		Mo-93m			
	Mo-99		Mo-99			
	Na-22	Na-22				
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-91m		Nb-91m		Nb-91m	
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m	Nb-93m				
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nb-94m		Nb-94m			
	Nb-99m					
	Nd-137					
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	Nd-147					
	Nd-151					
	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59
	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63
	Np-232		Np-232		Np-232	
	Np-233		Np-233			
	Np-234		Np-234			
	Np-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-236m		Np-236m		Np-236m	
	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
	Np-238	Np-238	Np-238	Np-238		
	Np-239	Np-239	Np-239	Np-239		
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m	Np-240m	Np-240m		
	Np-241		Np-241			
	Np-242		Np-242			
	Np-242m		Np-242m			
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	Os-194	Os-194	Os-194	Os-194		
	Pa-228					
	Pa-229		Pa-229		Pa-229	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**348**	**163**	**276**	**138**	**128**	**88**
	Pa-230		Pa-230		Pa-230	
	Pa-231	Pa-231	Pa-231	Pa-231		
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pa-233	Pa-233				
	Pa-235		Pa-235			
	Pa-236					
	Pa-237		Pa-237			
	Pb-194		Pb-194		Pb-194	
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m		Pb-202m		Pb-202m	
	Pb-210	Pb-210	Pb-210	Pb-210		
	Pd-97		Pd-97			
	Pd-101					
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-137m					
	Pm-144	Pm-144				
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145
	Pm-147	Pm-147				
	Pm-151		Pm-151			
	Po-205					
	Po-206					
	Po-207					
	Po-208	Po-208	Po-208	Po-208	Po-208	Po-208
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pr-137		Pr-137			
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pt-193	Pt-193				
	Pt-193m		Pt-193m			
	Pu-232		Pu-232		Pu-232	
	Pu-234		Pu-234			
	Pu-235		Pu-235			
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-237		Pu-237		Pu-237	
	Pu-238	Pu-238	Pu-238	Pu-238		
	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239
	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240
	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241
	Pu-242	Pu-242	Pu-242	Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	Pu-245		Pu-245			
	Pu-246	Pu-246	Pu-246	Pu-246		
	Ra-222		Ra-222			
	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
	Ra-227		Ra-227			
	Ra-228	Ra-228	Ra-228	Ra-228		
	Ra-230		Ra-230		Ra-230	
	Rb-87	Rb-87	Rb-87	Rb-87		
	Rb-90		Rb-90			
	Rb-90m		Rb-90m			
	Re-179		Re-179			
	Re-184m	Re-184m				
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187
	Rh-97		Rh-97			
	Rh-97m		Rh-97m			
	Rh-101	Rh-101	Rh-101	Rh-101		
	Rh-101m					
	Rh-102m	Rh-102m	Rh-102m	Rh-102m		
	Rn-207		Rn-207		Rn-207	
	Rn-209		Rn-209			
	Rn-210		Rn-210			
	Rn-211		Rn-211		Rn-211	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**348**	**163**	**276**	**138**	**128**	**88**
	Rn-212		Rn-212			
	Rn-218	Rn-218				
	Rn-222	Rn-222				
	Ru-97		Ru-97			
	Ru-106	Ru-106	Ru-106	Ru-106		
	Sb-125	Sb-125				
	Sb-129		Sb-129			
	Se-79	Se-79	Se-79	Se-79		
	Se-79m					
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	Sm-145	Sm-145	Sm-145	Sm-145		
	Sm-146	Sm-146	Sm-146	Sm-146	Sm-146	Sm-146
	Sm-147	Sm-147	Sm-147	Sm-147	Sm-147	Sm-147
	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148
	Sm-151	Sm-151	Sm-151	Sm-151		
	Sm-155					
	Sn-109		Sn-109			
	Sn-121m	Sn-121m				
	Sn-125					
	Sn-126	Sn-126	Sn-126	Sn-126	Sn-126	Sn-126
	Sn-129		Sn-129			
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	Ta-172					
	Ta-173					
	Ta-179	Ta-179	Ta-179	Ta-179		
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-149					
	Tb-150		Tb-150			
	Tb-150m		Tb-150m			
	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-91		Tc-91			
	Tc-91m		Tc-91m			
	Tc-93					
	Tc-93m		Tc-93m			
	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-97m		Tc-97m		Tc-97m	
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
	Tc-99m		Tc-99m			
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226		Th-226			
	Th-228	Th-228				
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Th-230	Th-230	Th-230	Th-230	Th-230	Th-230
	Th-231	Th-231	Th-231	Th-231		
	Th-232	Th-232	Th-232	Th-232	Th-232	Th-232
	Th-233		Th-233			
	Th-234	Th-234	Th-234	Th-234		
	Th-235		Th-235			
	Th-236		Th-236			
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194		Tl-194	
	Tl-194m		Tl-194m		Tl-194m	
	Tl-204	Tl-204	Tl-204	Tl-204		
	Tl-210	Tl-210				
	Tm-163		Tm-163			
	U-228					
	U-230		U-230		U-230	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	348	163	276	138	128	88
	U-231		U-231		U-231	
	U-232	U-232	U-232	U-232	U-232	U-232
	U-233	U-233	U-233	U-233	U-233	U-233
	U-234	U-234	U-234	U-234	U-234	U-234
	U-235	U-235	U-235	U-235	U-235	U-235
	U-235m	U-235m	U-235m	U-235m		
	U-236	U-236	U-236	U-236	U-236	U-236
	U-238	U-238	U-238	U-238	U-238	U-238
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242		U-242			
	V-49	V-49				
	V-50	V-50	V-50	V-50	V-50	V-50
	W-179		W-179			
	W-179m		W-179m			
	Xe-135		Xe-135			
	Xe-137		Xe-137			
	Y-93					
	Yb-163					
	Zr-93	Zr-93	Zr-93	Zr-93		

Table I-2. Tier-1 NCRP123 groundwater pathway SOF histogram for the Generic Trench disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	7	6	8	9	12	12	13	10	107
271	184	177	171	163	154	142	130	117	107	0
Ac-225	Ac-225									
Ac-227							Ac-227			
Ac-228			Ac-228							
Ag-108	Ag-108									
Ag-108m										Ag-108m
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26	Al-26									
Am-241										Am-241
Am-242	Am-242									
Am-242m										Am-242m
Am-243										Am-243
Am-245									Am-245	
Am-246m							Am-246m			
Ar-39	Ar-39									
At-217	At-217									
At-218							At-218			
At-219	At-219									
Au-194	Au-194									
Au-195					Au-195					
Ba-133						Ba-133				
Ba-137m	Ba-137m									
Be-10						Be-10				
Bi-207				Bi-207						
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214				Bi-214						

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	7	6	8	9	12	12	13	10	107
271	184	177	171	163	154	142	130	117	107	0
Bi-215	Bi-215									
Bk-247					Bk-247					
Bk-249										Bk-249
Bk-250								Bk-250		
C-14										C-14
Ca-41		Ca-41								
Ca-45	Ca-45									
Cd-109				Cd-109						
Cd-113	Cd-113									
Cd-113m										Cd-113m
Ce-139	Ce-139									
Ce-144			Ce-144							
Cf-248										Cf-248
Cf-249										Cf-249
Cf-250									Cf-250	
Cf-251										Cf-251
Cf-252						Cf-252				
Cf-253										Cf-253
Cl-36									Cl-36	
Cm-242					Cm-242					
Cm-243								Cm-243		
Cm-244										Cm-244
Cm-245										Cm-245
Cm-246									Cm-246	
Cm-247										Cm-247
Cm-248									Cm-248	
Cm-249										Cm-249
Cm-250										Cm-250
Co-57				Co-57						
Co-60							Co-60			
Co-60m									Co-60m	
Cs-134								Cs-134		
Cs-135							Cs-135			
Cs-137										Cs-137
Dy-154										Dy-154
Dy-159		Dy-159								
Es-253										Es-253
Es-254										Es-254
Eu-149	Eu-149									
Eu-150										Eu-150
Eu-152										Eu-152
Eu-154										Eu-154
Eu-155								Eu-155		
Fe-55								Fe-55		
Fe-60										Fe-60
Fm-254										Fm-254
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148										Gd-148
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153						Gd-153				
Ge-68								Ge-68		
H-3										H-3
Hf-172										Hf-172
Hf-174										Hf-174
Hf-178m										Hf-178m
Hf-182										Hf-182

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	7	6	8	9	12	12	13	10	107
271	184	177	171	163	154	142	130	117	107	0
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163										Ho-163
Ho-166m				Ho-166m						
I-129										I-129
In-113m	In-113m									
In-115										In-115
Ir-192	Ir-192									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m			Ir-194m							
K-40										K-40
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173								Lu-173		
Lu-174										Lu-174
Lu-174m										Lu-174m
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m		Lu-177m								
Mn-53										Mn-53
Mn-54					Mn-54					
Mo-93									Mo-93	
Na-22					Na-22					
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m							Nb-93m			
Nb-94										Nb-94
Nd-144										Nd-144
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237										Np-237
Np-238										Np-238
Np-239							Np-239			
Np-240								Np-240		
Np-240m							Np-240m			
Os-185	Os-185									
Os-186										Os-186
Os-194										Os-194
P-32	P-32									
Pa-231								Pa-231		
Pa-232										Pa-232
Pa-233					Pa-233					
Pa-234		Pa-234								
Pa-234m		Pa-234m								
Pb-202										Pb-202
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210										Pb-210
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214				Pb-214						
Pd-107					Pd-107					
Pm-143				Pm-143						

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	7	6	8	9	12	12	13	10	107
271	184	177	171	163	154	142	130	117	107	0
Pm-144						Pm-144				
Pm-145										Pm-145
Pm-146		Pm-146								
Pm-147							Pm-147			
Po-208										Po-208
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218			Po-218							
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193					Pt-193					
Pu-236										Pu-236
Pu-238										Pu-238
Pu-239										Pu-239
Pu-240										Pu-240
Pu-241										Pu-241
Pu-242										Pu-242
Pu-243										Pu-243
Pu-244				Pu-244						
Pu-246										Pu-246
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226										Ra-226
Ra-228									Ra-228	
Rb-87							Rb-87			
Re-184	Re-184									
Re-184m					Re-184m					
Re-186	Re-186									
Re-186m										Re-186m
Re-187										Re-187
Rh-101										Rh-101
Rh-102			Rh-102							
Rh-102m										Rh-102m
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218							Rn-218			
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222						Rn-222				
Ru-106								Ru-106		
S-35	S-35									
Sb-125						Sb-125				
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79									Se-79	
Si-32										Si-32
Sm-145										Sm-145
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151									Sm-151	

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	7	6	8	9	12	12	13	10	107
271	184	177	171	163	154	142	130	117	107	0
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m						Sn-121m				
Sn-123	Sn-123									
Sn-126								Sn-126		
Sr-90										Sr-90
Ta-179										Ta-179
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228							Th-228			
Th-229										Th-229
Th-230										Th-230
Th-231						Th-231				
Th-232										Th-232
Th-234						Th-234				
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204										Tl-204
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210						Tl-210				
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171		Tm-171								
U-232										U-232
U-233										U-233
U-234										U-234
U-235										U-235
U-235m						U-235m				
U-236										U-236
U-237	U-237									
U-238										U-238
U-240										U-240
V-49								V-49		
V-50										V-50
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65			Zn-65							
Zr-93								Zr-93		

Table I-3. Tier-1 RadScreen II pathway SOF histogram for the Generic Trench disposal unit.

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	163	**6**	**5**	**9**	**17**	**12**	**9**	**6**	**5**	**39**
271	**108**	**102**	**97**	**88**	**71**	**59**	**50**	**44**	**39**	**0**
Ac-225	Ac-225									
Ac-227	Ac-227									
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m									Ag-108m	
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26	Al-26									
Am-241						Am-241				
Am-242	Am-242									
Am-242m					Am-242m					
Am-243							Am-243			
Am-245				Am-245						
Am-246m	Am-246m									
Ar-39	Ar-39									
At-217	At-217									
At-218	At-218									
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									
Be-10	Be-10									
Bi-207	Bi-207									
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247	Bk-247									
Bk-249										Bk-249
Bk-250		Bk-250								
C-14						C-14				
Ca-41	Ca-41									
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113	Cd-113									
Cd-113m	Cd-113m									
Ce-139	Ce-139									
Ce-144	Ce-144									
Cf-248							Cf-248			
Cf-249						Cf-249				
Cf-250		Cf-250								
Cf-251						Cf-251				
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36			Cl-36							
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244			Cm-244							
Cm-245				Cm-245						
Cm-246			Cm-246							
Cm-247					Cm-247					
Cm-248					Cm-248					
Cm-249					Cm-249					

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	163	6	5	9	17	12	9	6	5	39
271	108	102	97	88	71	59	50	44	39	0
Cm-250										Cm-250
Co-57	Co-57									
Co-60	Co-60									
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135	Cs-135									
Cs-137								Cs-137		
Dy-154										Dy-154
Dy-159	Dy-159									
Es-253										Es-253
Es-254								Es-254		
Eu-149	Eu-149									
Eu-150								Eu-150		
Eu-152				Eu-152						
Eu-154		Eu-154								
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60										Fe-60
Fm-254					Fm-254					
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148									Gd-148	
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3		H-3								
Hf-172	Hf-172									
Hf-174										Hf-174
Hf-178m						Hf-178m				
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163							Ho-163			
Ho-166m		Ho-166m								
I-129					I-129					
In-113m	In-113m									
In-115										In-115
Ir-192	Ir-192									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40					K-40					
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53										Mn-53
Mn-54	Mn-54									

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	163	**6**	**5**	**9**	**17**	**12**	**9**	**6**	**5**	**39**
271	**108**	**102**	**97**	**88**	**71**	**59**	**50**	**44**	**39**	**0**
Mo-93				Mo-93						
Na-22	Na-22									
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m	Nb-93m									
Nb-94								Nb-94		
Nd-144										Nd-144
Ni-59					Ni-59					
Ni-63					Ni-63					
Np-235					Np-235					
Np-236										Np-236
Np-237						Np-237				
Np-238		Np-238								
Np-239	Np-239									
Np-240	Np-240									
Np-240m	Np-240m									
Os-185	Os-185									
Os-186										Os-186
Os-194			Os-194							
P-32	P-32									
Pa-231	Pa-231									
Pa-232					Pa-232					
Pa-233	Pa-233									
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210	Pb-210									
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107	Pd-107									
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145					Pm-145					
Pm-146	Pm-146									
Pm-147	Pm-147									
Po-208					Po-208					
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193	Pt-193									
Pu-236										Pu-236
Pu-238				Pu-238						
Pu-239						Pu-239				
Pu-240					Pu-240					
Pu-241						Pu-241				
Pu-242				Pu-242						
Pu-243					Pu-243					
Pu-244	Pu-244									
Pu-246				Pu-246						
Ra-223	Ra-223									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	163	**6**	**5**	**9**	**17**	**12**	**9**	**6**	**5**	**39**
271	**108**	**102**	**97**	**88**	**71**	**59**	**50**	**44**	**39**	**0**
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226							Ra-226			
Ra-228	Ra-228									
Rb-87	Rb-87									
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m										Re-186m
Re-187									Re-187	
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222	Rn-222									
Ru-106	Ru-106									
S-35	S-35									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79			Se-79							
Si-32										Si-32
Sm-145				Sm-145						
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151	Sm-151									
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m	Sn-121m									
Sn-123	Sn-123									
Sn-126						Sn-126				
Sr-90					Sr-90					
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157									Tb-157	
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99						Tc-99				
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229						Th-229				
Th-230							Th-230			
Th-231	Th-231									
Th-232							Th-232			
Th-234	Th-234									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	163	**6**	**5**	**9**	**17**	**12**	**9**	**6**	**5**	**39**
271	**108**	**102**	**97**	**88**	**71**	**59**	**50**	**44**	**39**	**0**
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210	Tl-210									
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232						U-232				
U-233								U-233		
U-234							U-234			
U-235							U-235			
U-235m	U-235m									
U-236					U-236					
U-237	U-237									
U-238								U-238		
U-240				U-240						
V-49	V-49									
V-50							V-50			
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65	Zn-65									
Zr-93	Zr-93									

I.2 ILV Model

Table I-4, Table I-5 and Table I-6 are the results for the ILV model that apply to only the ILV unit.

Table I-4. Tier-1 radionuclide listing for the ILV disposal unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	Ac-226		Ac-226		Ac-226	
	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233		Ac-233			
	Ag-108m	Ag-108m	Ag-108m	Ag-108m		
	Ag-113		Ag-113			
	Ag-113m					
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-237		Am-237			
	Am-238		Am-238			
	Am-239		Am-239			
	Am-240		Am-240			
	Am-241	Am-241	Am-241	Am-241		
	Am-242	Am-242	Am-242	Am-242		
	Am-242m	Am-242m	Am-242m	Am-242m		
	Am-243	Am-243	Am-243	Am-243		
	Am-244		Am-244			
	Am-244m		Am-244m			
	Am-245	Am-245	Am-245	Am-245		
	Am-246		Am-246			
	Am-246m	Am-246m	Am-246m	Am-246m		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	Am-247		Am-247			
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	As-79		As-79			
	At-206		At-206			
	At-207		At-207			
	At-209		At-209			
	At-211		At-211			
	At-218	At-218				
	Au-193		Au-193			
	Au-193m		Au-193m			
	Ba-133	Ba-133	Ba-133	Ba-133		
	Ba-133m		Ba-133m			
	Be-10	Be-10	Be-10	Be-10		
	Bi-202		Bi-202			
	Bi-205		Bi-205			
	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207
	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m
	Bk-245		Bk-245			
	Bk-246		Bk-246			
	Bk-247	Bk-247	Bk-247	Bk-247		
	Bk-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249		
	Bk-250	Bk-250	Bk-250	Bk-250		
	Bk-251		Bk-251			
	C-14	C-14	C-14	C-14		
	Ca-41	Ca-41	Ca-41	Ca-41		
	Cd-113	Cd-113	Cd-113	Cd-113		
	Ce-133					
	Ce-133m		Ce-133m			
	Ce-137		Ce-137			
	Ce-137m		Ce-137m			
	Cf-244		Cf-244		Cf-244	
	Cf-246		Cf-246			
	Cf-247		Cf-247			
	Cf-248	Cf-248	Cf-248	Cf-248		
	Cf-249	Cf-249	Cf-249	Cf-249		
	Cf-250	Cf-250	Cf-250	Cf-250		
	Cf-251	Cf-251	Cf-251	Cf-251		
	Cf-252	Cf-252	Cf-252	Cf-252		
	Cf-253	Cf-253	Cf-253	Cf-253		
	Cf-254		Cf-254			
	Cf-255		Cf-255			
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cl-39		Cl-39			
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	Cm-242	Cm-242				
	Cm-243	Cm-243	Cm-243	Cm-243		
	Cm-244	Cm-244	Cm-244	Cm-244		
	Cm-245	Cm-245	Cm-245	Cm-245		
	Cm-246	Cm-246	Cm-246	Cm-246		
	Cm-247	Cm-247	Cm-247	Cm-247		
	Cm-248	Cm-248	Cm-248	Cm-248		
	Cm-249	Cm-249	Cm-249	Cm-249		
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251		Cm-251			
	Cs-135	Cs-135	Cs-135	Cs-135		
	Cs-135m		Cs-135m			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-150		Dy-150			
	Dy-152		Dy-152			
	Dy-154	Dy-154	Dy-154	Dy-154		
	Dy-157		Dy-157			
	Er-154		Er-154			
	Er-163					
	Es-249		Es-249			
	Es-250		Es-250			
	Es-250m		Es-250m			
	Es-251		Es-251			
	Es-253	Es-253	Es-253	Es-253		
	Es-254	Es-254	Es-254	Es-254		
	Es-254m		Es-254m			
	Es-255		Es-255			
	Es-256		Es-256			
	Eu-145					
	Eu-146		Eu-146			
	Eu-147					
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m		Eu-150m			
	Eu-152n					
	Fe-53		Fe-53			
	Fe-53m					
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-251		Fm-251			
	Fm-252		Fm-252			
	Fm-253		Fm-253			
	Fm-254	Fm-254	Fm-254	Fm-254		
	Fm-255		Fm-255			
	Fm-256		Fm-256			
	Fm-257	Fm-257	Fm-257	Fm-257		
	Fr-222		Fr-222			
	Fr-227					
	Gd-145					
	Gd-146		Gd-146			
	Gd-147					
	Gd-148	Gd-148	Gd-148	Gd-148		
	Gd-150	Gd-150	Gd-150	Gd-150		
	Gd-152	Gd-152	Gd-152	Gd-152		
	H-3	H-3	H-3	H-3		
	Hf-174	Hf-174	Hf-174	Hf-174		
	Hf-178m	Hf-178m	Hf-178m	Hf-178m		
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hf-182m					
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-150					
	Ho-154		Ho-154			
	Ho-154m		Ho-154m			
	Ho-157					
	Ho-163	Ho-163	Ho-163	Ho-163		
	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m
	I-129	I-129	I-129	I-129		
	I-135		I-135			
	In-115	In-115	In-115	In-115		
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40		
	Kr-81	Kr-81	Kr-81	Kr-81		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	La-133		La-133			
	La-137	La-137	La-137	La-137		
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-176	Lu-176	Lu-176	Lu-176		
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mo-91		Mo-91			
	Mo-91m					
	Mo-93	Mo-93	Mo-93	Mo-93		
	Mo-93m		Mo-93m			
	Mo-99		Mo-99			
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-91m		Nb-91m			
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m	Nb-93m				
	Nb-94	Nb-94	Nb-94	Nb-94		
	Nb-94m		Nb-94m			
	Nb-99		Nb-99			
	Nb-99m		Nb-99m			
	Nd-137		Nd-137			
	Nd-144	Nd-144	Nd-144	Nd-144		
	Nd-147					
	Nd-151		Nd-151			
	Ni-59	Ni-59	Ni-59	Ni-59		
	Ni-63	Ni-63	Ni-63	Ni-63		
	Np-232		Np-232		Np-232	
	Np-233		Np-233			
	Np-234		Np-234			
	Np-235	Np-235	Np-235	Np-235		
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-236m		Np-236m		Np-236m	
	Np-237	Np-237	Np-237	Np-237		
	Np-238	Np-238	Np-238	Np-238		
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m	Np-240m	Np-240m		
	Np-241		Np-241			
	Np-242		Np-242			
	Np-242m		Np-242m			
	Os-186	Os-186	Os-186	Os-186		
	Os-194	Os-194				
	Pa-229		Pa-229			
	Pa-230		Pa-230		Pa-230	
	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pa-235		Pa-235			
	Pa-236					
	Pa-237		Pa-237			
	Pb-194		Pb-194			
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m		Pb-202m			
	Pb-205	Pb-205	Pb-205	Pb-205		
	Pb-210	Pb-210	Pb-210	Pb-210		
	Pd-97		Pd-97			
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-137m					
	Pm-145	Pm-145	Pm-145	Pm-145		
	Pm-146	Pm-146	Pm-146	Pm-146		
	Pm-151		Pm-151			
	Po-205					
	Po-206		Po-206			
	Po-207		Po-207			
	Po-208	Po-208	Po-208	Po-208		
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	Pr-137		Pr-137			
	Pt-190	Pt-190	Pt-190	Pt-190		
	Pt-193	Pt-193				
	Pt-193m		Pt-193m			
	Pu-232		Pu-232		Pu-232	
	Pu-234		Pu-234			
	Pu-235		Pu-235			
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-237		Pu-237			
	Pu-238	Pu-238	Pu-238	Pu-238		
	Pu-239	Pu-239	Pu-239	Pu-239		
	Pu-240	Pu-240	Pu-240	Pu-240		
	Pu-241	Pu-241	Pu-241	Pu-241		
	Pu-242	Pu-242	Pu-242	Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243		
	Pu-244	Pu-244	Pu-244	Pu-244		
	Pu-245		Pu-245			
	Pu-246	Pu-246	Pu-246	Pu-246		
	Ra-222					
	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
	Ra-227		Ra-227			
	Ra-230		Ra-230			
	Rb-81					
	Rb-87	Rb-87	Rb-87	Rb-87		
	Rb-90		Rb-90			
	Rb-90m		Rb-90m			
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187		
	Rh-97		Rh-97			
	Rh-97m		Rh-97m			
	Rh-107		Rh-107			
	Rn-207					
	Rn-209		Rn-209			
	Rn-210		Rn-210			
	Rn-211		Rn-211		Rn-211	
	Rn-222	Rn-222				
	Ru-97		Ru-97			
	Ru-107		Ru-107			
	Sb-129		Sb-129			
	Se-79	Se-79	Se-79	Se-79		
	Se-79m		Se-79m			
	Si-32	Si-32	Si-32	Si-32		
	Sm-145	Sm-145	Sm-145	Sm-145		
	Sm-146	Sm-146	Sm-146	Sm-146		
	Sm-147	Sm-147	Sm-147	Sm-147		
	Sm-148	Sm-148	Sm-148	Sm-148		
	Sm-151	Sm-151	Sm-151	Sm-151		
	Sn-126	Sn-126	Sn-126	Sn-126		
	Sn-129		Sn-129			
	Sr-90	Sr-90	Sr-90	Sr-90		
	Sr-93					
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-149					
	Tb-150		Tb-150			
	Tb-150m		Tb-150m			
	Tb-157	Tb-157	Tb-157	Tb-157		
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-91		Tc-91			
	Tc-91m		Tc-91m			
	Tc-93		Tc-93			
	Tc-93m		Tc-93m			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**272**	**1,252**	**272**	**1,252**	**272**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**313**	**141**	**280**	**133**	**38**	**29**
	Tc-97	Tc-97	Tc-97	Tc-97		
	Tc-97m		Tc-97m			
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99		
	Tc-99m		Tc-99m			
	Te-123	Te-123	Te-123	Te-123		
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226		Th-226			
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Th-230	Th-230	Th-230	Th-230		
	Th-231	Th-231	Th-231	Th-231		
	Th-232	Th-232	Th-232	Th-232		
	Th-233		Th-233			
	Th-234	Th-234				
	Th-235		Th-235			
	Th-236		Th-236			
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194			
	Tl-194m		Tl-194m			
	Tl-210	Tl-210				
	Tm-163		Tm-163			
	U-230		U-230			
	U-231		U-231			
	U-232	U-232	U-232	U-232		
	U-233	U-233	U-233	U-233		
	U-234	U-234	U-234	U-234		
	U-235	U-235	U-235	U-235		
	U-235m	U-235m	U-235m	U-235m		
	U-236	U-236	U-236	U-236		
	U-237	U-237	U-237	U-237		
	U-238	U-238	U-238	U-238		
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242		U-242			
	V-50	V-50	V-50	V-50	V-50	V-50
	W-187					
	Xe-135		Xe-135			
	Xe-135m		Xe-135m			
	Xe-137		Xe-137			
	Y-93		Y-93			
	Yb-163					
	Zr-93	Zr-93	Zr-93	Zr-93		

Table I-5. Tier-1 NCRP123 groundwater pathway SOF histogram for the ILV disposal unit.

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	116	**5**	**8**	**2**	**3**	**6**	**1**	**12**	**7**	**112**
272	**156**	**151**	**143**	**141**	**138**	**132**	**131**	**119**	**112**	**0**
Ac-225	Ac-225									
Ac-227										Ac-227
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m								Ag-108m		
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241										Am-241

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	116	5	8	2	3	6	1	12	7	112
272	156	151	143	141	138	132	131	119	112	0
Am-242										Am-242
Am-242m									Am-242m	
Am-243										Am-243
Am-245										Am-245
Am-246m										Am-246m
Ar-37	Ar-37									
Ar-39								Ar-39		
At-217	At-217									
At-218						At-218				
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133										Ba-133
Ba-137m	Ba-137m									
Be-10										Be-10
Bi-207										Bi-207
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214			Bi-214							
Bi-215	Bi-215									
Bk-247										Bk-247
Bk-249										Bk-249
Bk-250										Bk-250
C-14										C-14
Ca-41										Ca-41
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113										Cd-113
Cd-113m		Cd-113m								
Ce-139	Ce-139									
Ce-144	Ce-144									
Cf-248										Cf-248
Cf-249									Cf-249	
Cf-250										Cf-250
Cf-251									Cf-251	
Cf-252										Cf-252
Cf-253										Cf-253
Cl-36									Cl-36	
Cm-242					Cm-242					
Cm-243								Cm-243		
Cm-244										Cm-244
Cm-245										Cm-245
Cm-246								Cm-246		
Cm-247										Cm-247
Cm-248								Cm-248		
Cm-249										Cm-249
Cm-250										Cm-250
Co-57	Co-57									
Co-60		Co-60								
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135										Cs-135
Cs-137										Cs-137
Dy-154										Dy-154
Dy-159	Dy-159									
Es-253										Es-253
Es-254										Es-254
Eu-149	Eu-149									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	116	**5**	**8**	**2**	**3**	**6**	**1**	**12**	**7**	**112**
272	**156**	**151**	**143**	**141**	**138**	**132**	**131**	**119**	**112**	**0**
Eu-150										Eu-150
Eu-152			Eu-152							
Eu-154		Eu-154								
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60										Fe-60
Fm-254										Fm-254
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148										Gd-148
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3										H-3
Hf-172	Hf-172									
Hf-174										Hf-174
Hf-178m										Hf-178m
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163										Ho-163
Ho-166m										Ho-166m
I-129										I-129
In-113m	In-113m									
In-115										In-115
Ir-192	Ir-192									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40										K-40
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85			Kr-85							
La-137										La-137
La-138										La-138
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53										Mn-53
Mn-54	Mn-54									
Mo-93								Mo-93		
Na-22	Na-22									
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m						Nb-93m				
Nb-94										Nb-94
Nd-144										Nd-144
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237										Np-237

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	116	**5**	**8**	**2**	**3**	**6**	**1**	**12**	**7**	**112**
272	**156**	**151**	**143**	**141**	**138**	**132**	**131**	**119**	**112**	**0**
Np-238										Np-238
Np-239	Np-239									
Np-240										Np-240
Np-240m										Np-240m
Os-185	Os-185									
Os-186										Os-186
Os-194						Os-194				
P-32	P-32									
Pa-231										Pa-231
Pa-232										Pa-232
Pa-233			Pa-233							
Pa-234			Pa-234							
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205										Pb-205
Pb-209	Pb-209									
Pb-210									Pb-210	
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214			Pb-214							
Pd-107										Pd-107
Pm-143	Pm-143									
Pm-144			Pm-144							
Pm-145										Pm-145
Pm-146										Pm-146
Pm-147			Pm-147							
Po-208							Po-208			
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218		Po-218								
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193					Pt-193					
Pu-236										Pu-236
Pu-238										Pu-238
Pu-239										Pu-239
Pu-240										Pu-240
Pu-241										Pu-241
Pu-242										Pu-242
Pu-243										Pu-243
Pu-244										Pu-244
Pu-246										Pu-246
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226										Ra-226
Ra-228	Ra-228									
Rb-87										Rb-87
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m										Re-186m
Re-187										Re-187
Rh-101	Rh-101									
Rh-102	Rh-102									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	116	**5**	**8**	**2**	**3**	**6**	**1**	**12**	**7**	**112**
272	**156**	**151**	**143**	**141**	**138**	**132**	**131**	**119**	**112**	**0**
Rh-102m	Rh-102m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218				Rn-218						
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222						Rn-222				
Ru-106	Ru-106									
S-35	S-35									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79								Se-79		
Si-32										Si-32
Sm-145									Sm-145	
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151								Sm-151		
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m				Sn-121m						
Sn-123	Sn-123									
Sn-126								Sn-126		
Sr-90										Sr-90
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m		Te-123m								
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230										Th-230
Th-231						Th-231				
Th-232									Th-232	
Th-234					Th-234					
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210								Tl-210		
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232								U-232		

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	116	5	8	2	3	6	1	12	7	112
272	156	151	143	141	138	132	131	119	112	0
U-233										U-233
U-234										U-234
U-235										U-235
U-235m						U-235m				
U-236										U-236
U-237										U-237
U-238										U-238
U-240										U-240
V-49	V-49									
V-50										V-50
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65	Zn-65									
Zr-93								Zr-93		

Table I-6. Tier-1 RadScreen II pathway SOF histogram for the ILV disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	229	6	6	2	2	3	3	2	4	15
272	43	37	31	29	27	24	21	19	15	0
Ac-225	Ac-225									
Ac-227						Ac-227				
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m	Ag-108m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241	Am-241									
Am-242	Am-242									
Am-242m	Am-242m									
Am-243	Am-243									
Am-245	Am-245									
Am-246m	Am-246m									
Ar-37	Ar-37									
Ar-39	Ar-39									
At-217	At-217									
At-218	At-218									
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									
Be-10	Be-10									
Bi-207									Bi-207	
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m								Bi-210m		
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247				Bk-247						
Bk-249			Bk-249							
Bk-250	Bk-250									
C-14	C-14									
Ca-41	Ca-41									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	229	**6**	**6**	**2**	**2**	**3**	**3**	**2**	**4**	**15**
272	**43**	**37**	**31**	**29**	**27**	**24**	**21**	**19**	**15**	**0**
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113	Cd-113									
Cd-113m	Cd-113m									
Ce-139	Ce-139									
Ce-144	Ce-144									
Cf-248	Cf-248									
Cf-249	Cf-249									
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253		Cf-253								
Cl-36	Cl-36									
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245	Cm-245									
Cm-246	Cm-246									
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249	Cm-249									
Cm-250									Cm-250	
Co-57	Co-57									
Co-60	Co-60									
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135	Cs-135									
Cs-137					Cs-137					
Dy-154	Dy-154									
Dy-159	Dy-159									
Es-253		Es-253								
Es-254	Es-254									
Eu-149	Eu-149									
Eu-150									Eu-150	
Eu-152	Eu-152									
Eu-154	Eu-154									
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60										Fe-60
Fm-254	Fm-254									
Fm-257			Fm-257							
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-151	Gd-151									
Gd-152	Gd-152									
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3	H-3									
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163	Ho-163									
Ho-166m										Ho-166m
I-129	I-129									
In-113m	In-113m									
In-115	In-115									

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	229	**6**	**6**	**2**	**2**	**3**	**3**	**2**	**4**	**15**
272	**43**	**37**	**31**	**29**	**27**	**24**	**21**	**19**	**15**	**0**
Ir-192	Ir-192									
Ir-192n								Ir-192n		
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40		K-40								
K-42	K-42									
Kr-81	Kr-81									
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137	La-137									
La-138										La-138
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176	Lu-176									
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53	Mn-53									
Mn-54	Mn-54									
Mo-93	Mo-93									
Na-22	Na-22									
Nb-91						Nb-91				
Nb-92										Nb-92
Nb-93m	Nb-93m									
Nb-94			Nb-94							
Nd-144	Nd-144									
Ni-59	Ni-59									
Ni-63	Ni-63									
Np-235	Np-235									
Np-236										Np-236
Np-237	Np-237									
Np-238	Np-238									
Np-239	Np-239									
Np-240	Np-240									
Np-240m	Np-240m									
Os-185	Os-185									
Os-186	Os-186									
Os-194	Os-194									
P-32	P-32									
Pa-231									Pa-231	
Pa-232							Pa-232			
Pa-233	Pa-233									
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202							Pb-202			
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210	Pb-210									
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107	Pd-107									
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145	Pm-145									
Pm-146	Pm-146									
Pm-147	Pm-147									
Po-208			Po-208							
Po-209							Po-209			
Po-210	Po-210									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	229	**6**	**6**	**2**	**2**	**3**	**3**	**2**	**4**	**15**
272	**43**	**37**	**31**	**29**	**27**	**24**	**21**	**19**	**15**	**0**
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190	Pt-190									
Pt-193	Pt-193									
Pu-236										Pu-236
Pu-238	Pu-238									
Pu-239	Pu-239									
Pu-240	Pu-240									
Pu-241	Pu-241									
Pu-242	Pu-242									
Pu-243	Pu-243									
Pu-244		Pu-244								
Pu-246	Pu-246									
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226					Ra-226					
Ra-228	Ra-228									
Rb-87	Rb-87									
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m						Re-186m				
Re-187	Re-187									
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222	Rn-222									
Ru-106	Ru-106									
S-35	S-35									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79	Se-79									
Si-32	Si-32									
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m	Sn-121m									
Sn-123	Sn-123									
Sn-126	Sn-126									
Sr-90				Sr-90						

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	229	6	6	2	2	3	3	2	4	15
272	43	37	31	29	27	24	21	19	15	0
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157	Tb-157									
Tb-158										Tb-158
Tc-97	Tc-97									
Tc-98										Tc-98
Tc-99	Tc-99									
Te-121	Te-121									
Te-121m	Te-121m									
Te-123	Te-123									
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230	Th-230									
Th-231	Th-231									
Th-232		Th-232								
Th-234	Th-234									
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210	Tl-210									
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232	U-232									
U-233		U-233								
U-234			U-234							
U-235	U-235									
U-235m	U-235m									
U-236	U-236									
U-237	U-237									
U-238			U-238							
U-240	U-240									
V-49	V-49									
V-50										V-50
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65	Zn-65									
Zr-93	Zr-93									

I.3 LAWV Model

Table I-7, Table I-8 and Table I-9 are the results for the LAWV model that apply to only the LAWV unit.

Table I-7. Tier-1 radionuclide listing for the LAWV disposal unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	280	134	221	120	22	20
	Ac-226		Ac-226			
	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233		Ac-233			
	Ag-108m	Ag-108m	Ag-108m	Ag-108m		
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-237		Am-237			
	Am-238		Am-238			
	Am-239		Am-239			
	Am-240		Am-240			
	Am-241	Am-241	Am-241	Am-241		
	Am-242	Am-242	Am-242	Am-242		
	Am-242m	Am-242m	Am-242m	Am-242m		
	Am-243	Am-243	Am-243	Am-243		
	Am-244		Am-244			
	Am-244m		Am-244m			
	Am-245	Am-245	Am-245	Am-245		
	Am-246					
	Am-246m	Am-246m				
	Ar-42		Ar-42		Ar-42	
	At-206		At-206			
	At-207		At-207			
	At-209		At-209			
	At-211		At-211			
	Au-193		Au-193			
	Au-193m		Au-193m			
	Ba-133m					
	Be-10	Be-10	Be-10	Be-10		
	Bi-202		Bi-202			
	Bi-207	Bi-207	Bi-207	Bi-207		
	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m		
	Bk-245		Bk-245			
	Bk-246		Bk-246			
	Bk-247	Bk-247	Bk-247	Bk-247		
	Bk-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249		
	Bk-250	Bk-250	Bk-250	Bk-250		
	Bk-251		Bk-251			
	C-14	C-14	C-14	C-14		
	Ca-41	Ca-41	Ca-41	Ca-41		
	Cd-113	Cd-113	Cd-113	Cd-113		
	Ce-133					
	Ce-133m					
	Ce-137					
	Ce-137m					
	Cf-244		Cf-244			
	Cf-246		Cf-246			
	Cf-247		Cf-247			
	Cf-248	Cf-248	Cf-248	Cf-248		
	Cf-249	Cf-249				
	Cf-250	Cf-250	Cf-250	Cf-250		
	Cf-251	Cf-251	Cf-251	Cf-251		
	Cf-252	Cf-252				
	Cf-253	Cf-253	Cf-253	Cf-253		
	Cf-254		Cf-254			
	Cf-255		Cf-255			
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cl-39		Cl-39			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	280	134	221	120	22	20
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	Cm-243	Cm-243				
	Cm-244	Cm-244	Cm-244	Cm-244		
	Cm-245	Cm-245	Cm-245	Cm-245		
	Cm-246	Cm-246	Cm-246	Cm-246		
	Cm-249	Cm-249	Cm-249	Cm-249		
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251		Cm-251			
	Cs-137	Cs-137	Cs-137	Cs-137		
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-150		Dy-150			
	Dy-152		Dy-152			
	Dy-154	Dy-154	Dy-154	Dy-154		
	Er-154					
	Er-163					
	Es-249		Es-249			
	Es-250		Es-250			
	Es-250m		Es-250m			
	Es-251		Es-251			
	Es-253	Es-253	Es-253	Es-253		
	Es-254	Es-254	Es-254	Es-254		
	Es-254m		Es-254m			
	Es-255		Es-255			
	Es-256		Es-256			
	Eu-150	Eu-150	Eu-150	Eu-150		
	Eu-150m					
	Eu-152	Eu-152				
	Eu-152n					
	Fe-53					
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-251		Fm-251			
	Fm-252		Fm-252			
	Fm-253		Fm-253			
	Fm-254	Fm-254	Fm-254	Fm-254		
	Fm-255		Fm-255			
	Fm-256		Fm-256			
	Fm-257	Fm-257	Fm-257	Fm-257		
	Fr-222					
	Fr-227					
	Gd-146					
	Gd-148	Gd-148	Gd-148	Gd-148		
	Gd-150	Gd-150	Gd-150	Gd-150		
	Gd-152	Gd-152	Gd-152	Gd-152		
	H-3	H-3	H-3	H-3		
	Hf-174	Hf-174	Hf-174	Hf-174		
	Hf-178m	Hf-178m	Hf-178m	Hf-178m		
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hf-182m					
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-150					
	Ho-154		Ho-154			
	Ho-154m					
	Ho-157					
	Ho-163	Ho-163	Ho-163	Ho-163		
	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m
	I-129	I-129	I-129	I-129		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**280**	**134**	**221**	**120**	**22**	**20**
	In-115	In-115	In-115	In-115		
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40		
	Kr-81	Kr-81	Kr-81	Kr-81		
	La-137	La-137	La-137	La-137		
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-176	Lu-176	Lu-176	Lu-176		
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mo-91m					
	Mo-93	Mo-93	Mo-93	Mo-93		
	Mo-93m					
	Mo-99		Mo-99			
	Nb-91	Nb-91	Nb-91	Nb-91		
	Nb-91m		Nb-91m			
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m	Nb-93m				
	Nb-94	Nb-94	Nb-94	Nb-94		
	Nb-94m					
	Nd-137					
	Nd-144	Nd-144	Nd-144	Nd-144		
	Ni-59	Ni-59	Ni-59	Ni-59		
	Ni-63	Ni-63	Ni-63	Ni-63		
	Np-232		Np-232			
	Np-233		Np-233			
	Np-234		Np-234			
	Np-235	Np-235	Np-235	Np-235		
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-236m		Np-236m			
	Np-237	Np-237	Np-237	Np-237		
	Np-238	Np-238	Np-238	Np-238		
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m				
	Np-241		Np-241			
	Np-242		Np-242			
	Np-242m		Np-242m			
	Os-186	Os-186	Os-186	Os-186		
	Os-194	Os-194				
	Pa-229		Pa-229			
	Pa-230		Pa-230			
	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231
	Pa-232	Pa-232	Pa-232	Pa-232		
	Pa-233	Pa-233				
	Pa-235		Pa-235			
	Pa-236					
	Pa-237		Pa-237			
	Pb-194		Pb-194			
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m		Pb-202m			
	Pb-205	Pb-205	Pb-205	Pb-205		
	Pb-210	Pb-210				
	Pd-97		Pd-97			
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-137m					
	Pm-145	Pm-145	Pm-145	Pm-145		
	Pm-146	Pm-146	Pm-146	Pm-146		
	Pm-151					
	Po-205					
	Po-206					
	Po-207					
	Po-208	Po-208	Po-208	Po-208		
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pr-137		Pr-137			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**280**	**134**	**221**	**120**	**22**	**20**
	Pt-190	Pt-190	Pt-190	Pt-190		
	Pt-193	Pt-193	Pt-193	Pt-193		
	Pt-193m		Pt-193m			
	Pu-232		Pu-232			
	Pu-234		Pu-234			
	Pu-235		Pu-235			
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-237		Pu-237			
	Pu-238	Pu-238	Pu-238	Pu-238		
	Pu-239	Pu-239	Pu-239	Pu-239		
	Pu-240	Pu-240	Pu-240	Pu-240		
	Pu-241	Pu-241	Pu-241	Pu-241		
	Pu-242	Pu-242	Pu-242	Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243		
	Pu-245		Pu-245			
	Pu-246	Pu-246	Pu-246	Pu-246		
	Ra-222					
	Ra-226	Ra-226	Ra-226	Ra-226		
	Ra-227					
	Ra-230		Ra-230			
	Rb-87	Rb-87	Rb-87	Rb-87		
	Rb-90		Rb-90			
	Rb-90m		Rb-90m			
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187		
	Rh-97		Rh-97			
	Rh-97m		Rh-97m			
	Rn-207					
	Rn-209		Rn-209			
	Rn-210		Rn-210			
	Rn-211		Rn-211			
	Ru-97		Ru-97			
	Sb-129		Sb-129			
	Se-79	Se-79	Se-79	Se-79		
	Se-79m					
	Si-32	Si-32	Si-32	Si-32		
	Sm-145	Sm-145				
	Sm-146	Sm-146	Sm-146	Sm-146		
	Sm-147	Sm-147	Sm-147	Sm-147		
	Sm-148	Sm-148	Sm-148	Sm-148		
	Sm-151	Sm-151				
	Sn-121m	Sn-121m				
	Sn-126	Sn-126	Sn-126	Sn-126		
	Sn-129					
	Sr-90	Sr-90	Sr-90	Sr-90		
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-149					
	Tb-150		Tb-150			
	Tb-150m		Tb-150m			
	Tb-157	Tb-157	Tb-157	Tb-157		
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-91					
	Tc-91m					
	Tc-93					
	Tc-93m		Tc-93m			
	Tc-97	Tc-97	Tc-97	Tc-97		
	Tc-97m		Tc-97m			
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99		
	Tc-99m		Tc-99m			
	Te-123	Te-123	Te-123	Te-123		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	280	134	221	120	22	20
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226					
	Th-229	Th-229	Th-229	Th-229		
	Th-230	Th-230	Th-230	Th-230		
	Th-231	Th-231	Th-231	Th-231		
	Th-232	Th-232	Th-232	Th-232		
	Th-233		Th-233			
	Th-234	Th-234				
	Th-235					
	Th-236					
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194			
	Tl-194m		Tl-194m			
	Tm-163					
	U-230		U-230			
	U-231		U-231			
	U-232	U-232	U-232	U-232		
	U-233	U-233	U-233	U-233		
	U-234	U-234	U-234	U-234		
	U-235	U-235	U-235	U-235		
	U-235m	U-235m	U-235m	U-235m		
	U-236	U-236	U-236	U-236		
	U-237	U-237	U-237	U-237		
	U-238	U-238	U-238	U-238		
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242		U-242			
	V-50	V-50	V-50	V-50		
	Xe-135					
	Xe-137					
	Y-93					
	Yb-163					
	Zr-93	Zr-93	Zr-93	Zr-93		

Table I-8. Tier-1 NCRP123 groundwater pathway SOF histogram for the LAWV disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	123	4	6	4	6	9	9	4	10	96
271	148	144	138	134	128	119	110	106	96	0
Ac-225	Ac-225									
Ac-227										Ac-227
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m								Ag-108m		
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241										Am-241
Am-242										Am-242
Am-242m								Am-242m		
Am-243										Am-243
Am-245									Am-245	
Am-246m						Am-246m				
Ar-39		Ar-39								
At-217	At-217									
At-218				At-218						
At-219	At-219									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	123	4	6	4	6	9	9	4	10	96
271	148	144	138	134	128	119	110	106	96	0
Au-194	Au-194									
Au-195	Au-195									
Ba-133				Ba-133						
Ba-137m	Ba-137m									
Be-10										Be-10
Bi-207										Bi-207
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214		Bi-214								
Bi-215	Bi-215									
Bk-247										Bk-247
Bk-249										Bk-249
Bk-250							Bk-250			
C-14										C-14
Ca-41							Ca-41			
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113										Cd-113
Cd-113m			Cd-113m							
Ce-139	Ce-139									
Ce-144	Ce-144									
Cf-248										Cf-248
Cf-249						Cf-249				
Cf-250							Cf-250			
Cf-251							Cf-251			
Cf-252					Cf-252					
Cf-253										Cf-253
Cl-36										Cl-36
Cm-242				Cm-242						
Cm-243						Cm-243				
Cm-244										Cm-244
Cm-245										Cm-245
Cm-246										Cm-246
Cm-247		Cm-247								
Cm-248	Cm-248									
Cm-249									Cm-249	
Cm-250										Cm-250
Co-57	Co-57									
Co-60	Co-60									
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135			Cs-135							
Cs-137										Cs-137
Dy-154										Dy-154
Dy-159	Dy-159									
Es-253										Es-253
Es-254										Es-254
Eu-149	Eu-149									
Eu-150									Eu-150	
Eu-152						Eu-152				
Eu-154			Eu-154							
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60										Fe-60
Fm-254										Fm-254
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	123	4	6	4	6	9	9	4	10	96
271	148	144	138	134	128	119	110	106	96	0
Ga-68	Ga-68									
Gd-148										Gd-148
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3										H-3
Hf-172	Hf-172									
Hf-174										Hf-174
Hf-178m										Hf-178m
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163										Ho-163
Ho-166m										Ho-166m
I-129										I-129
In-113m	In-113m									
In-115										In-115
Ir-192	Ir-192									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40							K-40			
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53										Mn-53
Mn-54	Mn-54									
Mo-93									Mo-93	
Na-22	Na-22									
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m						Nb-93m				
Nb-94										Nb-94
Nd-144										Nd-144
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237										Np-237
Np-238									Np-238	
Np-239	Np-239									
Np-240							Np-240			
Np-240m						Np-240m				
Os-185	Os-185									
Os-186										Os-186
Os-194					Os-194					
P-32	P-32									
Pa-231										Pa-231
Pa-232									Pa-232	

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	123	**4**	**6**	**4**	**6**	**9**	**9**	**4**	**10**	**96**
271	**148**	**144**	**138**	**134**	**128**	**119**	**110**	**106**	**96**	**0**
Pa-233					Pa-233					
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205										Pb-205
Pb-209	Pb-209									
Pb-210							Pb-210			
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214		Pb-214								
Pd-107										Pd-107
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145										Pm-145
Pm-146							Pm-146			
Pm-147			Pm-147							
Po-208							Po-208			
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193						Pt-193				
Pu-236										Pu-236
Pu-238										Pu-238
Pu-239										Pu-239
Pu-240										Pu-240
Pu-241										Pu-241
Pu-242										Pu-242
Pu-243									Pu-243	
Pu-244	Pu-244									
Pu-246										Pu-246
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226										Ra-226
Ra-228	Ra-228									
Rb-87										Rb-87
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m										Re-186m
Re-187										Re-187
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218			Rn-218							
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222				Rn-222						
Ru-106	Ru-106									
S-35	S-35									
Sb-125	Sb-125									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	123	4	6	4	6	9	9	4	10	96
271	148	144	138	134	128	119	110	106	96	0
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79										Se-79
Si-32										Si-32
Sm-145								Sm-145		
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151					Sm-151					
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m						Sn-121m				
Sn-123	Sn-123									
Sn-126								Sn-126		
Sr-90										Sr-90
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230										Th-230
Th-231					Th-231					
Th-232										Th-232
Th-234					Th-234					
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210			Tl-210							
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232									U-232	
U-233										U-233
U-234										U-234
U-235										U-235
U-235m						U-235m				
U-236										U-236
U-237									U-237	
U-238										U-238
U-240										U-240
V-49	V-49									
V-50										V-50

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	123	**4**	**6**	**4**	**6**	**9**	**9**	**4**	**10**	**96**
271	**148**	**144**	**138**	**134**	**128**	**119**	**110**	**106**	**96**	**0**
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65	Zn-65									
Zr-93									Zr-93	

Table I-9. Tier-1 RadScreen II pathway SOF histogram for the LAWV disposal unit.

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	233	**7**	**4**	**7**	**6**	**4**	**4**	**2**	**2**	**2**
271	**38**	**31**	**27**	**20**	**14**	**10**	**6**	**4**	**2**	**0**
Ac-225	Ac-225									
Ac-227						Ac-227				
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m	Ag-108m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26							Al-26			
Am-241	Am-241									
Am-242	Am-242									
Am-242m	Am-242m									
Am-243	Am-243									
Am-245	Am-245									
Am-246m	Am-246m									
Ar-39	Ar-39									
At-217	At-217									
At-218	At-218									
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									
Be-10	Be-10									
Bi-207				Bi-207						
Bi-208							Bi-208			
Bi-210	Bi-210									
Bi-210m				Bi-210m						
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247	Bk-247									
Bk-249		Bk-249								
Bk-250	Bk-250									
C-14	C-14									
Ca-41	Ca-41									
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113	Cd-113									
Cd-113m	Cd-113m									
Ce-139	Ce-139									
Ce-144	Ce-144									
Cf-248	Cf-248									
Cf-249	Cf-249									
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253	Cf-253									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	233	**7**	**4**	**7**	**6**	**4**	**4**	**2**	**2**	**2**
271	**38**	**31**	**27**	**20**	**14**	**10**	**6**	**4**	**2**	**0**
Cl-36	Cl-36									
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245	Cm-245									
Cm-246	Cm-246									
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249	Cm-249									
Cm-250									Cm-250	
Co-57	Co-57									
Co-60	Co-60									
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135	Cs-135									
Cs-137				Cs-137						
Dy-154	Dy-154									
Dy-159	Dy-159									
Es-253	Es-253									
Es-254	Es-254									
Eu-149	Eu-149									
Eu-150				Eu-150						
Eu-152	Eu-152									
Eu-154	Eu-154									
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60										Fe-60
Fm-254	Fm-254									
Fm-257		Fm-257								
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-151	Gd-151									
Gd-152	Gd-152									
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3	H-3									
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182							Hf-182			
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163	Ho-163									
Ho-166m					Ho-166m					
I-129	I-129									
In-113m	In-113m									
In-115	In-115									
Ir-192	Ir-192									
Ir-192n								Ir-192n		
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40	K-40									
K-42	K-42									
Kr-81	Kr-81									
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137	La-137									
La-138						La-138				
Lu-172	Lu-172									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	233	7	4	7	6	4	4	2	2	2
271	38	31	27	20	14	10	6	4	2	0
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176	Lu-176									
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53	Mn-53									
Mn-54	Mn-54									
Mo-93	Mo-93									
Na-22	Na-22									
Nb-91				Nb-91						
Nb-92					Nb-92					
Nb-93m	Nb-93m									
Nb-94			Nb-94							
Nd-144	Nd-144									
Ni-59	Ni-59									
Ni-63	Ni-63									
Np-235	Np-235									
Np-236								Np-236		
Np-237	Np-237									
Np-238	Np-238									
Np-239	Np-239									
Np-240	Np-240									
Np-240m	Np-240m									
Os-185	Os-185									
Os-186	Os-186									
Os-194	Os-194									
P-32	P-32									
Pa-231						Pa-231				
Pa-232		Pa-232								
Pa-233	Pa-233									
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202						Pb-202				
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210	Pb-210									
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107	Pd-107									
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145	Pm-145									
Pm-146	Pm-146									
Pm-147	Pm-147									
Po-208		Po-208								
Po-209					Po-209					
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190	Pt-190									
Pt-193	Pt-193									
Pu-236									Pu-236	

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	233	7	4	7	6	4	4	2	2	2
271	38	31	27	20	14	10	6	4	2	0
Pu-238	Pu-238									
Pu-239	Pu-239									
Pu-240	Pu-240									
Pu-241	Pu-241									
Pu-242	Pu-242									
Pu-243	Pu-243									
Pu-244	Pu-244									
Pu-246	Pu-246									
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226				Ra-226						
Ra-228	Ra-228									
Rb-87	Rb-87									
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m					Re-186m					
Re-187	Re-187									
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222	Rn-222									
Ru-106	Ru-106									
S-35	S-35									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79	Se-79									
Si-32	Si-32									
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m	Sn-121m									
Sn-123	Sn-123									
Sn-126	Sn-126									
Sr-90				Sr-90						
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157	Tb-157									
Tb-158					Tb-158					
Tc-97	Tc-97									
Tc-98					Tc-98					
Tc-99	Tc-99									
Te-121	Te-121									
Te-121m	Te-121m									
Te-123	Te-123									
Te-123m	Te-123m									
Te-125m	Te-125m									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	233	7	4	7	6	4	4	2	2	2
271	38	31	27	20	14	10	6	4	2	0
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229	Th-229									
Th-230	Th-230									
Th-231	Th-231									
Th-232		Th-232								
Th-234	Th-234									
Ti-44							Ti-44			
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210	Tl-210									
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232			U-232							
U-233		U-233								
U-234		U-234								
U-235	U-235									
U-235m	U-235m									
U-236	U-236									
U-237	U-237									
U-238			U-238							
U-240	U-240									
V-49	V-49									
V-50			V-50							
W-181	W-181									
Y-88	Y-88									
Y-90	Y-90									
Zn-65	Zn-65									
Zr-93	Zr-93									

I.4 NRCDAG Model

Table I-10, Table I-11 and Table I-12 are the results for the NRCDAG model that apply to only the NRCDAG unit.

Table I-10. Tier-1 radionuclide listing for the NRCDAG disposal unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Ac-226		Ac-226		Ac-226	
	Ac-228	Ac-228	Ac-228	Ac-228		
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233		Ac-233			
	Ag-101					
	Ag-113		Ag-113			
	Ag-113m		Ag-113m			
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-237		Am-237			
	Am-238		Am-238			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**295**	**1,252**	**295**	**1,252**	**295**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**365**	**157**	**310**	**139**	**44**	**29**
	Am-239		Am-239			
	Am-240		Am-240			
	Am-241	Am-241	Am-241	Am-241		
	Am-242	Am-242	Am-242	Am-242		
	Am-242m	Am-242m				
	Am-243	Am-243	Am-243	Am-243		
	Am-244		Am-244			
	Am-244m		Am-244m			
	Am-245	Am-245	Am-245	Am-245		
	Am-246		Am-246			
	Am-246m	Am-246m	Am-246m	Am-246m		
	Am-247		Am-247			
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	As-79		As-79			
	At-205					
	At-206		At-206			
	At-207		At-207		At-207	
	At-208		At-208			
	At-209		At-209			
	At-211		At-211		At-211	
	At-218	At-218	At-218	At-218		
	Au-190					
	Au-193		Au-193			
	Au-193m		Au-193m			
	Ba-133	Ba-133	Ba-133	Ba-133		
	Ba-133m		Ba-133m			
	Bi-202		Bi-202			
	Bi-205		Bi-205			
	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207
	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m
	Bk-245		Bk-245			
	Bk-246		Bk-246			
	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249		
	Bk-250	Bk-250	Bk-250	Bk-250		
	Bk-251		Bk-251			
	C-14	C-14	C-14	C-14		
	Ca-41	Ca-41	Ca-41	Ca-41		
	Cd-101					
	Cd-109	Cd-109	Cd-109	Cd-109		
	Cd-113	Cd-113	Cd-113	Cd-113		
	Cd-113m	Cd-113m	Cd-113m	Cd-113m		
	Ce-133		Ce-133			
	Ce-133m		Ce-133m			
	Ce-137		Ce-137			
	Ce-137m		Ce-137m			
	Cf-244		Cf-244		Cf-244	
	Cf-246		Cf-246			
	Cf-247		Cf-247			
	Cf-248	Cf-248	Cf-248	Cf-248		
	Cf-250	Cf-250	Cf-250	Cf-250		
	Cf-252	Cf-252	Cf-252	Cf-252		
	Cf-253	Cf-253	Cf-253	Cf-253		
	Cf-254		Cf-254			
	Cf-255		Cf-255			
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cl-39		Cl-39			
	Cm-238		Cm-238			
	Cm-239		Cm-239			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	Cm-242	Cm-242	Cm-242	Cm-242		
	Cm-243	Cm-243				
	Cm-244	Cm-244	Cm-244	Cm-244		
	Cm-245	Cm-245				
	Cm-246	Cm-246	Cm-246	Cm-246		
	Cm-249	Cm-249	Cm-249	Cm-249		
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251		Cm-251			
	Co-55		Co-55			
	Co-57	Co-57				
	Co-60	Co-60	Co-60	Co-60		
	Co-60m	Co-60m	Co-60m	Co-60m		
	Cs-134	Cs-134				
	Cs-134m		Cs-134m			
	Cs-135	Cs-135	Cs-135	Cs-135		
	Cs-135m		Cs-135m			
	Cs-137	Cs-137	Cs-137	Cs-137		
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-149					
	Dy-150		Dy-150			
	Dy-152		Dy-152			
	Dy-154	Dy-154	Dy-154	Dy-154		
	Dy-157		Dy-157			
	Er-154		Er-154			
	Er-163		Er-163			
	Er-171					
	Es-249		Es-249			
	Es-250		Es-250			
	Es-250m		Es-250m			
	Es-251		Es-251			
	Es-253	Es-253	Es-253	Es-253		
	Es-254	Es-254	Es-254	Es-254		
	Es-254m		Es-254m			
	Es-255		Es-255			
	Es-256		Es-256			
	Eu-145		Eu-145			
	Eu-146		Eu-146			
	Eu-147		Eu-147			
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m		Eu-150m			
	Eu-152	Eu-152	Eu-152	Eu-152	Eu-152	Eu-152
	Eu-152n		Eu-152n			
	Eu-154	Eu-154				
	Eu-154m		Eu-154m			
	Fe-53		Fe-53			
	Fe-53m					
	Fe-55	Fe-55	Fe-55	Fe-55		
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-251		Fm-251			
	Fm-252		Fm-252			
	Fm-253		Fm-253			
	Fm-254	Fm-254	Fm-254	Fm-254		
	Fm-255		Fm-255			
	Fm-256		Fm-256			
	Fm-257	Fm-257	Fm-257	Fm-257		
	Fr-212					
	Fr-222		Fr-222			
	Fr-227		Fr-227			
	Gd-145					

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Gd-145m					
	Gd-146		Gd-146			
	Gd-147					
	Gd-148	Gd-148	Gd-148	Gd-148		
	Gd-150	Gd-150	Gd-150	Gd-150		
	Gd-152	Gd-152	Gd-152	Gd-152		
	Ge-68	Ge-68				
	H-3	H-3	H-3	H-3		
	Hf-172	Hf-172	Hf-172	Hf-172		
	Hf-173					
	Hf-174	Hf-174	Hf-174	Hf-174		
	Hf-178m	Hf-178m	Hf-178m	Hf-178m		
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hf-182m					
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-150		Ho-150			
	Ho-154		Ho-154			
	Ho-154m		Ho-154m			
	Ho-157		Ho-157			
	Ho-163	Ho-163	Ho-163	Ho-163		
	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m
	I-129	I-129	I-129	I-129		
	I-135		I-135			
	In-109					
	In-109m					
	In-115	In-115	In-115	In-115		
	In-121					
	In-121m					
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40	K-40	K-40
	Kr-81	Kr-81	Kr-81	Kr-81		
	Kr-87					
	La-133		La-133			
	La-137	La-137	La-137	La-137		
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-173	Lu-173				
	Lu-174	Lu-174	Lu-174	Lu-174		
	Lu-174m	Lu-174m	Lu-174m	Lu-174m		
	Lu-176	Lu-176	Lu-176	Lu-176		
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mn-54	Mn-54				
	Mo-91		Mo-91			
	Mo-91m		Mo-91m			
	Mo-93	Mo-93	Mo-93	Mo-93		
	Mo-93m		Mo-93m			
	Mo-99		Mo-99			
	Na-22	Na-22	Na-22	Na-22		
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-91m		Nb-91m			
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m	Nb-93m	Nb-93m	Nb-93m		
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nb-94m		Nb-94m			
	Nb-99		Nb-99			
	Nb-99m		Nb-99m			
	Nd-137		Nd-137			
	Nd-144	Nd-144	Nd-144	Nd-144		
	Nd-147		Nd-147			
	Nd-151		Nd-151			
	Ni-59	Ni-59	Ni-59	Ni-59		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Ni-63	Ni-63	Ni-63	Ni-63		
	Np-232		Np-232		Np-232	
	Np-233		Np-233			
	Np-234		Np-234			
	Np-235	Np-235	Np-235	Np-235		
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-236m		Np-236m		Np-236m	
	Np-237	Np-237	Np-237	Np-237		
	Np-238	Np-238	Np-238	Np-238		
	Np-239	Np-239	Np-239	Np-239		
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m	Np-240m	Np-240m		
	Np-241		Np-241			
	Np-242		Np-242			
	Np-242m		Np-242m			
	Os-186	Os-186	Os-186	Os-186		
	Os-194	Os-194	Os-194	Os-194		
	Pa-228		Pa-228			
	Pa-229		Pa-229		Pa-229	
	Pa-230		Pa-230		Pa-230	
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pa-233	Pa-233	Pa-233	Pa-233		
	Pa-235		Pa-235			
	Pa-236					
	Pa-237		Pa-237			
	Pb-194		Pb-194			
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m		Pb-202m			
	Pb-205	Pb-205	Pb-205	Pb-205		
	Pb-210	Pb-210	Pb-210	Pb-210		
	Pd-97		Pd-97			
	Pd-101					
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-137m					
	Pm-144	Pm-144				
	Pm-145	Pm-145	Pm-145	Pm-145		
	Pm-146	Pm-146	Pm-146	Pm-146		
	Pm-147	Pm-147				
	Pm-151		Pm-151			
	Po-205					
	Po-206		Po-206			
	Po-207		Po-207		Po-207	
	Po-208	Po-208	Po-208	Po-208		
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pr-137		Pr-137			
	Pr-147					
	Pt-190	Pt-190	Pt-190	Pt-190		
	Pt-193	Pt-193	Pt-193	Pt-193		
	Pt-193m		Pt-193m			
	Pu-232		Pu-232		Pu-232	
	Pu-234		Pu-234			
	Pu-235		Pu-235			
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-237		Pu-237			
	Pu-238	Pu-238	Pu-238	Pu-238		
	Pu-239	Pu-239	Pu-239	Pu-239		
	Pu-240	Pu-240	Pu-240	Pu-240		
	Pu-241	Pu-241	Pu-241	Pu-241		
	Pu-242	Pu-242	Pu-242	Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243		
	Pu-245		Pu-245			
	Pu-246	Pu-246	Pu-246	Pu-246		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Ra-222		Ra-222			
	Ra-227		Ra-227			
	Ra-228	Ra-228	Ra-228	Ra-228		
	Ra-230		Ra-230			
	Rb-81		Rb-81			
	Rb-81m					
	Rb-87	Rb-87	Rb-87	Rb-87		
	Rb-90		Rb-90			
	Rb-90m		Rb-90m			
	Re-179		Re-179			
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187		
	Rh-97		Rh-97			
	Rh-97m		Rh-97m			
	Rh-101	Rh-101	Rh-101	Rh-101		
	Rh-101m					
	Rh-102m	Rh-102m	Rh-102m	Rh-102m		
	Rh-107		Rh-107			
	Rn-207		Rn-207			
	Rn-209		Rn-209			
	Rn-210		Rn-210			
	Rn-211		Rn-211		Rn-211	
	Rn-212					
	Rn-218	Rn-218	Rn-218	Rn-218		
	Ru-97		Ru-97			
	Ru-106	Ru-106				
	Ru-107		Ru-107			
	Sb-125	Sb-125	Sb-125	Sb-125		
	Sb-129		Sb-129			
	Se-79	Se-79				
	Se-79m		Se-79m			
	Si-32	Si-32	Si-32	Si-32		
	Sm-145	Sm-145	Sm-145	Sm-145		
	Sm-146	Sm-146	Sm-146	Sm-146		
	Sm-147	Sm-147	Sm-147	Sm-147		
	Sm-148	Sm-148	Sm-148	Sm-148		
	Sm-151	Sm-151				
	Sm-155					
	Sn-109					
	Sn-125		Sn-125			
	Sn-125m					
	Sn-126	Sn-126				
	Sn-129		Sn-129			
	Sr-81					
	Sr-90	Sr-90	Sr-90	Sr-90		
	Sr-93					
	Ta-172					
	Ta-173					
	Ta-179	Ta-179	Ta-179	Ta-179		
	Tb-146					
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-149		Tb-149			
	Tb-150		Tb-150			
	Tb-150m		Tb-150m			
	Tb-157	Tb-157	Tb-157	Tb-157		
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-91		Tc-91			
	Tc-91m		Tc-91m			
	Tc-93		Tc-93			
	Tc-93m		Tc-93m			
	Tc-97	Tc-97	Tc-97	Tc-97		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	365	157	310	139	44	29
	Tc-97m		Tc-97m			
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99		
	Tc-99m		Tc-99m			
	Te-123	Te-123	Te-123	Te-123		
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226		Th-226			
	Th-228	Th-228	Th-228	Th-228		
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Th-233		Th-233			
	Th-235		Th-235			
	Th-236		Th-236			
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194		Tl-194	
	Tl-194m		Tl-194m		Tl-194m	
	Tl-204	Tl-204	Tl-204	Tl-204		
	Tl-210	Tl-210	Tl-210	Tl-210		
	Tm-163		Tm-163			
	Tm-171	Tm-171	Tm-171	Tm-171		
	U-228					
	U-230		U-230			
	U-231		U-231			
	U-232	U-232				
	U-233	U-233				
	U-234	U-234	U-234	U-234		
	U-235	U-235	U-235	U-235		
	U-235m	U-235m	U-235m	U-235m		
	U-237	U-237	U-237	U-237		
	U-238	U-238	U-238	U-238		
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242		U-242			
	V-49	V-49				
	V-50	V-50	V-50	V-50	V-50	V-50
	W-179		W-179			
	W-179m					
	W-187		W-187			
	Xe-135		Xe-135			
	Xe-135m		Xe-135m			
	Xe-137		Xe-137			
	Y-93		Y-93			
	Yb-163					
	Zr-93	Zr-93	Zr-93	Zr-93		

Table I-11. Tier-1 NCRP123 groundwater pathway SOF histogram for the NRCDAG disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	121	8	3	6	6	11	6	3	7	124
295	174	166	163	157	151	140	134	131	124	0
Ac-225	Ac-225									
Ac-227	Ac-227									
Ac-228										Ac-228
Ag-108	Ag-108									
Ag-108m				Ag-108m						
Ag-109m	Ag-109m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	121	8	3	6	6	11	6	3	7	124
295	174	166	163	157	151	140	134	131	124	0
Al-26										Al-26
Am-241									Am-241	
Am-242										Am-242
Am-242m							Am-242m			
Am-243										Am-243
Am-245										Am-245
Am-246m										Am-246m
Ar-39										Ar-39
At-217	At-217									
At-218									At-218	
At-219	At-219									
Au-194	Au-194									
Au-195		Au-195								
Ba-133										Ba-133
Ba-137m	Ba-137m									
Ba-140	Ba-140									
Be-10	Be-10									
Bi-207										Bi-207
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247										Bk-247
Bk-249										Bk-249
Bk-250										Bk-250
C-14										C-14
Ca-41										Ca-41
Ca-45	Ca-45									
Cd-109										Cd-109
Cd-113										Cd-113
Cd-113m										Cd-113m
Cd-115m		Cd-115m								
Ce-139	Ce-139									
Ce-141	Ce-141									
Ce-144	Ce-144									
Cf-248										Cf-248
Cf-249	Cf-249									
Cf-250										Cf-250
Cf-251	Cf-251									
Cf-252										Cf-252
Cf-253										Cf-253
Cl-36						Cl-36				
Cm-242									Cm-242	
Cm-243					Cm-243					
Cm-244										Cm-244
Cm-245						Cm-245				
Cm-246							Cm-246			
Cm-247	Cm-247									
Cm-248		Cm-248								
Cm-249										Cm-249
Cm-250										Cm-250
Co-57						Co-57				
Co-58	Co-58									
Co-60										Co-60
Co-60m										Co-60m
Cr-51	Cr-51									

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	121	**8**	**3**	**6**	**6**	**11**	**6**	**3**	**7**	**124**
295	**174**	**166**	**163**	**157**	**151**	**140**	**134**	**131**	**124**	**0**
Cs-134							Cs-134			
Cs-135						Cs-135				
Cs-137										Cs-137
Dy-154										Dy-154
Dy-159	Dy-159									
Es-253										Es-253
Es-254										Es-254
Eu-149	Eu-149									
Eu-150										Eu-150
Eu-152										Eu-152
Eu-154						Eu-154				
Eu-155		Eu-155								
Fe-55									Fe-55	
Fe-59	Fe-59									
Fe-60										Fe-60
Fm-254										Fm-254
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148										Gd-148
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153				Gd-153						
Ge-68					Ge-68					
H-3										H-3
Hf-172										Hf-172
Hf-174										Hf-174
Hf-175	Hf-175									
Hf-178m										Hf-178m
Hf-181	Hf-181									
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163										Ho-163
Ho-166m										Ho-166m
I-129										I-129
In-113m	In-113m									
In-114	In-114									
In-114m	In-114m									
In-115										In-115
Ir-192	Ir-192									
Ir-192m	Ir-192m									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40										K-40
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
La-140	La-140									
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173									Lu-173	
Lu-174										Lu-174
Lu-174m										Lu-174m
Lu-176										Lu-176
Lu-177	Lu-177									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	121	8	3	6	6	11	6	3	7	124
295	174	166	163	157	151	140	134	131	124	0
Lu-177m	Lu-177m									
Mn-53										Mn-53
Mn-54						Mn-54				
Mo-93										Mo-93
Na-22										Na-22
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m										Nb-93m
Nb-94										Nb-94
Nb-95	Nb-95									
Nb-95m	Nb-95m									
Nd-144										Nd-144
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237						Np-237				
Np-238										Np-238
Np-239										Np-239
Np-240										Np-240
Np-240m										Np-240m
Os-185	Os-185									
Os-186										Os-186
Os-194										Os-194
P-32	P-32									
P-33	P-33									
Pa-231				Pa-231						
Pa-232										Pa-232
Pa-233										Pa-233
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205										Pb-205
Pb-209	Pb-209									
Pb-210										Pb-210
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107										Pd-107
Pm-143				Pm-143						
Pm-144							Pm-144			
Pm-145										Pm-145
Pm-146										Pm-146
Pm-147						Pm-147				
Po-208										Po-208
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193										Pt-193
Pu-236										Pu-236
Pu-238										Pu-238
Pu-239										Pu-239
Pu-240										Pu-240

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	121	8	3	6	6	11	6	3	7	124
295	174	166	163	157	151	140	134	131	124	0
Pu-241									Pu-241	
Pu-242								Pu-242		
Pu-243										Pu-243
Pu-244			Pu-244							
Pu-246										Pu-246
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226			Ra-226							
Ra-228										Ra-228
Rb-87										Rb-87
Re-184	Re-184									
Re-184m			Re-184m							
Re-186		Re-186								
Re-186m										Re-186m
Re-187										Re-187
Rh-101										Rh-101
Rh-102		Rh-102								
Rh-102m										Rh-102m
Rh-103m	Rh-103m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218							Rn-218			
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222	Rn-222									
Ru-103	Ru-103									
Ru-106						Ru-106				
S-35	S-35									
Sb-124	Sb-124									
Sb-125										Sb-125
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79					Se-79					
Si-32										Si-32
Sm-145										Sm-145
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151					Sm-151					
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m	Sn-121m									
Sn-123	Sn-123									
Sn-126					Sn-126					
Sr-89	Sr-89									
Sr-90										Sr-90
Ta-179										Ta-179
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m		Te-123m								

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	121	8	3	6	6	11	6	3	7	124
295	174	166	163	157	151	140	134	131	124	0
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228										Th-228
Th-229										Th-229
Th-230				Th-230						
Th-231	Th-231									
Th-232				Th-232						
Th-234	Th-234									
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204										Tl-204
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210										Tl-210
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171										Tm-171
U-232							U-232			
U-233					U-233					
U-234									U-234	
U-235								U-235		
U-235m						U-235m				
U-236		U-236								
U-237										U-237
U-238										U-238
U-240										U-240
V-49						V-49				
V-50										V-50
W-181	W-181									
W-185	W-185									
W-188	W-188									
Y-88	Y-88									
Y-90	Y-90									
Y-91	Y-91									
Zn-65	Zn-65									
Zr-93								Zr-93		
Zr-95	Zr-95									

Table I-12. Tier-1 RadScreen II pathway SOF histogram for the NRCDAG disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	256	2	3	5	1	1	1	4	3	19
295	39	37	34	29	28	27	26	22	19	0
Ac-225	Ac-225									
Ac-227	Ac-227									
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m	Ag-108m									
Ag-109m	Ag-109m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241	Am-241									
Am-242		Am-242								
Am-242m	Am-242m									
Am-243	Am-243									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	256	2	3	5	1	1	1	4	3	19
295	39	37	34	29	28	27	26	22	19	0
Am-245	Am-245									
Am-246m	Am-246m									
Ar-39	Ar-39									
At-217	At-217									
At-218	At-218									
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									
Ba-140	Ba-140									
Be-10	Be-10									
Bi-207										Bi-207
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m									Bi-210m	
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247					Bk-247					
Bk-249				Bk-249						
Bk-250	Bk-250									
C-14	C-14									
Ca-41	Ca-41									
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113	Cd-113									
Cd-113m	Cd-113m									
Cd-115m	Cd-115m									
Ce-139	Ce-139									
Ce-141	Ce-141									
Ce-144	Ce-144									
Cf-248	Cf-248									
Cf-249	Cf-249									
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253			Cf-253							
Cl-36	Cl-36									
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245	Cm-245									
Cm-246	Cm-246									
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249	Cm-249									
Cm-250										Cm-250
Co-57	Co-57									
Co-58	Co-58									
Co-60	Co-60									
Co-60m	Co-60m									
Cr-51	Cr-51									
Cs-134	Cs-134									
Cs-135	Cs-135									
Cs-137	Cs-137									
Dy-154	Dy-154									
Dy-159	Dy-159									
Es-253			Es-253							
Es-254	Es-254									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	256	2	3	5	1	1	1	4	3	19
295	39	37	34	29	28	27	26	22	19	0
Eu-149	Eu-149									
Eu-150										Eu-150
Eu-152								Eu-152		
Eu-154	Eu-154									
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-59	Fe-59									
Fe-60										Fe-60
Fm-254	Fm-254									
Fm-257				Fm-257						
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-151	Gd-151									
Gd-152	Gd-152									
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3	H-3									
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-175	Hf-175									
Hf-178m	Hf-178m									
Hf-181	Hf-181									
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163	Ho-163									
Ho-166m										Ho-166m
I-129	I-129									
In-113m	In-113m									
In-114	In-114									
In-114m	In-114m									
In-115	In-115									
Ir-192	Ir-192									
Ir-192m	Ir-192m									
Ir-192n									Ir-192n	
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40										K-40
K-42	K-42									
Kr-81	Kr-81									
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137	La-137									
La-138										La-138
La-140	La-140									
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176	Lu-176									
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53	Mn-53									
Mn-54	Mn-54									
Mo-93	Mo-93									
Na-22	Na-22									
Nb-91							Nb-91			
Nb-92										Nb-92

Tier-0	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	256	**2**	**3**	**5**	**1**	**1**	**1**	**4**	**3**	**19**
295	**39**	**37**	**34**	**29**	**28**	**27**	**26**	**22**	**19**	**0**
Nb-93m	Nb-93m									
Nb-94						Nb-94				
Nb-95	Nb-95									
Nb-95m	Nb-95m									
Nd-144	Nd-144									
Ni-59	Ni-59									
Ni-63	Ni-63									
Np-235	Np-235									
Np-236										Np-236
Np-237	Np-237									
Np-238		Np-238								
Np-239	Np-239									
Np-240	Np-240									
Np-240m	Np-240m									
Os-185	Os-185									
Os-186	Os-186									
Os-194	Os-194									
P-32	P-32									
P-33	P-33									
Pa-231	Pa-231									
Pa-232								Pa-232		
Pa-233				Pa-233						
Pa-234	Pa-234									
Pa-234m	Pa-234m									
Pb-202									Pb-202	
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210			Pb-210							
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107	Pd-107									
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145	Pm-145									
Pm-146	Pm-146									
Pm-147	Pm-147									
Po-208				Po-208						
Po-209								Po-209		
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190	Pt-190									
Pt-193	Pt-193									
Pu-236										Pu-236
Pu-238	Pu-238									
Pu-239	Pu-239									
Pu-240	Pu-240									
Pu-241	Pu-241									
Pu-242	Pu-242									
Pu-243	Pu-243									
Pu-244	Pu-244									
Pu-246	Pu-246									
Ra-223	Ra-223									
Ra-224	Ra-224									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	256	2	3	5	1	1	1	4	3	19
295	39	37	34	29	28	27	26	22	19	0
Ra-225	Ra-225									
Ra-226	Ra-226									
Ra-228				Ra-228						
Rb-87	Rb-87									
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m								Re-186m		
Re-187	Re-187									
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-103m	Rh-103m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222	Rn-222									
Ru-103	Ru-103									
Ru-106	Ru-106									
S-35	S-35									
Sb-124	Sb-124									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79	Se-79									
Si-32	Si-32									
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m	Sn-121m									
Sn-123	Sn-123									
Sn-126	Sn-126									
Sr-89	Sr-89									
Sr-90	Sr-90									
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157	Tb-157									
Tb-158										Tb-158
Tc-97	Tc-97									
Tc-98										Tc-98
Tc-99	Tc-99									
Te-121	Te-121									
Te-121m	Te-121m									
Te-123	Te-123									
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230	Th-230									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	256	2	3	5	1	1	1	4	3	19
295	39	37	34	29	28	27	26	22	19	0
Th-231	Th-231									
Th-232	Th-232									
Th-234	Th-234									
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210	Tl-210									
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232	U-232									
U-233	U-233									
U-234	U-234									
U-235	U-235									
U-235m	U-235m									
U-236	U-236									
U-237	U-237									
U-238	U-238									
U-240	U-240									
V-49	V-49									
V-50										V-50
W-181	W-181									
W-185	W-185									
W-188	W-188									
Y-88	Y-88									
Y-90	Y-90									
Y-91	Y-91									
Zn-65	Zn-65									
Zr-93	Zr-93									
Zr-95	Zr-95									

I.5 NRCDAS Model

Table I-13, Table I-14 and Table I-15 are the results for the NRCDAS model that apply to only the NRCDAS unit.

Table I-13. Tier-1 radionuclide listing for the NRCDAS disposal unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	270	122	221	112	148	75
	Ac-226		Ac-226		Ac-226	
	Ac-227	Ac-227			Ac-227	Ac-227
	Ac-230		Ac-230		Ac-230	
	Ac-231		Ac-231		Ac-231	
	Ac-233		Ac-233			
	Ag-108m	Ag-108m	Ag-108m	Ag-108m		
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-237		Am-237			
	Am-238		Am-238			
	Am-239		Am-239			
	Am-240		Am-240			
	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
	Am-242m	Am-242m	Am-242m	Am-242m		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	270	122	221	112	148	75
	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243
	Am-244		Am-244			
	Am-244m		Am-244m			
	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245
	Am-246		Am-246		Am-246	
	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m
	Am-247					
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	As-79					
	At-206				At-206	
					At-207	
	At-209		At-209		At-209	
					At-211	
	Au-193		Au-193			
					Ba-133m	
	Be-10	Be-10	Be-10	Be-10		
	Bi-202		Bi-202		Bi-202	
	Bi-205					
	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207	Bi-207
	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m
	Bk-245		Bk-245		Bk-245	
	Bk-246		Bk-246		Bk-246	
	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-248m		Bk-248m		Bk-248m	
	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250
	Bk-251		Bk-251		Bk-251	
	C-14	C-14	C-14	C-14		
	Ca-41	Ca-41	Ca-41	Ca-41		
	Cd-113	Cd-113	Cd-113	Cd-113		
					Ce-133	
					Ce-133m	
	Ce-137		Ce-137		Ce-137	
	Ce-137m		Ce-137m		Ce-137m	
	Cf-244		Cf-244		Cf-244	
	Cf-246		Cf-246		Cf-246	
	Cf-247		Cf-247		Cf-247	
	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248
	Cf-250	Cf-250	Cf-250	Cf-250	Cf-250	Cf-250
	Cf-252	Cf-252	Cf-252	Cf-252	Cf-252	Cf-252
	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253
	Cf-254		Cf-254		Cf-254	
	Cf-255		Cf-255		Cf-255	
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cl-39		Cl-39			
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241		Cm-241	
	Cm-242	Cm-242	Cm-242	Cm-242		
	Cm-243	Cm-243				
	Cm-244	Cm-244	Cm-244	Cm-244		
	Cm-245	Cm-245	Cm-245	Cm-245		
	Cm-246	Cm-246				
	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251		Cm-251		Cm-251	
					Co-60	Co-60
	Cs-135	Cs-135	Cs-135	Cs-135		
	Cs-135m		Cs-135m			
	Cs-137	Cs-137			Cs-137	Cs-137

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**295**	**1,252**	**295**	**1,252**	**295**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**270**	**122**	**221**	**112**	**148**	**75**
	Cu-59		Cu-59			
	Dy-148					
	Dy-150					
	Dy-152					
	Dy-154	Dy-154	Dy-154	Dy-154		
	Dy-157				Dy-157	
	Er-154					
	Er-163					
	Es-249		Es-249		Es-249	
	Es-250		Es-250		Es-250	
	Es-250m		Es-250m		Es-250m	
	Es-251		Es-251		Es-251	
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Es-254m		Es-254m		Es-254m	
	Es-255		Es-255		Es-255	
	Es-256		Es-256			
					Eu-145	
	Eu-146		Eu-146			
	Eu-147					
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m		Eu-150m			
					Eu-152n	
	Fe-53					
	Fe-53m					
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-251		Fm-251		Fm-251	
	Fm-252		Fm-252			
	Fm-253		Fm-253		Fm-253	
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-255		Fm-255		Fm-255	
	Fm-256		Fm-256		Fm-256	
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
					Fr-227	
	Gd-146		Gd-146			
	Gd-147					
	Gd-148	Gd-148	Gd-148	Gd-148		
	Gd-150	Gd-150	Gd-150	Gd-150		
	Gd-152	Gd-152	Gd-152	Gd-152		
	Hf-174	Hf-174	Hf-174	Hf-174		
	Hf-178m	Hf-178m	Hf-178m	Hf-178m		
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hf-182m					
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-150					
	Ho-154					
	Ho-154m					
					Ho-157	
	Ho-163	Ho-163	Ho-163	Ho-163		
	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m
	I-129	I-129	I-129	I-129		
	I-135		I-135			
	In-115	In-115	In-115	In-115		
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40	K-40	K-40
	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81
					La-133	
	La-137	La-137	La-137	La-137	La-137	La-137
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-176	Lu-176	Lu-176	Lu-176	Lu-176	Lu-176

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	270	122	221	112	148	75
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mo-91		Mo-91		Mo-91	
	Mo-91m					
	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93
	Mo-93m		Mo-93m			
	Mo-99		Mo-99			
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-91m		Nb-91m		Nb-91m	
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
					Nb-93m	Nb-93m
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nb-94m		Nb-94m		Nb-94m	
	Nb-99		Nb-99			
	Nb-99m		Nb-99m			
	Nd-137					
	Nd-144	Nd-144	Nd-144	Nd-144		
	Nd-147					
	Nd-151					
	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59
	Ni-63	Ni-63	Ni-63	Ni-63		
	Np-232		Np-232		Np-232	
	Np-233		Np-233			
	Np-234		Np-234		Np-234	
	Np-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-236m		Np-236m		Np-236m	
	Np-237	Np-237	Np-237	Np-237		
	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m	Np-240m	Np-240m		
	Np-241		Np-241		Np-241	
	Np-242		Np-242			
	Np-242m		Np-242m			
	Os-186	Os-186	Os-186	Os-186		
					Os-194	Os-194
	Pa-229		Pa-229		Pa-229	
	Pa-230		Pa-230		Pa-230	
	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pa-233	Pa-233	Pa-233	Pa-233	Pa-233	Pa-233
	Pa-234	Pa-234	Pa-234	Pa-234		
	Pa-235		Pa-235			
	Pa-236					
	Pa-237		Pa-237			
	Pb-194		Pb-194		Pb-194	
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m		Pb-202m		Pb-202m	
	Pb-210	Pb-210			Pb-210	Pb-210
	Pd-97		Pd-97			
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-137m					
					Pm-145	Pm-145
	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146
	Pm-151		Pm-151			
	Po-205					
	Po-206		Po-206		Po-206	
					Po-207	
	Po-208	Po-208			Po-208	Po-208
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pr-137					
	Pt-190	Pt-190	Pt-190	Pt-190		
	Pt-193m		Pt-193m			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	**1,252**	**295**	**1,252**	**295**	**1,252**	**295**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Tier-1 List	**270**	**122**	**221**	**112**	**148**	**75**
	Pu-232		Pu-232		Pu-232	
	Pu-234		Pu-234			
	Pu-235		Pu-235			
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-237		Pu-237		Pu-237	
	Pu-238	Pu-238	Pu-238	Pu-238		
	Pu-239	Pu-239	Pu-239	Pu-239		
	Pu-240	Pu-240	Pu-240	Pu-240		
	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241
	Pu-242	Pu-242	Pu-242	Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	Pu-245		Pu-245		Pu-245	
	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246
	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
					Ra-227	
					Ra-228	Ra-228
	Ra-230		Ra-230		Ra-230	
	Rb-81		Rb-81			
	Rb-87	Rb-87	Rb-87	Rb-87		
	Rb-90				Rb-90	
	Rb-90m				Rb-90m	
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187		
	Rh-97		Rh-97			
	Rh-97m		Rh-97m			
	Rh-107		Rh-107			
					Rn-207	
	Rn-209		Rn-209		Rn-209	
	Rn-210		Rn-210		Rn-210	
					Rn-211	
					Rn-222	Rn-222
	Ru-97		Ru-97			
	Ru-107					
	Sb-129		Sb-129			
	Se-79	Se-79	Se-79	Se-79		
	Se-79m					
	Si-32	Si-32	Si-32	Si-32		
					Sm-145	Sm-145
	Sm-146	Sm-146	Sm-146	Sm-146		
	Sm-147	Sm-147	Sm-147	Sm-147		
	Sm-148	Sm-148	Sm-148	Sm-148		
	Sm-151	Sm-151				
	Sn-121m	Sn-121m			Sn-121m	Sn-121m
	Sn-126	Sn-126			Sn-126	Sn-126
	Sn-129		Sn-129			
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	Sr-93					
	Tb-148		Tb-148			
	Tb-148m					
					Tb-149	
	Tb-150		Tb-150			
	Tb-150m					
	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-91					
	Tc-91m					
	Tc-93		Tc-93			
	Tc-93m		Tc-93m			
	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-97m		Tc-97m			
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Initial List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Tier-1 List	270	122	221	112	148	75
	Tc-99m		Tc-99m			
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Th-230	Th-230	Th-230	Th-230	Th-230	Th-230
	Th-232	Th-232				
	Th-233		Th-233			
	Th-235		Th-235			
	Th-236					
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194		Tl-194	
	Tl-194m		Tl-194m		Tl-194m	
	Tm-163					
					U-230	
	U-231		U-231		U-231	
	U-233	U-233	U-233	U-233		
	U-234	U-234	U-234	U-234		
	U-235	U-235	U-235	U-235		
	U-235m	U-235m	U-235m	U-235m		
	U-236	U-236	U-236	U-236		
	U-238	U-238	U-238	U-238		
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242		U-242			
	V-50	V-50	V-50	V-50	V-50	V-50
	W-187					
	Xe-135		Xe-135			
	Xe-135m		Xe-135m			
					Xe-137	
	Y-93		Y-93			
	Yb-163					
	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93

Table I-14. Tier-1 NCRP123 groundwater pathway SOF histogram for the NRCDAS disposal unit.

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	162	7	2	2	2	6	11	8	6	89
295	133	126	124	122	120	114	103	95	89	0
Ac-225	Ac-225									
Ac-227							Ac-227			
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m						Ag-108m				
Ag-109m	Ag-109m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241										Am-241
Am-242	Am-242									
Am-242m								Am-242m		
Am-243										Am-243
Am-245										Am-245
Am-246m										Am-246m
Ar-39										Ar-39
At-217	At-217									
At-218	At-218									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	162	7	2	2	2	6	11	8	6	89
295	133	126	124	122	120	114	103	95	89	0
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									
Ba-140	Ba-140									
Be-10								Be-10		
Bi-207									Bi-207	
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214	Bi-214									
Bi-215	Bi-215									
Bk-247										Bk-247
Bk-249	Bk-249									
Bk-250										Bk-250
C-14										C-14
Ca-41										Ca-41
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113										Cd-113
Cd-113m	Cd-113m									
Cd-115m	Cd-115m									
Ce-139	Ce-139									
Ce-141	Ce-141									
Ce-144	Ce-144									
Cf-248										Cf-248
Cf-249		Cf-249								
Cf-250										Cf-250
Cf-251	Cf-251									
Cf-252										Cf-252
Cf-253										Cf-253
Cl-36										Cl-36
Cm-242							Cm-242			
Cm-243							Cm-243			
Cm-244									Cm-244	
Cm-245								Cm-245		
Cm-246							Cm-246			
Cm-247	Cm-247									
Cm-248		Cm-248								
Cm-249										Cm-249
Cm-250										Cm-250
Co-57	Co-57									
Co-58	Co-58									
Co-60	Co-60									
Co-60m	Co-60m									
Cr-51	Cr-51									
Cs-134	Cs-134									
Cs-135								Cs-135		
Cs-137					Cs-137					
Dy-154										Dy-154
Dy-159	Dy-159									
Es-253										Es-253
Es-254										Es-254
Eu-149	Eu-149									
Eu-150									Eu-150	
Eu-152	Eu-152									
Eu-154	Eu-154									
Eu-155	Eu-155									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	162	7	2	2	2	6	11	8	6	89
295	133	126	124	122	120	114	103	95	89	0
Fe-55	Fe-55									
Fe-59	Fe-59									
Fe-60										Fe-60
Fm-254										Fm-254
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148										Gd-148
Gd-150										Gd-150
Gd-151	Gd-151									
Gd-152										Gd-152
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3	H-3									
Hf-172	Hf-172									
Hf-174										Hf-174
Hf-175	Hf-175									
Hf-178m								Hf-178m		
Hf-181	Hf-181									
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163										Ho-163
Ho-166m										Ho-166m
I-129										I-129
In-113m	In-113m									
In-114	In-114									
In-114m	In-114m									
In-115										In-115
Ir-192	Ir-192									
Ir-192m	Ir-192m									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40										K-40
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
La-140	La-140									
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53										Mn-53
Mn-54	Mn-54									
Mo-93										Mo-93
Na-22	Na-22									
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m	Nb-93m									
Nb-94										Nb-94
Nb-95	Nb-95									
Nb-95m	Nb-95m									
Nd-144										Nd-144

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	162	**7**	**2**	**2**	**2**	**6**	**11**	**8**	**6**	**89**
295	**133**	**126**	**124**	**122**	**120**	**114**	**103**	**95**	**89**	**0**
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237									Np-237	
Np-238										Np-238
Np-239			Np-239							
Np-240										Np-240
Np-240m										Np-240m
Os-185	Os-185									
Os-186										Os-186
Os-194	Os-194									
P-32	P-32									
P-33	P-33									
Pa-231										Pa-231
Pa-232										Pa-232
Pa-233										Pa-233
Pa-234									Pa-234	
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205		Pb-205								
Pb-209	Pb-209									
Pb-210							Pb-210			
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214	Pb-214									
Pd-107						Pd-107				
Pm-143	Pm-143									
Pm-144			Pm-144							
Pm-145	Pm-145									
Pm-146										Pm-146
Pm-147		Pm-147								
Po-208							Po-208			
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218	Po-218									
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190										Pt-190
Pt-193		Pt-193								
Pu-236										Pu-236
Pu-238								Pu-238		
Pu-239										Pu-239
Pu-240										Pu-240
Pu-241										Pu-241
Pu-242									Pu-242	
Pu-243										Pu-243
Pu-244		Pu-244								
Pu-246										Pu-246
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226										Ra-226
Ra-228	Ra-228									
Rb-87										Rb-87
Re-184	Re-184									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	162	7	2	2	2	6	11	8	6	89
295	133	126	124	122	120	114	103	95	89	0
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m										Re-186m
Re-187										Re-187
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m	Rh-102m									
Rh-103m	Rh-103m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222				Rn-222						
Ru-103	Ru-103									
Ru-106	Ru-106									
S-35	S-35									
Sb-124	Sb-124									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79								Se-79		
Si-32										Si-32
Sm-145	Sm-145									
Sm-146										Sm-146
Sm-147										Sm-147
Sm-148										Sm-148
Sm-151						Sm-151				
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m					Sn-121m					
Sn-123	Sn-123									
Sn-126							Sn-126			
Sr-89	Sr-89									
Sr-90						Sr-90				
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-121	Te-121									
Te-121m	Te-121m									
Te-123										Te-123
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230										Th-230
Th-231	Th-231									
Th-232						Th-232				
Th-234	Th-234									
Ti-44										Ti-44
Tl-202	Tl-202									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	162	**7**	**2**	**2**	**2**	**6**	**11**	**8**	**6**	**89**
295	**133**	**126**	**124**	**122**	**120**	**114**	**103**	**95**	**89**	**0**
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210	Tl-210									
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232				U-232						
U-233							U-233			
U-234							U-234			
U-235							U-235			
U-235m						U-235m				
U-236							U-236			
U-237		U-237								
U-238								U-238		
U-240										U-240
V-49	V-49									
V-50										V-50
W-181	W-181									
W-185	W-185									
W-188	W-188									
Y-88	Y-88									
Y-90	Y-90									
Y-91	Y-91									
Zn-65	Zn-65									
Zr-93										Zr-93
Zr-95	Zr-95									

Table I-15. Tier-1 RadScreen II pathway SOF histogram for the NRCDAS disposal unit.

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	188	**11**	**11**	**10**	**5**	**11**	**7**	**5**	**3**	**44**
295	**107**	**96**	**85**	**75**	**70**	**59**	**52**	**47**	**44**	**0**
Ac-225	Ac-225									
Ac-227										Ac-227
Ac-228	Ac-228									
Ag-108	Ag-108									
Ag-108m			Ag-108m							
Ag-109m	Ag-109m									
Ag-110	Ag-110									
Ag-110m	Ag-110m									
Al-26										Al-26
Am-241							Am-241			
Am-242	Am-242									
Am-242m				Am-242m						
Am-243						Am-243				
Am-245							Am-245			
Am-246m					Am-246m					
Ar-39	Ar-39									
At-217	At-217									
At-218	At-218									
At-219	At-219									
Au-194	Au-194									
Au-195	Au-195									
Ba-133	Ba-133									
Ba-137m	Ba-137m									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	188	11	11	10	5	11	7	5	3	44
295	107	96	85	75	70	59	52	47	44	0
Ba-140	Ba-140									
Be-10	Be-10									
Bi-207										Bi-207
Bi-208										Bi-208
Bi-210	Bi-210									
Bi-210m										Bi-210m
Bi-211	Bi-211									
Bi-212	Bi-212									
Bi-213	Bi-213									
Bi-214				Bi-214						
Bi-215	Bi-215									
Bk-247										Bk-247
Bk-249	Bk-249									
Bk-250						Bk-250				
C-14	C-14									
Ca-41	Ca-41									
Ca-45	Ca-45									
Cd-109	Cd-109									
Cd-113	Cd-113									
Cd-113m	Cd-113m									
Cd-115m	Cd-115m									
Ce-139	Ce-139									
Ce-141	Ce-141									
Ce-144	Ce-144									
Cf-248							Cf-248			
Cf-249	Cf-249									
Cf-250										Cf-250
Cf-251	Cf-251									
Cf-252										Cf-252
Cf-253										Cf-253
Cl-36				Cl-36						
Cm-242		Cm-242								
Cm-243				Cm-243						
Cm-244		Cm-244								
Cm-245			Cm-245							
Cm-246		Cm-246								
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249								Cm-249		
Cm-250										Cm-250
Co-57	Co-57									
Co-58	Co-58									
Co-60					Co-60					
Co-60m	Co-60m									
Cr-51	Cr-51									
Cs-134	Cs-134									
Cs-135	Cs-135									
Cs-137								Cs-137		
Dy-154	Dy-154									
Dy-159	Dy-159									
Es-253										Es-253
Es-254									Es-254	
Eu-149	Eu-149									
Eu-150										Eu-150
Eu-152		Eu-152								
Eu-154			Eu-154							
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-59	Fe-59									
Fe-60										Fe-60
Fm-254						Fm-254				

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	188	11	11	10	5	11	7	5	3	44
295	107	96	85	75	70	59	52	47	44	0
Fm-257										Fm-257
Fr-221	Fr-221									
Fr-223	Fr-223									
Ga-68	Ga-68									
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-151	Gd-151									
Gd-152	Gd-152									
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3	H-3									
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-175	Hf-175									
Hf-178m	Hf-178m									
Hf-181	Hf-181									
Hf-182										Hf-182
Hg-194										Hg-194
Hg-206	Hg-206									
Ho-163	Ho-163									
Ho-166m										Ho-166m
I-129		I-129								
In-113m	In-113m									
In-114	In-114									
In-114m	In-114m									
In-115	In-115									
Ir-192	Ir-192									
Ir-192m	Ir-192m									
Ir-192n										Ir-192n
Ir-194	Ir-194									
Ir-194m	Ir-194m									
K-40										K-40
K-42	K-42									
Kr-81										Kr-81
Kr-83m	Kr-83m									
Kr-85	Kr-85									
La-137										La-137
La-138										La-138
La-140	La-140									
Lu-172	Lu-172									
Lu-172m	Lu-172m									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176										Lu-176
Lu-177	Lu-177									
Lu-177m	Lu-177m									
Mn-53	Mn-53									
Mn-54	Mn-54									
Mo-93					Mo-93					
Na-22	Na-22									
Nb-91										Nb-91
Nb-92										Nb-92
Nb-93m					Nb-93m					
Nb-94										Nb-94
Nb-95	Nb-95									
Nb-95m	Nb-95m									
Nd-144	Nd-144									
Ni-59								Ni-59		
Ni-63	Ni-63									
Np-235						Np-235				
Np-236										Np-236

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	188	11	11	10	5	11	7	5	3	44
295	107	96	85	75	70	59	52	47	44	0
Np-237			Np-237							
Np-238						Np-238				
Np-239	Np-239									
Np-240			Np-240							
Np-240m		Np-240m								
Os-185	Os-185									
Os-186	Os-186									
Os-194						Os-194				
P-32	P-32									
P-33	P-33									
Pa-231										Pa-231
Pa-232										Pa-232
Pa-233							Pa-233			
Pa-234				Pa-234						
Pa-234m	Pa-234m									
Pb-202										Pb-202
Pb-205	Pb-205									
Pb-209	Pb-209									
Pb-210										Pb-210
Pb-211	Pb-211									
Pb-212	Pb-212									
Pb-214				Pb-214						
Pd-107	Pd-107									
Pm-143	Pm-143									
Pm-144	Pm-144									
Pm-145										Pm-145
Pm-146						Pm-146				
Pm-147	Pm-147									
Po-208						Po-208				
Po-209										Po-209
Po-210	Po-210									
Po-211	Po-211									
Po-212	Po-212									
Po-213	Po-213									
Po-214	Po-214									
Po-215	Po-215									
Po-216	Po-216									
Po-218			Po-218							
Pr-144	Pr-144									
Pr-144m	Pr-144m									
Pt-190	Pt-190									
Pt-193	Pt-193									
Pu-236										Pu-236
Pu-238			Pu-238							
Pu-239				Pu-239						
Pu-240				Pu-240						
Pu-241							Pu-241			
Pu-242		Pu-242								
Pu-243							Pu-243			
Pu-244	Pu-244									
Pu-246								Pu-246		
Ra-223	Ra-223									
Ra-224	Ra-224									
Ra-225	Ra-225									
Ra-226										Ra-226
Ra-228							Ra-228			
Rb-87	Rb-87									
Re-184	Re-184									
Re-184m	Re-184m									
Re-186	Re-186									
Re-186m										Re-186m
Re-187	Re-187									

Tier-0	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	188	11	11	10	5	11	7	5	3	44
295	107	96	85	75	70	59	52	47	44	0
Rh-101	Rh-101									
Rh-102	Rh-102									
Rh-102m		Rh-102m								
Rh-103m	Rh-103m									
Rh-106	Rh-106									
Rn-217	Rn-217									
Rn-218	Rn-218									
Rn-219	Rn-219									
Rn-220	Rn-220									
Rn-222						Rn-222				
Ru-103	Ru-103									
Ru-106	Ru-106									
S-35	S-35									
Sb-124	Sb-124									
Sb-125	Sb-125									
Sb-126	Sb-126									
Sb-126m	Sb-126m									
Sc-44	Sc-44									
Sc-46	Sc-46									
Se-75	Se-75									
Se-79	Se-79									
Si-32	Si-32									
Sm-145									Sm-145	
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-113	Sn-113									
Sn-119m	Sn-119m									
Sn-121	Sn-121									
Sn-121m						Sn-121m				
Sn-123	Sn-123									
Sn-126					Sn-126					
Sr-89	Sr-89									
Sr-90						Sr-90				
Ta-179	Ta-179									
Ta-182	Ta-182									
Tb-157										Tb-157
Tb-158										Tb-158
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99				Tc-99						
Te-121	Te-121									
Te-121m	Te-121m									
Te-123									Te-123	
Te-123m	Te-123m									
Te-125m	Te-125m									
Te-127	Te-127									
Te-127m	Te-127m									
Th-227	Th-227									
Th-228	Th-228									
Th-229										Th-229
Th-230										Th-230
Th-231	Th-231									
Th-232		Th-232								
Th-234	Th-234									
Ti-44										Ti-44
Tl-202	Tl-202									
Tl-204	Tl-204									
Tl-206	Tl-206									
Tl-207	Tl-207									

Tier-0	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	188	**11**	**11**	**10**	**5**	**11**	**7**	**5**	**3**	**44**
295	**107**	**96**	**85**	**75**	**70**	**59**	**52**	**47**	**44**	**0**
Tl-208	Tl-208									
Tl-209	Tl-209									
Tl-210			Tl-210							
Tm-168	Tm-168									
Tm-170	Tm-170									
Tm-171	Tm-171									
U-232			U-232							
U-233			U-233							
U-234		U-234								
U-235		U-235								
U-235m	U-235m									
U-236	U-236									
U-237	U-237									
U-238			U-238							
U-240				U-240						
V-49	V-49									
V-50										V-50
W-181	W-181									
W-185	W-185									
W-188	W-188									
Y-88	Y-88									
Y-90	Y-90									
Y-91	Y-91									
Zn-65	Zn-65									
Zr-93								Zr-93		
Zr-95	Zr-95									

Appendix J. Details/Results Associated with Tier-2 Radionuclide Lists

For each of the five DU types, the PorflowPS screening model using the Tier-1 radionuclide lists were used to ascertain the impact of aquifer dilution on the Tier-2 GW pathway screening. The model, nuclide lists and pathways considered were:

- **GW model** – PorflowPS screening model;
- **Initial nuclide list** –Tier-1 radionuclide lists computed from the NCRP123 screening model with the Tier-0 radionuclide lists;
- **Pathways** – GW pathways

For each DU type two tables are provided below:

- The first table contains the Tier-2 radionuclide list and the initial Tier-1 radionuclide list used in the PorflowPS screening model with and without aquifer dilution. The rate constant for aquifer dilution, w_d, is discussed in Appendix G.
- The second table contains the Tier-2 PorflowPS GW SOF histogram bins (row 2), counts (row 3) and running totals of radionuclides remaining (row 4). The range of histogram bins varies from < 1E-6 to > 1E+2. The screening criteria is a SOF equal to 1E-3 (0.1%). For example, the count in the SOF bin 1E-3 represents all radionuclides with a SOF • 1E-4 and < 1E-3. Any radionuclides in bins beyond 1E-3 failed Tier-2 screening.

J.1 Generic Trench Model

Table J-1 and Table J-2 are the results for the generic trench model that apply to all ST, ET, and CIG units.

Table J-1. Tier-2 radionuclide listing for the Generic Trench disposal unit.

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	1.3
163	44	43
Ac-227		
Ag-108m	Ag-108m	Ag-108m
Am-241	Am-241	Am-241
Am-242m		
Am-243		
Am-245	Am-245	Am-245
Am-246m		
At-218		
Au-195		
Ba-133		
Be-10	Be-10	Be-10
Bi-208		
Bi-210m		
Bk-247		
Bk-249	Bk-249	Bk-249
Bk-250		
C-14	C-14	C-14
Cd-113m		
Cf-248		
Cf-249	Cf-249	Cf-249
Cf-250		
Cf-251		
Cf-252		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	1.3
163	44	43
Cf-253	Cf-253	Cf-253
Cl-36	Cl-36	Cl-36
Cm-242		
Cm-243		
Cm-244		
Cm-245	Cm-245	Cm-245
Cm-246		
Cm-247		
Cm-248		
Cm-249	Cm-249	Cm-249
Cm-250		
Co-60		
Co-60m		
Cs-134		
Cs-135	Cs-135	Cs-135
Cs-137	Cs-137	Cs-137
Dy-154		
Es-253	Es-253	Es-253
Es-254		
Eu-150		
Eu-152		
Eu-154		
Eu-155		
Fe-55		
Fe-60		
Fm-254		
Fm-257	Fm-257	Fm-257
Gd-148		
Gd-150		
Gd-152		
Gd-153		
Ge-68		
H-3	H-3	H-3
Hf-172		
Hf-174		
Hf-178m		
Hf-182		
Hg-194		
Ho-163		
I-129	I-129	I-129
In-115		
Ir-192n		
K-40	K-40	K-40
Kr-81	Kr-81	Kr-81
La-137		
La-138		
Lu-173		
Lu-174		
Lu-174m		
Lu-176		
Mn-53	Mn-53	Mn-53
Mn-54		
Mo-93		
Na-22		
Nb-91		
Nb-92		
Nb-93m		
Nb-94		
Nd-144		
Ni-59	Ni-59	Ni-59
Ni-63	Ni-63	Ni-63
Np-235	Np-235	Np-235

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	1.3
163	44	43
Np-236	Np-236	Np-236
Np-237	Np-237	Np-237
Np-238		
Np-239		
Np-240		
Np-240m		
Os-186		
Os-194		
Pa-231	Pa-231	Pa-231
Pa-232		
Pa-233		
Pb-202		
Pb-210		
Pd-107	Pd-107	Pd-107
Pm-144		
Pm-145		
Pm-147		
Po-208		
Po-209		
Pt-190	Pt-190	Pt-190
Pt-193		
Pu-236		
Pu-238	Pu-238	
Pu-239	Pu-239	Pu-239
Pu-240		
Pu-241	Pu-241	Pu-241
Pu-242		
Pu-243		
Pu-246		
Ra-226	Ra-226	Ra-226
Ra-228		
Rb-87	Rb-87	Rb-87
Re-184m		
Re-186m	Re-186m	Re-186m
Re-187	Re-187	Re-187
Rh-101		
Rh-102m		
Rn-218		
Rn-222		
Ru-106		
Sb-125		
Se-79		
Si-32	Si-32	Si-32
Sm-145		
Sm-146		
Sm-147		
Sm-148		
Sm-151		
Sn-121m		
Sn-126		
Sr-90	Sr-90	Sr-90
Ta-179		
Tb-157		
Tb-158		
Tc-97	Tc-97	Tc-97
Tc-98	Tc-98	Tc-98
Tc-99	Tc-99	Tc-99
Te-123		
Th-228		
Th-229		
Th-230	Th-230	Th-230
Th-231	Th-231	Th-231

Tier-1	PorflowPS	PorflowPS
Pathway	**GW**	**GW**
w_d	**0**	**1.3**
163	**44**	**43**
Th-232		
Th-234		
Ti-44		
Tl-204		
Tl-210		
U-232		
U-233		
U-234	U-234	U-234
U-235	U-235	U-235
U-235m		
U-236		
U-238		
U-240		
V-49		
V-50		
Zr-93		

Table J-2. Tier-2 PorflowPS groundwater pathway SOF histogram for the Generic Trench disposal unit.

Tier-1	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	113	**3**	**1**	**3**	**3**	**6**	**3**	**1**	**4**	**26**
163	**50**	**47**	**46**	**43**	**40**	**34**	**31**	**30**	**26**	**0**
Ac-227	Ac-227									
Ag-108m										Ag-108m
Am-241										Am-241
Am-242m		Am-242m								
Am-243		Am-243								
Am-245						Am-245				
Am-246m	Am-246m									
At-218	At-218									
Au-195	Au-195									
Ba-133	Ba-133									
Be-10						Be-10				
Bi-208	Bi-208									
Bi-210m	Bi-210m									
Bk-247	Bk-247									
Bk-249										Bk-249
Bk-250	Bk-250									
C-14										C-14
Cd-113m	Cd-113m									
Cf-248	Cf-248									
Cf-249						Cf-249				
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36							Cl-36			
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245						Cm-245				
Cm-246	Cm-246									
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249					Cm-249					
Cm-250	Cm-250									
Co-60	Co-60									
Co-60m	Co-60m									

Tier-1	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	113	**3**	**1**	**3**	**3**	**6**	**3**	**1**	**4**	**26**
163	**50**	**47**	**46**	**43**	**40**	**34**	**31**	**30**	**26**	**0**
Cs-134	Cs-134									
Cs-135						Cs-135				
Cs-137										Cs-137
Dy-154	Dy-154									
Es-253									Es-253	
Es-254	Es-254									
Eu-150	Eu-150									
Eu-152	Eu-152									
Eu-154	Eu-154									
Eu-155	Eu-155									
Fe-55	Fe-55									
Fe-60	Fe-60									
Fm-254	Fm-254									
Fm-257										Fm-257
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-152	Gd-152									
Gd-153	Gd-153									
Ge-68	Ge-68									
H-3										H-3
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182	Hf-182									
Hg-194	Hg-194									
Ho-163	Ho-163									
I-129										I-129
In-115	In-115									
Ir-192n	Ir-192n									
K-40										K-40
Kr-81										Kr-81
La-137	La-137									
La-138	La-138									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176	Lu-176									
Mn-53										Mn-53
Mn-54	Mn-54									
Mo-93	Mo-93									
Na-22	Na-22									
Nb-91	Nb-91									
Nb-92	Nb-92									
Nb-93m	Nb-93m									
Nb-94	Nb-94									
Nd-144	Nd-144									
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237										Np-237
Np-238		Np-238								
Np-239	Np-239									
Np-240	Np-240									
Np-240m	Np-240m									
Os-186	Os-186									
Os-194	Os-194									
Pa-231							Pa-231			
Pa-232	Pa-232									
Pa-233	Pa-233									
Pb-202	Pb-202									
Pb-210	Pb-210									

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	113	3	1	3	3	6	3	1	4	26
163	50	47	46	43	40	34	31	30	26	0
Pd-107					Pd-107					
Pm-144	Pm-144									
Pm-145	Pm-145									
Pm-147	Pm-147									
Po-208	Po-208									
Po-209	Po-209									
Pt-190										Pt-190
Pt-193			Pt-193							
Pu-236	Pu-236									
Pu-238				Pu-238						
Pu-239						Pu-239				
Pu-240	Pu-240									
Pu-241									Pu-241	
Pu-242	Pu-242									
Pu-243	Pu-243									
Pu-246	Pu-246									
Ra-226										Ra-226
Ra-228	Ra-228									
Rb-87							Rb-87			
Re-184m	Re-184m									
Re-186m										Re-186m
Re-187										Re-187
Rh-101	Rh-101									
Rh-102m	Rh-102m									
Rn-218	Rn-218									
Rn-222	Rn-222									
Ru-106	Ru-106									
Sb-125	Sb-125									
Se-79	Se-79									
Si-32										Si-32
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-121m	Sn-121m									
Sn-126	Sn-126									
Sr-90										Sr-90
Ta-179	Ta-179									
Tb-157	Tb-157									
Tb-158	Tb-158									
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-123	Te-123									
Th-228	Th-228									
Th-229	Th-229									
Th-230									Th-230	
Th-231					Th-231					
Th-232	Th-232									
Th-234	Th-234									
Ti-44	Ti-44									
Tl-204	Tl-204									
Tl-210	Tl-210									
U-232	U-232									
U-233	U-233									
U-234								U-234		
U-235										U-235
U-235m				U-235m						
U-236	U-236									
U-238				U-238						
U-240	U-240									

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	113	3	1	3	3	6	3	1	4	26
163	50	47	46	43	40	34	31	30	26	0
V-49	V-49									
V-50	V-50									
Zr-93	Zr-93									

J.2 ILV Model

Table J-3 and Table J-4 are the results for the ILV model that apply to only the ILV unit.

Table J-3. Tier-2 radionuclide listing for the ILV disposal unit.

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	10.7
141	47	45
Ac-227		
Ag-108m	Ag-108m	Ag-108m
Al-26		
Am-241	Am-241	Am-241
Am-242		
Am-242m		
Am-243		
Am-245	Am-245	Am-245
Am-246m		
Ar-39	Ar-39	Ar-39
At-218		
Ba-133		
Be-10	Be-10	Be-10
Bi-207		
Bi-208		
Bi-210m		
Bk-247	Bk-247	Bk-247
Bk-249	Bk-249	Bk-249
Bk-250		
C-14	C-14	C-14
Ca-41	Ca-41	Ca-41
Cd-113	Cd-113	Cd-113
Cf-248		
Cf-249	Cf-249	Cf-249
Cf-250		
Cf-251		
Cf-252		
Cf-253	Cf-253	Cf-253
Cl-36	Cl-36	Cl-36
Cm-242		
Cm-243		
Cm-244		
Cm-245	Cm-245	Cm-245
Cm-246		
Cm-247		
Cm-248		
Cm-249	Cm-249	Cm-249
Cm-250		
Cs-135	Cs-135	Cs-135
Cs-137	Cs-137	Cs-137
Dy-154		
Es-253	Es-253	Es-253
Es-254		
Eu-150		
Fe-60		
Fm-254		

Tier-1	**PorflowPS**	**PorflowPS**
Pathway	**GW**	**GW**
w_d	**0**	**10.7**
141	**47**	**45**
Fm-257	Fm-257	Fm-257
Gd-148		
Gd-150		
Gd-152		
H-3	H-3	H-3
Hf-174		
Hf-178m		
Hf-182		
Hg-194		
Ho-163		
Ho-166m		
I-129	I-129	I-129
In-115		
Ir-192n		
K-40	K-40	K-40
Kr-81	Kr-81	Kr-81
La-137		
La-138		
Lu-176		
Mn-53	Mn-53	Mn-53
Mo-93		
Nb-91		
Nb-92		
Nb-93m		
Nb-94		
Nd-144		
Ni-59	Ni-59	Ni-59
Ni-63	Ni-63	Ni-63
Np-235	Np-235	Np-235
Np-236	Np-236	Np-236
Np-237	Np-237	Np-237
Np-238		
Np-240		
Np-240m		
Os-186		
Os-194		
Pa-231	Pa-231	Pa-231
Pa-232		
Pb-202		
Pb-205		
Pb-210		
Pd-107	Pd-107	Pd-107
Pm-145		
Pm-146		
Po-208		
Po-209		
Pt-190	Pt-190	Pt-190
Pt-193		
Pu-236		
Pu-238		
Pu-239	Pu-239	Pu-239
Pu-240		
Pu-241	Pu-241	Pu-241
Pu-242		
Pu-243		
Pu-244		
Pu-246		
Ra-226	Ra-226	Ra-226
Rb-87	Rb-87	Rb-87
Re-186m	Re-186m	Re-186m
Re-187	Re-187	Re-187
Rn-222		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	10.7
141	47	45
Se-79		
Si-32	Si-32	Si-32
Sm-145		
Sm-146		
Sm-147		
Sm-148		
Sm-151		
Sn-126		
Sr-90	Sr-90	Sr-90
Tb-157		
Tb-158		
Tc-97	Tc-97	Tc-97
Tc-98	Tc-98	Tc-98
Tc-99	Tc-99	Tc-99
Te-123		
Th-229		
Th-230		
Th-231	Th-231	
Th-232		
Th-234		
Ti-44		
Tl-210		
U-232		
U-233		
U-234		
U-235	U-235	U-235
U-235m	U-235m	
U-236		
U-237	U-237	U-237
U-238		
U-240		
V-50		
Zr-93		

Table J-4. Tier-2 PorflowPS groundwater pathway SOF histogram for the ILV disposal unit.

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	91	3	0	2	2	3	5	2	4	29
141	50	47	47	45	43	40	35	33	29	0
Ac-227	Ac-227									
Ag-108m						Ag-108m				
Al-26	Al-26									
Am-241									Am-241	
Am-242	Am-242									
Am-242m	Am-242m									
Am-243	Am-243									
Am-245							Am-245			
Am-246m	Am-246m									
Ar-39							Ar-39			
At-218	At-218									
Ba-133	Ba-133									
Be-10										Be-10
Bi-207	Bi-207									
Bi-208	Bi-208									
Bi-210m	Bi-210m									
Bk-247							Bk-247			
Bk-249										Bk-249
Bk-250	Bk-250									

Tier-1	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	91	**3**	**0**	**2**	**2**	**3**	**5**	**2**	**4**	**29**
141	**50**	**47**	**47**	**45**	**43**	**40**	**35**	**33**	**29**	**0**
C-14										C-14
Ca-41										Ca-41
Cd-113										Cd-113
Cf-248	Cf-248									
Cf-249					Cf-249					
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36								Cl-36		
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245							Cm-245			
Cm-246	Cm-246									
Cm-247	Cm-247									
Cm-248	Cm-248									
Cm-249							Cm-249			
Cm-250	Cm-250									
Cs-135										Cs-135
Cs-137						Cs-137				
Dy-154	Dy-154									
Es-253									Es-253	
Es-254	Es-254									
Eu-150	Eu-150									
Fe-60	Fe-60									
Fm-254	Fm-254									
Fm-257										Fm-257
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-152	Gd-152									
H-3										H-3
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182	Hf-182									
Hg-194	Hg-194									
Ho-163	Ho-163									
Ho-166m	Ho-166m									
I-129										I-129
In-115	In-115									
Ir-192n	Ir-192n									
K-40										K-40
Kr-81										Kr-81
La-137	La-137									
La-138	La-138									
Lu-176	Lu-176									
Mn-53										Mn-53
Mo-93	Mo-93									
Nb-91	Nb-91									
Nb-92	Nb-92									
Nb-93m	Nb-93m									
Nb-94	Nb-94									
Nd-144	Nd-144									
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237										Np-237
Np-238	Np-238									
Np-240	Np-240									
Np-240m	Np-240m									
Os-186	Os-186									

Tier-1	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	91	**3**	**0**	**2**	**2**	**3**	**5**	**2**	**4**	**29**
141	**50**	**47**	**47**	**45**	**43**	**40**	**35**	**33**	**29**	**0**
Os-194	Os-194									
Pa-231										Pa-231
Pa-232	Pa-232									
Pb-202	Pb-202									
Pb-205	Pb-205									
Pb-210	Pb-210									
Pd-107										Pd-107
Pm-145	Pm-145									
Pm-146	Pm-146									
Po-208	Po-208									
Po-209	Po-209									
Pt-190										Pt-190
Pt-193		Pt-193								
Pu-236	Pu-236									
Pu-238	Pu-238									
Pu-239					Pu-239					
Pu-240	Pu-240									
Pu-241								Pu-241		
Pu-242	Pu-242									
Pu-243		Pu-243								
Pu-244	Pu-244									
Pu-246	Pu-246									
Ra-226						Ra-226				
Rb-87										Rb-87
Re-186m										Re-186m
Re-187										Re-187
Rn-222	Rn-222									
Se-79	Se-79									
Si-32										Si-32
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-126	Sn-126									
Sr-90										Sr-90
Tb-157	Tb-157									
Tb-158	Tb-158									
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-123	Te-123									
Th-229	Th-229									
Th-230	Th-230									
Th-231				Th-231						
Th-232	Th-232									
Th-234	Th-234									
Ti-44	Ti-44									
Tl-210	Tl-210									
U-232	U-232									
U-233	U-233									
U-234		U-234								
U-235									U-235	
U-235m				U-235m						
U-236	U-236									
U-237										U-237
U-238	U-238									
U-240	U-240									
V-50	V-50									
Zr-93	Zr-93									

J.3 LAWV Model

Table J-5 and Table J-6 are the results for the LAWV model that apply to only the LAWV unit.

Table J-5. Tier-2 radionuclide listing for the LAWV disposal unit.

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	8
134	43	39
Ac-227		
Ag-108m	Ag-108m	Ag-108m
Al-26		
Am-241	Am-241	Am-241
Am-242		
Am-242m		
Am-243		
Am-245	Am-245	
Am-246m		
Be-10	Be-10	Be-10
Bi-207		
Bi-208		
Bi-210m		
Bk-247		
Bk-249	Bk-249	Bk-249
Bk-250		
C-14	C-14	C-14
Ca-41	Ca-41	Ca-41
Cd-113	Cd-113	Cd-113
Cf-248		
Cf-249		
Cf-250		
Cf-251		
Cf-252		
Cf-253	Cf-253	Cf-253
Cl-36	Cl-36	Cl-36
Cm-243		
Cm-244		
Cm-245	Cm-245	Cm-245
Cm-246		
Cm-249	Cm-249	
Cm-250		
Cs-137	Cs-137	Cs-137
Dy-154		
Es-253	Es-253	Es-253
Es-254		
Eu-150		
Eu-152		
Fe-60		
Fm-254		
Fm-257	Fm-257	Fm-257
Gd-148		
Gd-150		
Gd-152		
H-3	H-3	H-3
Hf-174		
Hf-178m		
Hf-182		
Hg-194		
Ho-163		
Ho-166m		
I-129	I-129	I-129
In-115		
Ir-192n		
K-40	K-40	K-40
Kr-81	Kr-81	Kr-81

Tier-1	**PorflowPS**	**PorflowPS**
Pathway	**GW**	**GW**
w_d	**0**	**8**
134	**43**	**39**
La-137		
La-138		
Lu-176		
Mn-53	Mn-53	Mn-53
Mo-93		
Nb-91		
Nb-92		
Nb-93m		
Nb-94		
Nd-144		
Ni-59	Ni-59	Ni-59
Ni-63	Ni-63	Ni-63
Np-235	Np-235	Np-235
Np-236	Np-236	Np-236
Np-237	Np-237	Np-237
Np-238		
Np-240		
Np-240m		
Os-186		
Os-194		
Pa-231	Pa-231	Pa-231
Pa-232		
Pa-233		
Pb-202		
Pb-205		
Pb-210		
Pd-107	Pd-107	Pd-107
Pm-145		
Pm-146		
Po-208		
Po-209		
Pt-190	Pt-190	Pt-190
Pt-193		
Pu-236		
Pu-238		
Pu-239	Pu-239	Pu-239
Pu-240		
Pu-241	Pu-241	Pu-241
Pu-242		
Pu-243		
Pu-246		
Ra-226	Ra-226	Ra-226
Rb-87	Rb-87	Rb-87
Re-186m	Re-186m	Re-186m
Re-187	Re-187	Re-187
Se-79		
Si-32	Si-32	Si-32
Sm-145		
Sm-146		
Sm-147		
Sm-148		
Sm-151		
Sn-121m		
Sn-126		
Sr-90	Sr-90	Sr-90
Tb-157		
Tb-158		
Tc-97	Tc-97	Tc-97
Tc-98	Tc-98	Tc-98
Tc-99	Tc-99	Tc-99
Te-123		
Th-229		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	8
134	43	39
Th-230		
Th-231	Th-231	
Th-232		
Th-234		
Ti-44		
U-232		
U-233		
U-234	U-234	
U-235	U-235	U-235
U-235m		
U-236		
U-237	U-237	U-237
U-238		
U-240		
V-50		
Zr-93		

Table J-6. Tier-2 PorflowPS groundwater pathway SOF histogram for the LAWV disposal unit.

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	0	4	4	3	3	1	2	7	23
134	47	47	43	39	36	33	32	30	23	0
Ac-227	Ac-227									
Ag-108m						Ag-108m				
Al-26	Al-26									
Am-241									Am-241	
Am-242	Am-242									
Am-242m	Am-242m									
Am-243	Am-243									
Am-245				Am-245						
Am-246m	Am-246m									
Be-10										Be-10
Bi-207	Bi-207									
Bi-208	Bi-208									
Bi-210m	Bi-210m									
Bk-247			Bk-247							
Bk-249										Bk-249
Bk-250	Bk-250									
C-14										C-14
Ca-41					Ca-41					
Cd-113										Cd-113
Cf-248	Cf-248									
Cf-249	Cf-249									
Cf-250	Cf-250									
Cf-251	Cf-251									
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36									Cl-36	
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245						Cm-245				
Cm-246	Cm-246									
Cm-249				Cm-249						
Cm-250	Cm-250									
Cs-137						Cs-137				
Dy-154	Dy-154									
Es-253								Es-253		
Es-254	Es-254									

Tier-1	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	87	**0**	**4**	**4**	**3**	**3**	**1**	**2**	**7**	**23**
134	**47**	**47**	**43**	**39**	**36**	**33**	**32**	**30**	**23**	**0**
Eu-150	Eu-150									
Eu-152	Eu-152									
Fe-60	Fe-60									
Fm-254	Fm-254									
Fm-257									Fm-257	
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-152	Gd-152									
H-3										H-3
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182	Hf-182									
Hg-194	Hg-194									
Ho-163	Ho-163									
Ho-166m	Ho-166m									
I-129										I-129
In-115	In-115									
Ir-192n	Ir-192n									
K-40					K-40					
Kr-81										Kr-81
La-137	La-137									
La-138	La-138									
Lu-176	Lu-176									
Mn-53										Mn-53
Mo-93	Mo-93									
Nb-91	Nb-91									
Nb-92	Nb-92									
Nb-93m	Nb-93m									
Nb-94	Nb-94									
Nd-144	Nd-144									
Ni-59										Ni-59
Ni-63										Ni-63
Np-235									Np-235	
Np-236										Np-236
Np-237										Np-237
Np-238	Np-238									
Np-240	Np-240									
Np-240m	Np-240m									
Os-186	Os-186									
Os-194	Os-194									
Pa-231										Pa-231
Pa-232	Pa-232									
Pa-233	Pa-233									
Pb-202	Pb-202									
Pb-205	Pb-205									
Pb-210	Pb-210									
Pd-107										Pd-107
Pm-145	Pm-145									
Pm-146	Pm-146									
Po-208	Po-208									
Po-209	Po-209									
Pt-190										Pt-190
Pt-193			Pt-193							
Pu-236	Pu-236									
Pu-238	Pu-238									
Pu-239					Pu-239					
Pu-240	Pu-240									
Pu-241									Pu-241	
Pu-242	Pu-242									
Pu-243	Pu-243									
Pu-246	Pu-246									
Ra-226							Ra-226			

Tier-1	SOF bins									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	87	**0**	**4**	**4**	**3**	**3**	**1**	**2**	**7**	**23**
134	**47**	**47**	**43**	**39**	**36**	**33**	**32**	**30**	**23**	**0**
Rb-87										Rb-87
Re-186m										Re-186m
Re-187										Re-187
Se-79	Se-79									
Si-32										Si-32
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-121m	Sn-121m									
Sn-126	Sn-126									
Sr-90										Sr-90
Tb-157	Tb-157									
Tb-158	Tb-158									
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-123	Te-123									
Th-229	Th-229									
Th-230			Th-230							
Th-231				Th-231						
Th-232	Th-232									
Th-234	Th-234									
Ti-44	Ti-44									
U-232	U-232									
U-233	U-233									
U-234				U-234						
U-235									U-235	
U-235m			U-235m							
U-236	U-236									
U-237								U-237		
U-238	U-238									
U-240	U-240									
V-50	V-50									
Zr-93	Zr-93									

J.4 NRCDAG Model

Table J-7 and Table J-8 are the results for the NRCDAG model that apply to only the NRCDAG unit.

Table J-7. Tier-2 radionuclide listing for the NRCDAG disposal unit.

Tier-1	PorflowPS	PorflowPS
Pathway	**GW**	**GW**
w_d	**0**	**12.5**
157	**41**	**38**
Ac-228		
Al-26		
Am-241	Am-241	Am-241
Am-242		
Am-242m		
Am-243		
Am-245	Am-245	Am-245
Am-246m		
Ar-39	Ar-39	Ar-39
At-218		
Ba-133		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	12.5
157	41	38
Bi-207		
Bi-208		
Bi-210m		
Bk-247	Bk-247	Bk-247
Bk-249	Bk-249	Bk-249
Bk-250		
C-14	C-14	C-14
Ca-41	Ca-41	Ca-41
Cd-109		
Cd-113	Cd-113	Cd-113
Cd-113m		
Cf-248		
Cf-250		
Cf-252		
Cf-253	Cf-253	Cf-253
Cl-36	Cl-36	Cl-36
Cm-242		
Cm-243		
Cm-244		
Cm-245		
Cm-246		
Cm-249	Cm-249	Cm-249
Cm-250		
Co-57		
Co-60		
Co-60m		
Cs-134		
Cs-135	Cs-135	Cs-135
Cs-137		
Dy-154		
Es-253	Es-253	Es-253
Es-254		
Eu-150		
Eu-152		
Eu-154		
Fe-55		
Fe-60		
Fm-254		
Fm-257	Fm-257	Fm-257
Gd-148		
Gd-150		
Gd-152		
Ge-68		
H-3	H-3	H-3
Hf-172		
Hf-174		
Hf-178m		
Hf-182		
Hg-194		
Ho-163		
Ho-166m		
I-129	I-129	I-129
In-115		
Ir-192n		
K-40	K-40	K-40
Kr-81	Kr-81	Kr-81
La-137		
La-138		
Lu-173		
Lu-174		
Lu-174m		
Lu-176		

Tier-1	**PorflowPS**	**PorflowPS**
Pathway	**GW**	**GW**
w_d	**0**	**12.5**
157	**41**	**38**
Mn-53	Mn-53	Mn-53
Mn-54		
Mo-93		
Na-22		
Nb-91		
Nb-92		
Nb-93m		
Nb-94		
Nd-144		
Ni-59	Ni-59	Ni-59
Ni-63	Ni-63	Ni-63
Np-235	Np-235	Np-235
Np-236	Np-236	Np-236
Np-237	Np-237	Np-237
Np-238		
Np-239	Np-239	
Np-240		
Np-240m		
Os-186		
Os-194		
Pa-232		
Pa-233		
Pb-202		
Pb-205		
Pb-210		
Pd-107	Pd-107	Pd-107
Pm-144		
Pm-145		
Pm-146		
Pm-147		
Po-208		
Po-209		
Pt-190	Pt-190	Pt-190
Pt-193	Pt-193	Pt-193
Pu-236		
Pu-238		
Pu-239	Pu-239	
Pu-240		
Pu-241	Pu-241	Pu-241
Pu-242		
Pu-243		
Pu-246		
Ra-228		
Rb-87	Rb-87	Rb-87
Re-186m	Re-186m	Re-186m
Re-187	Re-187	Re-187
Rh-101		
Rh-102m		
Rn-218		
Ru-106		
Sb-125		
Se-79		
Si-32	Si-32	Si-32
Sm-145		
Sm-146		
Sm-147		
Sm-148		
Sm-151		
Sn-126		
Sr-90	Sr-90	Sr-90
Ta-179		
Tb-157		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	12.5
157	41	38
Tb-158		
Tc-97	Tc-97	Tc-97
Tc-98	Tc-98	Tc-98
Tc-99	Tc-99	Tc-99
Te-123		
Th-228		
Th-229		
Ti-44		
Tl-204		
Tl-210		
Tm-171		
U-232		
U-233		
U-234		
U-235	U-235	U-235
U-235m	U-235m	
U-237	U-237	U-237
U-238		
U-240		
V-49		
V-50		
Zr-93		

Table J-8. Tier-2 PorflowPS groundwater pathway SOF histogram for the NRCDAG disposal unit.

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	113	3	0	3	3	3	4	1	3	24
157	44	41	41	38	35	32	28	27	24	0
Ac-228	Ac-228									
Al-26	Al-26									
Am-241						Am-241				
Am-242	Am-242									
Am-242m	Am-242m									
Am-243	Am-243									
Am-245							Am-245			
Am-246m	Am-246m									
Ar-39										Ar-39
At-218	At-218									
Ba-133	Ba-133									
Bi-207	Bi-207									
Bi-208	Bi-208									
Bi-210m	Bi-210m									
Bk-247							Bk-247			
Bk-249										Bk-249
Bk-250	Bk-250									
C-14										C-14
Ca-41										Ca-41
Cd-109	Cd-109									
Cd-113										Cd-113
Cd-113m	Cd-113m									
Cf-248	Cf-248									
Cf-250	Cf-250									
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36					Cl-36					
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									

Tier-1	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	113	**3**	**0**	**3**	**3**	**3**	**4**	**1**	**3**	**24**
157	**44**	**41**	**41**	**38**	**35**	**32**	**28**	**27**	**24**	**0**
Cm-245		Cm-245								
Cm-246	Cm-246									
Cm-249							Cm-249			
Cm-250	Cm-250									
Co-57	Co-57									
Co-60	Co-60									
Co-60m	Co-60m									
Cs-134	Cs-134									
Cs-135					Cs-135					
Cs-137		Cs-137								
Dy-154	Dy-154									
Es-253									Es-253	
Es-254	Es-254									
Eu-150	Eu-150									
Eu-152	Eu-152									
Eu-154	Eu-154									
Fe-55	Fe-55									
Fe-60	Fe-60									
Fm-254	Fm-254									
Fm-257										Fm-257
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-152	Gd-152									
Ge-68	Ge-68									
H-3								H-3		
Hf-172	Hf-172									
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182	Hf-182									
Hg-194	Hg-194									
Ho-163	Ho-163									
Ho-166m	Ho-166m									
I-129										I-129
In-115	In-115									
Ir-192n	Ir-192n									
K-40										K-40
Kr-81										Kr-81
La-137	La-137									
La-138	La-138									
Lu-173	Lu-173									
Lu-174	Lu-174									
Lu-174m	Lu-174m									
Lu-176	Lu-176									
Mn-53										Mn-53
Mn-54	Mn-54									
Mo-93	Mo-93									
Na-22	Na-22									
Nb-91	Nb-91									
Nb-92	Nb-92									
Nb-93m	Nb-93m									
Nb-94	Nb-94									
Nd-144	Nd-144									
Ni-59										Ni-59
Ni-63										Ni-63
Np-235										Np-235
Np-236										Np-236
Np-237					Np-237					
Np-238	Np-238									
Np-239				Np-239						
Np-240	Np-240									
Np-240m	Np-240m									
Os-186	Os-186									

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	113	3	0	3	3	3	4	1	3	24
157	44	41	41	38	35	32	28	27	24	0
Os-194	Os-194									
Pa-232	Pa-232									
Pa-233	Pa-233									
Pb-202	Pb-202									
Pb-205	Pb-205									
Pb-210	Pb-210									
Pd-107										Pd-107
Pm-144	Pm-144									
Pm-145	Pm-145									
Pm-146	Pm-146									
Pm-147	Pm-147									
Po-208	Po-208									
Po-209	Po-209									
Pt-190										Pt-190
Pt-193										Pt-193
Pu-236	Pu-236									
Pu-238	Pu-238									
Pu-239				Pu-239						
Pu-240	Pu-240									
Pu-241						Pu-241				
Pu-242	Pu-242									
Pu-243		Pu-243								
Pu-246	Pu-246									
Ra-228	Ra-228									
Rb-87										Rb-87
Re-186m										Re-186m
Re-187										Re-187
Rh-101	Rh-101									
Rh-102m	Rh-102m									
Rn-218	Rn-218									
Ru-106	Ru-106									
Sb-125	Sb-125									
Se-79	Se-79									
Si-32										Si-32
Sm-145	Sm-145									
Sm-146	Sm-146									
Sm-147	Sm-147									
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-126	Sn-126									
Sr-90							Sr-90			
Ta-179	Ta-179									
Tb-157	Tb-157									
Tb-158	Tb-158									
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99									Tc-99	
Te-123	Te-123									
Th-228	Th-228									
Th-229	Th-229									
Ti-44	Ti-44									
Tl-204	Tl-204									
Tl-210	Tl-210									
Tm-171	Tm-171									
U-232	U-232									
U-233	U-233									
U-234	U-234									
U-235						U-235				
U-235m				U-235m						
U-237										U-237
U-238	U-238									
U-240	U-240									

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	113	3	0	3	3	3	4	1	3	24
157	44	41	41	38	35	32	28	27	24	0
V-49	V-49									
V-50	V-50									
Zr-93	Zr-93									

J.5 NRCDAS Model

Table J-9 and Table J-10 are the results for the NRCDAS model that apply to only the NRCDAS unit.

Table J-9. Tier-2 radionuclide listing for the NRCDAS disposal unit.

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	12.5
122	34	31
Ac-227		
Ag-108m		
Al-26		
Am-241	Am-241	Am-241
Am-242m		
Am-243		
Am-245	Am-245	Am-245
Am-246m		
Ar-39	Ar-39	Ar-39
Be-10	Be-10	Be-10
Bi-207		
Bi-208		
Bi-210m		
Bk-247	Bk-247	Bk-247
Bk-250		
C-14	C-14	C-14
Ca-41	Ca-41	Ca-41
Cd-113		
Cf-248		
Cf-250		
Cf-252		
Cf-253	Cf-253	Cf-253
Cl-36	Cl-36	Cl-36
Cm-242		
Cm-243		
Cm-244		
Cm-245	Cm-245	
Cm-246		
Cm-249	Cm-249	Cm-249
Cm-250		
Cs-135		
Cs-137		
Dy-154		
Es-253	Es-253	Es-253
Es-254		
Eu-150		
Fe-60		
Fm-254		
Fm-257	Fm-257	Fm-257
Gd-148		
Gd-150		
Gd-152		
Hf-174		
Hf-178m		

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	12.5
122	34	31
Hf-182		
Hg-194		
Ho-163		
Ho-166m		
I-129	I-129	I-129
In-115		
Ir-192n		
K-40	K-40	K-40
Kr-81	Kr-81	Kr-81
La-137		
La-138		
Lu-176		
Mn-53		
Mo-93		
Nb-91		
Nb-92		
Nb-94		
Nd-144		
Ni-59	Ni-59	Ni-59
Ni-63	Ni-63	Ni-63
Np-235	Np-235	Np-235
Np-236	Np-236	Np-236
Np-237	Np-237	Np-237
Np-238		
Np-240		
Np-240m		
Os-186		
Pa-231	Pa-231	Pa-231
Pa-232		
Pa-233		
Pa-234		
Pb-202		
Pb-210		
Pd-107		
Pm-146		
Po-208		
Po-209		
Pt-190	Pt-190	Pt-190
Pu-236		
Pu-238		
Pu-239	Pu-239	
Pu-240		
Pu-241	Pu-241	Pu-241
Pu-242		
Pu-243		
Pu-246		
Ra-226		
Rb-87	Rb-87	Rb-87
Re-186m	Re-186m	Re-186m
Re-187	Re-187	Re-187
Se-79		
Si-32	Si-32	Si-32
Sm-146		
Sm-147		
Sm-148		
Sm-151		
Sn-121m		
Sn-126		
Sr-90		
Tb-157		
Tb-158		
Tc-97	Tc-97	Tc-97

Tier-1	PorflowPS	PorflowPS
Pathway	GW	GW
w_d	0	12.5
122	34	31
Tc-98	Tc-98	Tc-98
Tc-99	Tc-99	Tc-99
Te-123		
Th-229		
Th-230		
Th-232		
Ti-44		
U-233		
U-234		
U-235	U-235	U-235
U-235m	U-235m	
U-236		
U-238		
U-240		
V-50		
Zr-93		

Table J-10. Tier-2 PorflowPS groundwater pathway SOF histogram for the NRCDAS disposal unit.

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	1	0	3	2	1	3	1	7	17
122	35	34	34	31	29	28	25	24	17	0
Ac-227	Ac-227									
Ag-108m	Ag-108m									
Al-26	Al-26									
Am-241									Am-241	
Am-242m	Am-242m									
Am-243	Am-243									
Am-245							Am-245			
Am-246m	Am-246m									
Ar-39										Ar-39
Be-10					Be-10					
Bi-207	Bi-207									
Bi-208	Bi-208									
Bi-210m	Bi-210m									
Bk-247							Bk-247			
Bk-250	Bk-250									
C-14										C-14
Ca-41										Ca-41
Cd-113	Cd-113									
Cf-248	Cf-248									
Cf-250	Cf-250									
Cf-252	Cf-252									
Cf-253									Cf-253	
Cl-36									Cl-36	
Cm-242	Cm-242									
Cm-243	Cm-243									
Cm-244	Cm-244									
Cm-245				Cm-245						
Cm-246	Cm-246									
Cm-249							Cm-249			
Cm-250	Cm-250									
Cs-135	Cs-135									
Cs-137	Cs-137									
Dy-154	Dy-154									
Es-253									Es-253	
Es-254	Es-254									
Eu-150	Eu-150									

Tier-1	SOF bins									
	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01	1.E+00	1.E+01	1.E+02	>
	87	1	0	3	2	1	3	1	7	17
122	35	34	34	31	29	28	25	24	17	0
Fe-60	Fe-60									
Fm-254	Fm-254									
Fm-257										Fm-257
Gd-148	Gd-148									
Gd-150	Gd-150									
Gd-152	Gd-152									
Hf-174	Hf-174									
Hf-178m	Hf-178m									
Hf-182	Hf-182									
Hg-194	Hg-194									
Ho-163	Ho-163									
Ho-166m	Ho-166m									
I-129									I-129	
In-115	In-115									
Ir-192n	Ir-192n									
K-40										K-40
Kr-81										Kr-81
La-137	La-137									
La-138	La-138									
Lu-176	Lu-176									
Mn-53	Mn-53									
Mo-93	Mo-93									
Nb-91	Nb-91									
Nb-92	Nb-92									
Nb-94	Nb-94									
Nd-144	Nd-144									
Ni-59										Ni-59
Ni-63									Ni-63	
Np-235										Np-235
Np-236										Np-236
Np-237								Np-237		
Np-238	Np-238									
Np-240	Np-240									
Np-240m	Np-240m									
Os-186	Os-186									
Pa-231										Pa-231
Pa-232	Pa-232									
Pa-233	Pa-233									
Pa-234	Pa-234									
Pb-202	Pb-202									
Pb-210	Pb-210									
Pd-107	Pd-107									
Pm-146	Pm-146									
Po-208	Po-208									
Po-209	Po-209									
Pt-190										Pt-190
Pu-236	Pu-236									
Pu-238	Pu-238									
Pu-239				Pu-239						
Pu-240	Pu-240									
Pu-241									Pu-241	
Pu-242	Pu-242									
Pu-243		Pu-243								
Pu-246	Pu-246									
Ra-226	Ra-226									
Rb-87						Rb-87				
Re-186m										Re-186m
Re-187										Re-187
Se-79	Se-79									
Si-32										Si-32
Sm-146	Sm-146									
Sm-147	Sm-147									

Tier-1	**SOF bins**									
	1.E-06	**1.E-05**	**1.E-04**	**1.E-03**	**1.E-02**	**1.E-01**	**1.E+00**	**1.E+01**	**1.E+02**	**>**
	87	**1**	**0**	**3**	**2**	**1**	**3**	**1**	**7**	**17**
122	**35**	**34**	**34**	**31**	**29**	**28**	**25**	**24**	**17**	**0**
Sm-148	Sm-148									
Sm-151	Sm-151									
Sn-121m	Sn-121m									
Sn-126	Sn-126									
Sr-90	Sr-90									
Tb-157	Tb-157									
Tb-158	Tb-158									
Tc-97										Tc-97
Tc-98										Tc-98
Tc-99										Tc-99
Te-123	Te-123									
Th-229	Th-229									
Th-230	Th-230									
Th-232	Th-232									
Ti-44	Ti-44									
U-233	U-233									
U-234	U-234									
U-235					U-235					
U-235m				U-235m						
U-236	U-236									
U-238	U-238									
U-240	U-240									
V-50	V-50									
Zr-93	Zr-93									

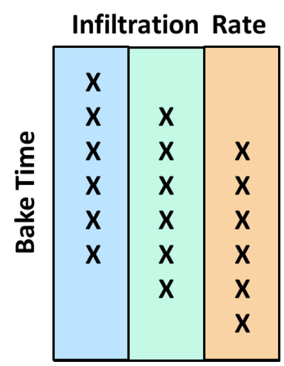
Appendix K. PORFLOW Vadose Zone Confirmation Results

In this appendix the NCRP Matrix approach is confirmed by comparing PORFLOW-based 1D vadose zone modeling results to the more realistic transient infiltration rates employed in the downstream limits system analyses. (i.e., the Tier-3 and Tier-4 analysis approaches). In the NCRP123 Tier-1 methodology only the waste and aquifer zones are modeled explicitly (i.e., the 2 box models described within Appendix A and Appendix B). In the NRCDWSM Tier-1 methodology the waste zone, vadose zone, and aquifer zone are modeled explicitly (i.e., the 3 box models described within Appendix A and Appendix B).

The Tier-2 approach chosen in this report is a hybrid model where the waste zone and vadose zones are being handled explicitly by PORFLOW 1D fate and transport calculations. The computed fluxes to the watertable then become input into a 1 box model for the aquifer as discussed in Appendix A (i.e., the PorflowPS model). This Tier-2 approach employs the Tier-1 radionuclide listings generated from the NCRP123 Tier-1 methodology.

K.1 The NCRP Matrix

The methodology employed in the GW screening process accommodates a range of bake times and DU infiltration rates. As provided in Chapter 3.0 for each DU type a matrix of bake times versus infiltration rates is considered. These bake times versus infiltration rates are related through conservative travel times from each DU to the 100-m POA (see Appendix F for details). The NCRP matrix has the form:



where extreme parameter combinations were not considered (i.e., a partially populated matrix). For each infiltration rate a corresponding water saturation value was required and was computed based on PORFLOW flow runs. To illustrate the matrix and accompanying water saturation values employed for the DU Trench type, a listing of its values is provided in Table K-1. The range of infiltration rates considered span the entire range of possible infiltration rates (i.e., a completely intact cover over a DU to the completely uncovered situation). The basis for an uncovered infiltration rate of ~40 cm/yr can be found in McDowell-Boyer et al. (2000, see Section C.1.1.1).

Table K-1. Tier-1 and Tier-2 NCRP Matrix for the Trenches disposal type.

Scenario ID	Infiltration (cm/yr)	Bake-Time (yr)	Water Saturation (-)
1	0.0035	1071	0.636
2	0.0035	1100	0.636
3	10	34	0.7217
4	10	50	0.7217
5	10	100	0.7217
6	10	200	0.7217
7	10	300	0.7217
8	10	400	0.7217
9	10	500	0.7217
10	10	600	0.7217
11	10	700	0.7217
12	10	800	0.7217
13	10	900	0.7217
14	10	1000	0.7217
15	10	1100	0.7217
16	40.5	13	0.77
17	40.5	50	0.77
18	40.5	100	0.77
19	40.5	200	0.77
20	40.5	300	0.77
21	40.5	400	0.77
22	40.5	500	0.77
23	40.5	600	0.77
24	40.5	700	0.77
25	40.5	800	0.77
26	40.5	900	0.77
27	40.5	1000	0.77
28	40.5	1100	0.77

As shown in Table K-1, a total of 28 case runs are considered over a broad range of bake times and infiltration rate values.

For every bake time-infiltration rate combination, a GW screening calculation was performed followed by dose analyses. For every DU type and parent radionuclide of interest, its max SOF per dose pathway was determined. From these computed max SOF values, bounding inventories, and dose criteria applied at the 100-m POA, each parent radionuclide was either filtered out of the list or passed on to the next higher tier level (i.e., Tier-1 to Tier-2 and beyond).

In the Tier-2 processing scheme the degree of conservatism is reduced from its level in the Tier-1 scheme. Here the fate and transport aspects within the vadose zone are included where PORFLOW-based transport simulations are included. In this appendix the details associated with the PORFLOW-based vadose zone transport runs are discussed. These Tier-2 flux-to-watertable results are compared to the original Tier-1 values to confirm the overall strategy.

The approach taken is highlighted by focusing in on the Trenches DU type and only showing flux-to-watertable plots for a limited list of parent nuclides.

K.2 PORFLOW-based 1D Vadose Zone Model

A PORFLOW 1D model (that explicitly includes waste and vadose zones) was created for each DU type for computing fluxes to the watertable. The geometrical configurations were made identical to the configurations employed in the Tier-1 set of analyses (i.e., specifically, the vertical travel distances were set consistent with those employed in computing travel times as discussed in Appendix F). For example, the vertical geometry employed for the Trenches DU type is given in Figure K-1. The thicknesses and number of PORFLOW cells employed are listed as well (i.e., the vertical distance from the bottom of the waste zone to the watertable was set equal to the average distance of all trench unit in E-Area).

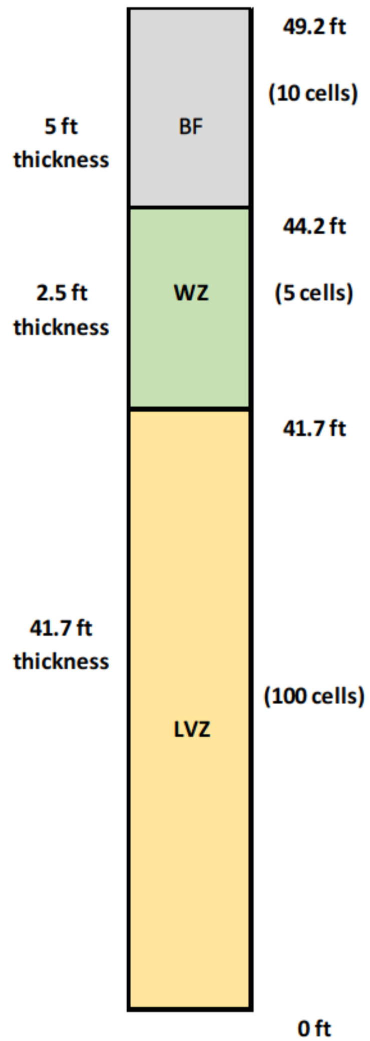


Figure K-1. Vertical geometry of PORFLOW-based vadose zone model for the Trenches disposal type.

Three material zones were included:

- **Backfill zone (BF)** – not explicitly required but employed to better handle numerical back diffusion in the PORFLOW model;
- **Waste zone (WZ)** – only the collapsed waste zone height employed to be consistent with the original Tier-1 analyses; and
- **Lower Vadose Zone (LVZ)** – only sandy material beneath the WZ is considered to be consistent with the Tier-1 analyses.

To be consistent with the original Tier-1 material properties, the hydraulic and chemical properties employed in the PORFLOW-based vadose zone models were all set to the sandy soil properties of the LowerVadoseZone material type as defined in the hydraulic data package.

During the bake time periods the buried inventory (i.e., uniformly placed within the WZ) is fixed within the WZ by using a very large K_d value for every chain member (i.e., $1x10^{20}$ ml/g). The burial time was set to time 0 while the bake and run times were consistent with the original Tier-1 analyses.

K.3 PORFLOW-based Flux-to-Watertable Results for the NCRP Matrix

PORFLOW-based vadose zone runs for all 28 scenarios listed in Table K-1 were made for all of the Tier-1 radionuclide listings. Below, for the Trenches DU type, a short list of parent radionuclides (including a tracer) are presented that are representative of the overall observed behavior obtained. For each parent radionuclide a "worst case" (WC) is also shown (i.e., black dashed curve) that is employed in the subsequent dose analyses efforts. Also, the curves shown Are color-coded to be consistent with the color-coded shown in Table K-1.

The list of nuclides presented span a broad range of half-lives and K_d values, as listed in Table K-2. These radionuclides are the typical ones that generally show up throughout the DOE complex and as shown in this report are not filtered out during either Tier-1 or Tier-2 processing.

Table K-2. Key properties for the short list of nuclides presented.

Radionuclide (ID)	Half-life (yr)	Sand Kd (ml/g)
C-14	5700	1.0
H-3	12.32	0.0
I-129	1.57E+07	1.0
Sr-90	28.79	5.0
Tc-99	2.11E+05	0.6
Tracer	>1e20	0.0

In Figure K-2 the results for a "conservative" tracer are shown. Given the long-lived and unretarded aspects of a tracer, the results highlight the key aspects associated with the bake time delays of each flux peak while the magnitudes of these peaks are reflected by the infiltration rate differences.

For example, as the infiltration rate is increased the leaching rate, as shown by Eq. (A-12) increases. Also, for increased infiltration rates the time to reach a flux peak is reduced. Thus, for higher infiltration rates and for long-lived radionuclides, higher flux to the watertable peaks are observed as shown in Figure K-2. With insignificant decay occurring, the flux peak values for a given infiltration rate will be essentially the same value.

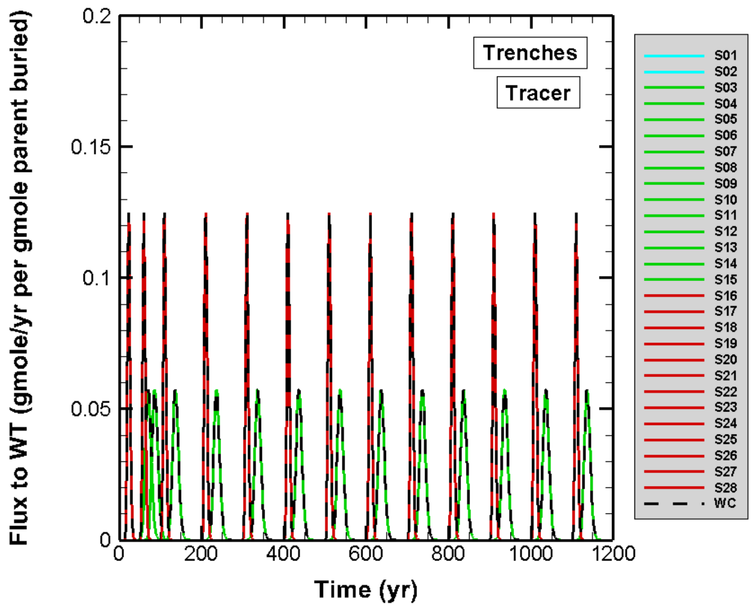


Table K-2

Figure K-2. Flux to watertable for a tracer in the Trenches disposal unit based on the NCRP Matrix conditions.

When viewing the results for C-14, as shown in Figure K-3, only a slight reduction in flux peak occurs as bake time is extended.

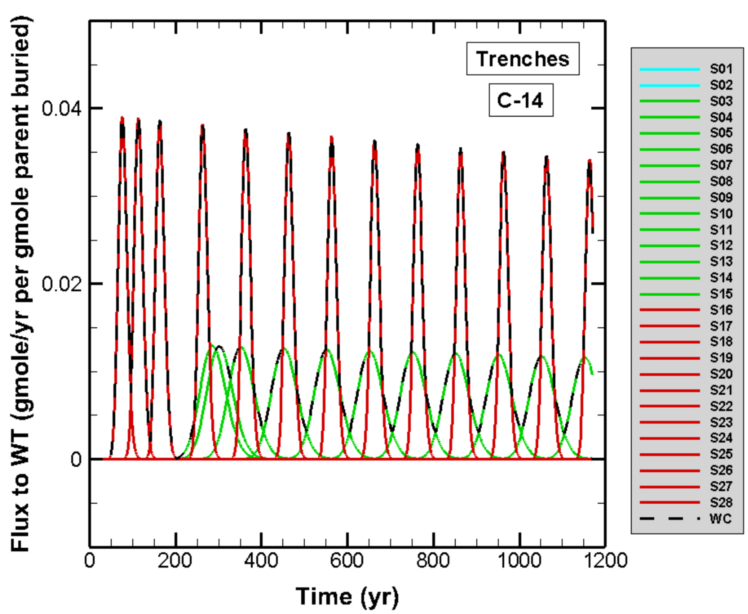


Figure K-3. Flux to watertable for C-14 in the Trenches disposal unit based on the NCRP Matrix conditions.

For H-3 the short half-life results in a significant drop in flux peak with increasing bake time as shown in Figure K-4. Thus, engineering barriers that delay the release of H-3 can have significant beneficial impacts.

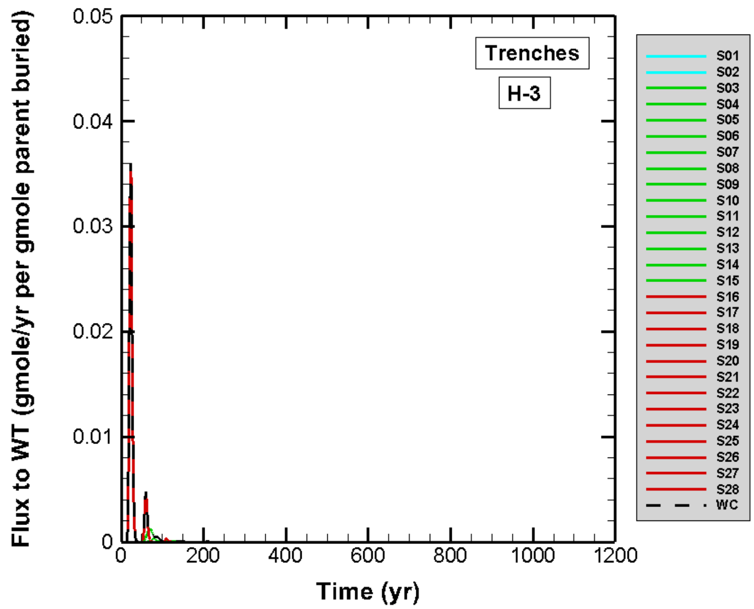


Figure K-4. Flux to watertable for H-3 in the Trenches disposal unit based on the NCRP Matrix conditions.

For I-129, a long-lived and only slightly retarded, the results are very similar in shape to a tracer.

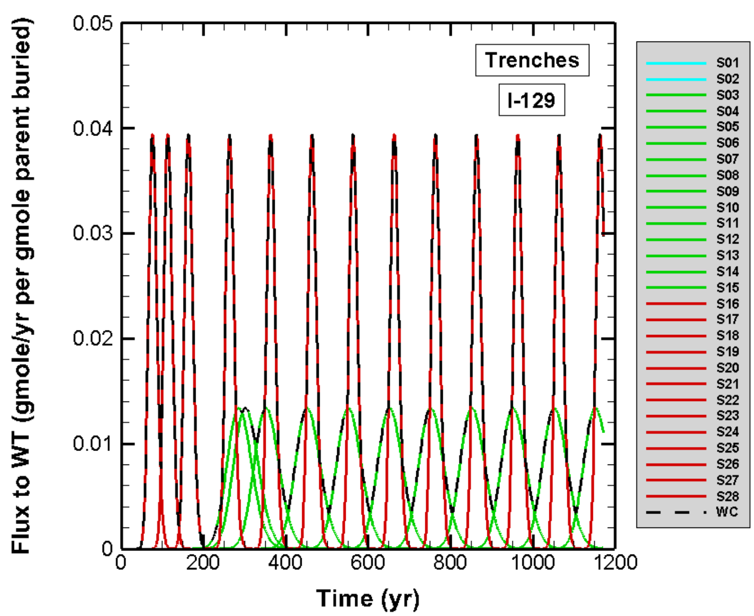


Figure K-5. Flux to watertable for I-129 in the Trenches disposal unit based on the NCRP Matrix conditions.

For Sr-90, unique in that it has both mid-range values for half-live and K_d, its behavior varies depending upon the infiltration rate. For example, for the infiltration rates of 0.0035 and 10.0 cm/yr little dependence is observed with respect to varying bake times. While for the infiltration rate of 40.5 cm/yr a modest shift in flux peak is seen.

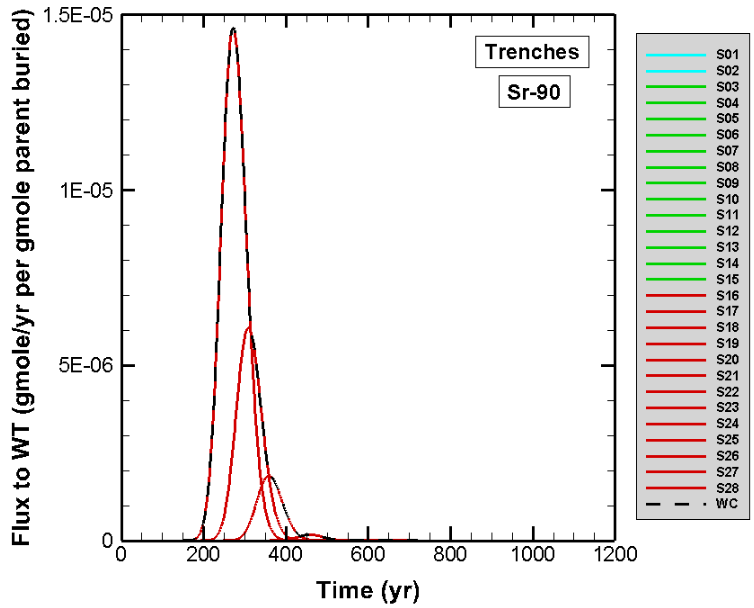


Figure K-6. Flux to watertable for Sr-90 in the Trenches disposal unit based on the NCRP Matrix conditions.

For Tc-99, again a long-lived and fairly unretarded, shows very similar behavior as a tracer in its shapes.

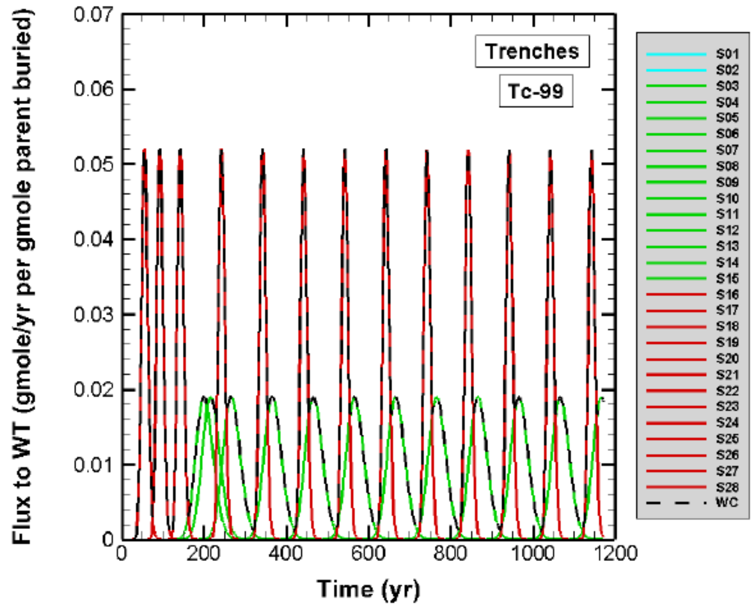


Figure K-7. Flux to watertable for Tc-99 in the Trenches disposal unit based on the NCRP Matrix conditions.

K.4 Time Dependent Infiltration Rates

Infiltration rates vary throughout the entire compliance period as a result of being:

- Uncovered during operational periods;
- Operational covers for STs once filled but not yet at the EIC;
- Interim covered that are maintained throughout the IC period;
- Intact final cover (cap) that is no longer maintained and degrades over time to background conditions; and
- Subsidence of an intact cover conservatively assumed to occur at the EIC and represented geometrically by placement at various trench locations.

Note that for subsidence conditions to occur it requires the existence of "non-crushable" containers within a trench unit. Non-crushable containers are considered to be waste containers that are structurally strong enough to withstand dynamic compaction just prior to placement of the final cover. It is assumed that all of these non-crushable containers are located together and all fail at the same time and that failure occurs right after placement of the final cover at the EIC. In the PA2008 analyses a limit of 10% non-crushable containers was allowed within a given trench DU. In the upcoming PA2022 this limit is being reduced to 2%.

In Figure K-8, a comparison is provided for the infiltration rates over time for the various conditions listed above.

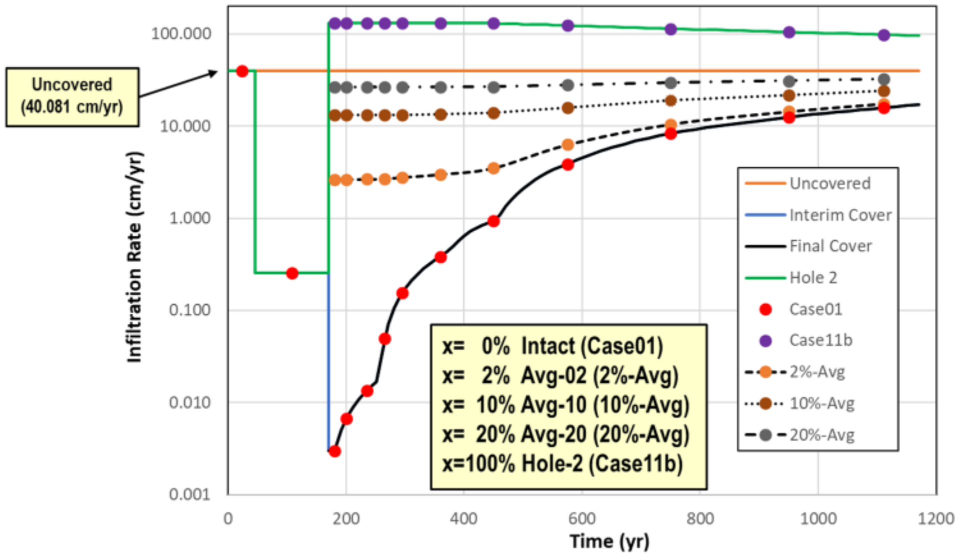


Figure K-8. Infiltration rates for trenches under various conditions.

The subsidence curves represent the average infiltration rate obtained when x% of the DU has subsided:

$$\langle I_x \rangle = x \times I_{Hole-2} + (1-x) \times I_{intact} \tag{K-1}$$

where

$\langle I_x \rangle$ .... area average infiltration rate with x% subsidence (cm/yr)
x .... area fraction of subsidence (-)
I_{Hole-2} .... infiltration rate within Hole-2 geometry (cm/yr)
I_{intact} .... infiltration rate for intact conditions (cm/yr)

In Figure K-8 five different subsided cases are shown:

- 0% - a trench unit with no non-crushable present;
- 2% - the limit on non-crushable containers for the upcoming PA2022;
- 10% - the limit on non-crushable containers for the PA2008;
- 20% - an upper bound on non-crushable containers; and
- 100% - actual infiltration rate within a hole 2 geometry.

The bottom curve represents the intact cover over time. Within the "Limits System" a range of possible subsided situations are addressed. This is accomplished by employing both an intact scenario (i.e., zero subsidence) and an upper bound operational constraint on placement of non-crushable containers (i.e., 2% for the upcoming PA2022). The need to only consider just the two end points of the range results from the fact that the fate and transport equations are linear ODEs.

K.5 PORFLOW-based Flux-to-Watertable Results for Time Dependent Infiltration Rate

To assist in confirming that the above NCRP Matrix method yields relatively conservative flux-to-watertable results, additional PORFLOW-based 1D vadose zone transport runs were made. All parameter settings employed in the above sections is employed here except the constant value of infiltration rate is now replaced with time varying values in each run considered. The five transient infiltration rate cases described above were employed and PORFLOW-based 1D vadose zone transport runs were made. The results of these runs, along with a comparison to the NCRP Matrix worst case results, are shown in Figure K-9 through Figure K-14 for the short list of nuclides in Table K-2.

For a tracer, as shown in Figure K-9, the peak fluxes for all five transient infiltration cases are close in value to those for the NCRP Matrix cases.

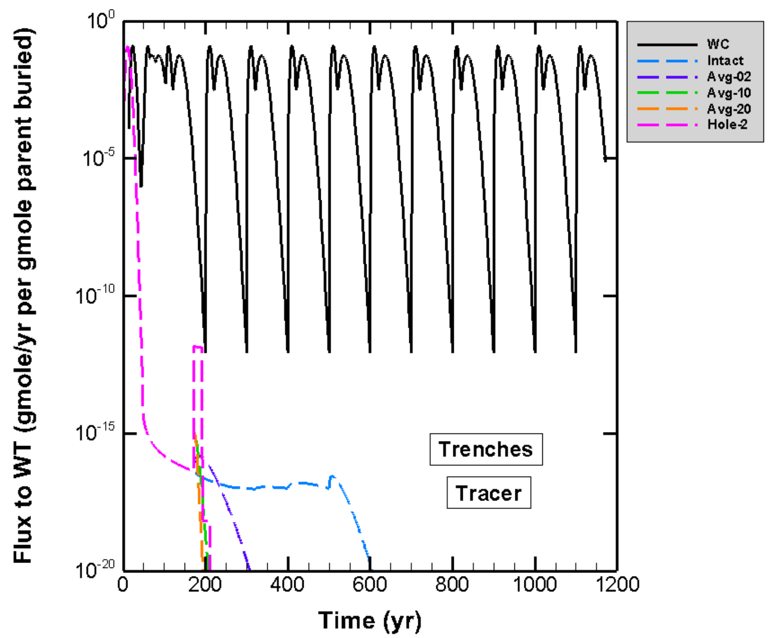


Figure K-9. Flux to watertable for a tracer in the Trenches disposal unit based on transient infiltration conditions.

For C-14, as shown in Figure K-10, only the peak flux for the Hole-2 transient infiltration case exceeds those for the NCRP Matrix cases.

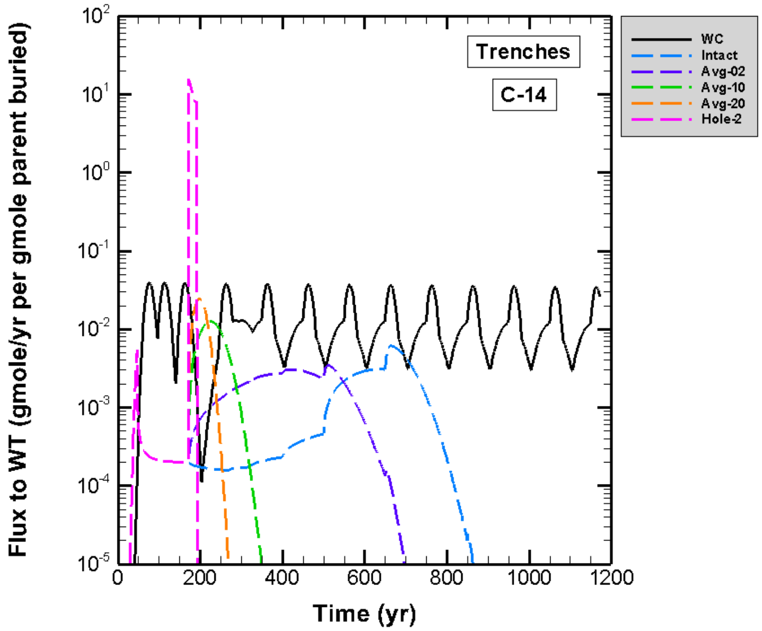


Figure K-10. Flux to watertable for C-14 in the Trenches disposal unit based on transient infiltration conditions.

For H-3, as shown in Figure K-11, the peak flux for all five transient infiltration cases are just slightly higher in value than those for the NCRP Matrix cases.

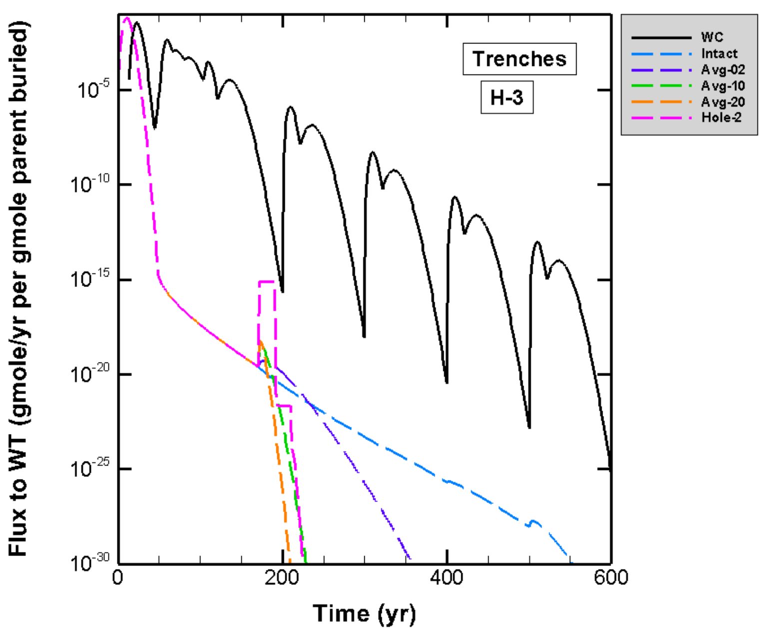


Figure K-11. Flux to watertable for H-3 in the Trenches disposal unit based on transient infiltration conditions.

For I-129, as shown in Figure K-12, only the peak flux for the Hole-2 transient infiltration case exceeds those for the NCRP Matrix cases.

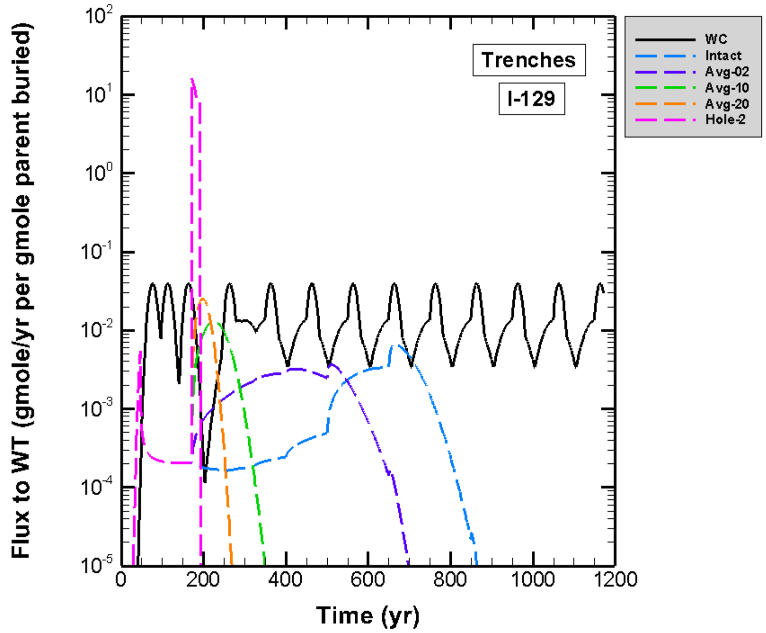


Figure K-12. Flux to watertable for I-129 in the Trenches disposal unit based on transient infiltration conditions.

For Sr-90, as shown in Figure K-13, only the peak flux for the Hole-2 transient infiltration case exceeds those for the NCRP Matrix cases.

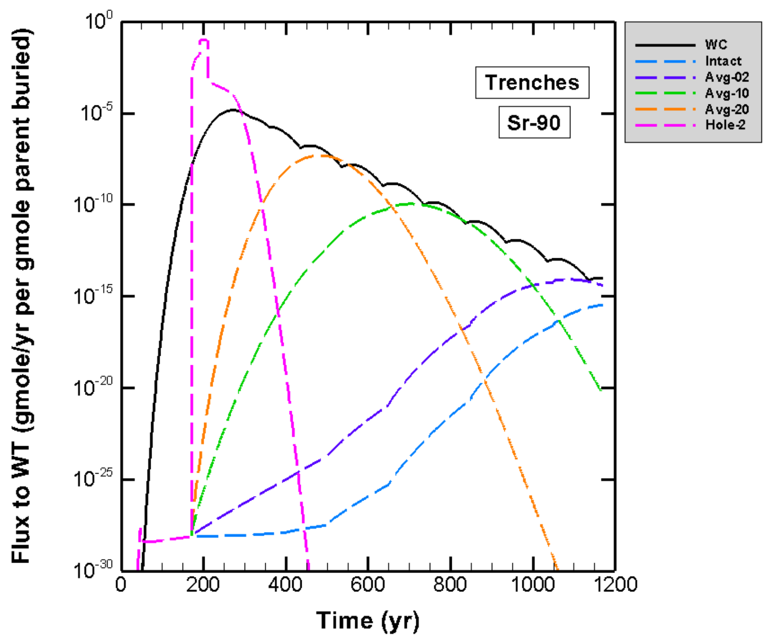


Figure K-13. Flux to watertable for Sr-90 in the Trenches disposal unit based on transient infiltration conditions.

For Tc-99, as shown in Figure K-14, only the peak flux for the Hole-2 transient infiltration case exceeds those for the NCRP Matrix cases.

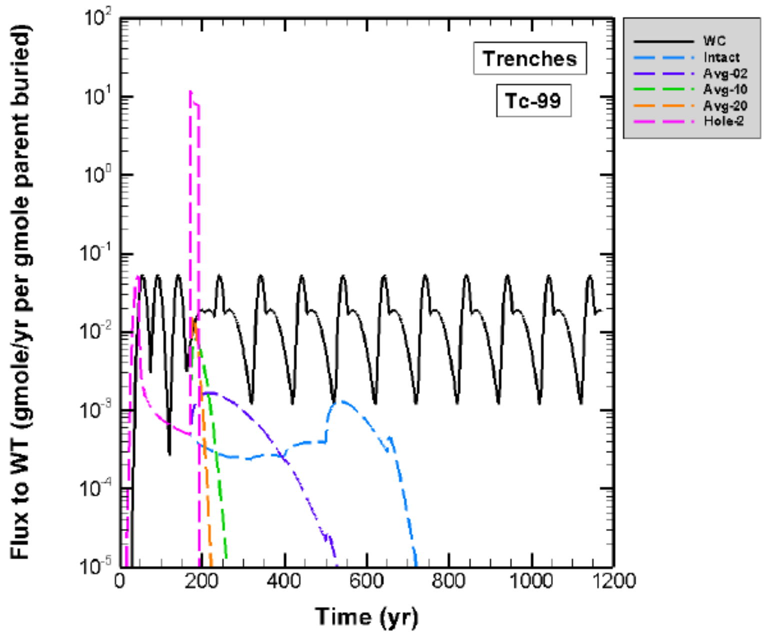


Figure K-14. Flux to watertable for Tc-99 in the Trenches disposal unit based on transient infiltration conditions.

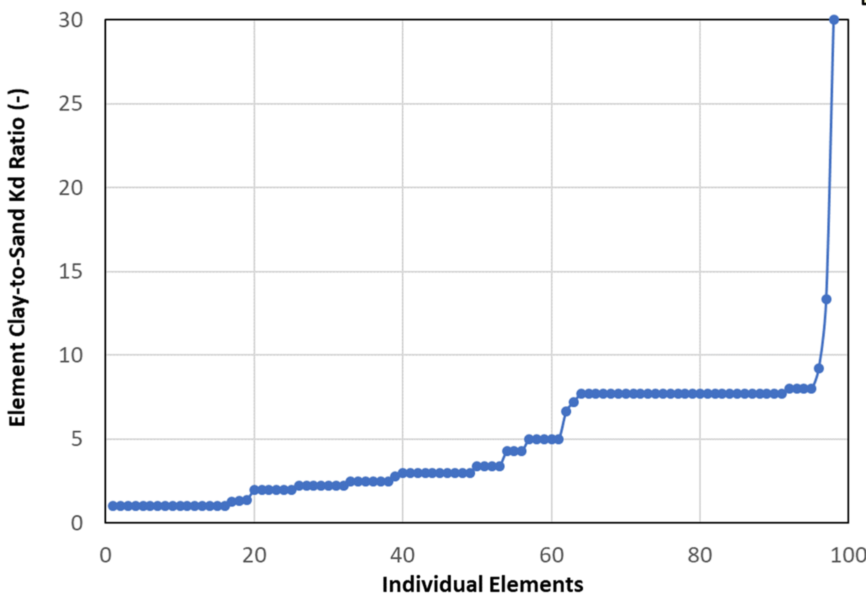
K.6 Confirmation of NCRP Matrix Approach

In this appendix PORFLOW-based 1D vadose zones models were employed to assess (and confirm) the validity of using the NCRP Matrix approach. The NCRP Matrix approach is based on using a baking time then leaching model for waste zone releasing where a time invariant infiltration rate is assumed. Here both baking time and infiltration rates are limited/coupled due to the finite time required to transport from the waste zone to the 100-m POA.

To verify that this matrix approach is acceptable PORFLOW-based 1D vadose zone (that included the waste zone) modeling was performed for comparison to the NCRP Matrix approach results. As shown in Figure K-9 through Figure K-14, the Matrix approach is basically conservative except for some mobile radionuclides where their transient peak fluxes were slightly higher than their corresponding values using the Matrix approach.

A graphic and listing of the mobile radionuclides within the Tier-1 listing for the Trenches DU type is provided in Figure K-15, along with their sandy and clayey K_d values. As shown in Figure K-15:

- All elemental clay-to-sand K_d values are equal to or greater than one; and
- The majority of elements have K_d values greater than one.



List of Mobiles (Sand K_d < 1)

Element Name	Best Sand Kd (ml/g)	Best Clay Kd (ml/g)
Ar	0.0	0.0
H	0.0	0.0
Kr	0.0	0.0
Ne	0.0	0.0
O	0.0	0.0
Rn	0.0	0.0
Si	0.0	0.0
Xe	0.0	0.0
Tracer	0.0	0.0
Re	0.6	1.8
Ru	0.6	1.8
Tc	0.6	1.8
At	1.0	3.0
Br	1.0	8.0
C	1.0	30.0
Cl	1.0	8.0
F	1.0	8.0
I	1.0	3.0
N	1.0	8.0

Figure K-15. Elemental Clay-to-Sand K_d ratios for all 97 elements contained within the Tier-1 listing for the trench disposal unit type.

Within both the Tier-1 and Tier-2 screening processes, the waste zone properties were conservatively set to those for sandy material. For the mobile radionuclides (as listed on the right side of Figure K-15), those with zero K_d values are highlighted in light orange where four of them are noble gases. H-3 is the only mobile of potential concern here and is not filtered out of the Tier-2 list for other conditions. Thus, the PORFLOW-based 1D vadose modeling based on the NCRP Matrix approach is confirmed with respect to the results obtained using the more realistic transient infiltration rates.

Appendix L. Potential Post-Analysis Radionuclide Listing Reductions

During the Tier-1 and Tier-2 set of analyses, a host of information was computed and then dumped to output files for potential use. For example, in Table L-1 key information associated with the Max SOF status for every radionuclide with the Tier-1 list for Trenches is provided for review. In Table L-1 the binning of max SOF for each radionuclide is provided along with its half-life, the inventory employed, and how the inventory value was established. In Table L-1 the sources employed for establishing the upper bound inventories are highlighted by shading where:

1	**Gamma weighting**
2	**WITS Projections**
3	**Box weight**
4	**1.0E+07**

Table L-1. Key Max SOF information for the Tier-1 radionuclide list for the Trenches disposal unit type.

Nuclide List	SOF < 0.000001	SOF < 0.00001	SOF < 0.0001	SOF < 0.001	SOF < 0.01	SOF < 0.1	SOF < 1	SOF < 10	SOF < 100	SOF > 100	Max SOF	Halflife (yr)	Inventory (Ci)	Inventory Flag
163	113	3	1	3	3	6	3	1	4	26	-	-	-	-
-	50	47	46	43	40	34	31	30	26	0	-	-	-	-
Ac-227	Ac-227										2.63E-144	2.18E+01	4.01E-03	2
Ag-108m										Ag-108m	9.72E+03	4.18E+02	6.09E+01	2
Am-241										Am-241	1.25E+02	4.32E+02	2.12E+01	2
Am-242m		Am-242m									2.88E-06	1.41E+02	4.09E+00	2
Am-243		Am-243									2.45E-06	7.37E+03	1.74E+00	2
Am-245						Am-245					1.58E-02	2.34E-04	2.38E+05	1
Am-246m	Am-246m										1.22E-22	4.75E-05	6.06E+03	1
At-218	At-218										8.67E-170	4.75E-08	7.37E+05	1
Au-195	Au-195										1.54E-91	5.10E-01	3.09E+05	1
Ba-133	Ba-133										9.54E-20	1.05E+01	3.28E-03	2
Be-10						Be-10					1.03E-02	1.51E+06	2.17E-05	2
Bi-208	Bi-208										7.92E-124	3.68E+05	2.81E+03	1
Bi-210m	Bi-210m										4.13E-121	3.04E+06	2.13E+04	1
Bk-247	Bk-247										1.21E-14	1.38E+03	3.99E-07	2
Bk-249										Bk-249	1.01E+03	9.03E-01	1.00E+07	4
Bk-250	Bk-250										6.82E-22	3.66E-04	6.57E+03	1
C-14										C-14	3.09E+04	5.70E+03	7.81E+01	2
Cd-113m	Cd-113m										1.23E-11	1.41E+01	2.96E+00	2
Cf-248	Cf-248										2.23E-44	9.14E-01	1.00E+07	4
Cf-249						Cf-249					3.83E-02	3.51E+02	9.69E-01	2
Cf-250	Cf-250										2.78E-21	1.31E+01	7.50E-01	2
Cf-251	Cf-251										2.35E-13	9.00E+02	8.80E-01	2
Cf-252	Cf-252										1.73E-61	2.65E+00	1.05E-01	2
Cf-253									Cf-253		5.49E+01	4.88E-02	1.00E+07	4
Cl-36							Cl-36				8.18E-01	3.01E+05	7.00E-04	2
Cm-242	Cm-242										2.47E-11	4.46E-01	1.65E-03	2
Cm-243	Cm-243										6.97E-09	2.91E+01	4.21E-02	2
Cm-244	Cm-244										1.94E-48	1.81E+01	4.35E+01	2
Cm-245						Cm-245					3.75E-02	8.50E+03	1.56E-02	2
Cm-246	Cm-246										1.48E-20	4.76E+03	7.33E-03	2
Cm-247	Cm-247										1.14E-09	1.56E+07	3.41E-02	2
Cm-248	Cm-248										1.09E-57	3.48E+05	4.73E-03	2
Cm-249					Cm-249						4.03E-03	1.22E-04	2.94E+05	1
Cm-250	Cm-250										2.46E-14	8.30E+03	1.00E+07	4
Co-60	Co-60										7.09E-58	5.27E+00	6.11E-02	3
Co-60m	Co-60m										7.93E-56	1.99E-05	1.81E+06	1
Cs-134	Cs-134										5.13E-44	2.06E+00	2.08E+00	2
Cs-135						Cs-135					2.15E-02	2.30E+06	9.58E-05	2
Cs-137										Cs-137	2.37E+02	3.02E+01	4.42E+04	2

Nuclide List	SOF < 0.000001	SOF < 0.00001	SOF < 0.0001	SOF < 0.001	SOF < 0.01	SOF < 0.1	SOF < 1	SOF < 10	SOF < 100	SOF > 100	Max SOF	Halflife (yr)	Inventory (Ci)	Inventory Flag
163	113	3	1	3	3	6	3	1	4	26	-	-	-	-
-	50	47	46	43	40	34	31	30	26	0	-	-	-	-
Dy-154	Dy-154										1.94E-118	3.00E+06	1.00E+07	4
Es-253									Es-253		6.31E+01	5.60E-02	1.00E+07	4
Es-254	Es-254										1.15E-15	7.55E-01	5.54E+06	1
Eu-150	Eu-150										7.98E-134	3.69E+01	3.65E+03	1
Eu-152	Eu-152										6.02E-137	1.35E+01	8.87E+01	2
Eu-154	Eu-154										1.61E-165	8.59E+00	2.24E+02	2
Eu-155	Eu-155										6.77E-193	4.76E+00	1.91E+01	2
Fe-55	Fe-55										2.69E-143	2.74E+00	3.69E+02	2
Fe-60	Fe-60										8.07E-39	1.50E+06	1.00E+07	4
Fm-254	Fm-254										1.05E-18	3.70E-04	1.00E+07	4
Fm-257										Fm-257	3.09E+02	2.75E-01	1.00E+07	4
Gd-148	Gd-148										1.74E-123	7.46E+01	1.00E+07	4
Gd-150	Gd-150										1.94E-118	1.79E+06	1.00E+07	4
Gd-152	Gd-152										1.94E-118	1.08E+14	1.00E+07	4
Gd-153	Gd-153										1.48E-278	6.58E-01	2.52E+05	1
Ge-68	Ge-68										1.07E-262	7.42E-01	1.00E+07	4
H-3										H-3	3.27E+05	1.23E+01	1.15E+05	2
Hf-172	Hf-172										1.49E-221	1.87E+00	3.08E+05	1
Hf-174	Hf-174										7.59E-110	2.00E+15	1.00E+07	4
Hf-178m	Hf-178m										2.01E-126	3.10E+01	5.93E+03	1
Hf-182	Hf-182										3.41E-113	9.00E+06	2.43E+04	1
Hg-194	Hg-194										2.33E-107	4.40E+02	1.00E+07	4
Ho-163	Ho-163										6.50E-123	4.57E+03	1.00E+07	4
I-129										I-129	1.35E+05	1.57E+07	1.65E-01	2
In-115	In-115										9.70E-120	4.41E+14	1.00E+07	4
Ir-192n	Ir-192n										3.34E-112	2.41E+02	1.00E+07	4
K-40										K-40	1.03E+02	1.25E+09	4.12E-02	2
Kr-81										Kr-81	1.48E+04	2.29E+05	6.60E+06	1
La-137	La-137										2.16E-121	6.00E+04	1.00E+07	4
La-138	La-138										1.36E-123	1.02E+11	5.04E+03	1
Lu-173	Lu-173										5.75E-246	1.37E+00	6.13E+04	1
Lu-174	Lu-174										3.88E-206	3.31E+00	8.97E+04	1
Lu-174m	Lu-174m										2.91E-206	3.89E-01	5.08E+05	1
Lu-176	Lu-176										5.88E-123	3.85E+10	1.24E+04	1
Mn-53										Mn-53	5.66E+07	3.70E+06	1.00E+07	4
Mn-54	Mn-54										8.09E-89	8.55E-01	9.98E+00	2
Mo-93	Mo-93										2.15E-123	4.00E+03	2.52E-01	2
Na-22	Na-22										1.30E-26	2.60E+00	7.65E-04	2
Nb-91	Nb-91										1.40E-118	6.80E+02	3.39E+06	1
Nb-92	Nb-92										1.15E-119	3.47E+07	3.80E+03	1
Nb-93m	Nb-93m										7.45E-146	1.61E+01	1.62E+00	2
Nb-94	Nb-94										8.40E-123	2.03E+04	1.64E+00	2
Nd-144	Nd-144										1.94E-118	2.29E+15	1.00E+07	4
Ni-59										Ni-59	3.68E+05	1.01E+05	5.48E+02	2
Ni-63										Ni-63	1.28E+07	1.00E+02	4.84E+04	2
Np-235										Np-235	3.17E+02	1.08E+00	6.35E+06	1
Np-236										Np-236	1.07E+09	1.54E+05	7.19E+04	1
Np-237										Np-237	2.33E+04	2.14E+06	4.28E-01	2
Np-238		Np-238									1.98E-06	5.80E-03	1.01E+04	1
Np-239	Np-239										6.43E-09	6.45E-03	1.61E+02	2
Np-240	Np-240										1.80E-51	1.18E-04	5.18E+03	1
Np-240m	Np-240m										7.32E-52	1.37E-05	1.81E+04	1
Os-186	Os-186										7.59E-110	2.00E+15	1.00E+07	4
Os-194	Os-194										1.89E-167	6.00E+00	1.00E+07	4
Pa-231							Pa-231				1.17E-01	3.28E+04	2.06E-06	2
Pa-232	Pa-232										4.95E-49	3.59E-03	6.25E+03	1
Pa-233	Pa-233										5.19E-79	7.38E-02	3.14E-01	2
Pb-202	Pb-202										7.86E-145	5.25E+04	1.00E+07	4
Pb-210	Pb-210										2.53E-167	2.22E+01	4.60E-01	2
Pd-107					Pd-107						1.04E-03	6.50E+06	1.44E-04	2
Pm-144	Pm-144										3.04E-137	9.94E-01	3.61E+03	1
Pm-145	Pm-145										3.58E-142	1.77E+01	1.00E+07	4
Pm-147	Pm-147										8.64E-135	2.62E+00	1.80E+01	2

Nuclide List	SOF < 0.000001	SOF < 0.00001	SOF < 0.0001	SOF < 0.001	SOF < 0.01	SOF < 0.1	SOF < 1	SOF < 10	SOF < 100	SOF > 100	Max SOF	Halflife (yr)	Inventory (Ci)	Inventory Flag
163	113	3	1	3	3	6	3	1	4	26	-	-	-	-
-	50	47	46	43	40	34	31	30	26	0	-	-	-	-
Po-208	Po-208										4.91E-130	2.90E+00	1.00E+07	4
Po-209	Po-209										6.74E-149	1.02E+02	1.10E+06	1
Pt-190										Pt-190	1.35E+11	6.50E+11	1.00E+07	4
Pt-193			Pt-193								1.61E-05	5.00E+01	5.28E-05	2
Pu-236	Pu-236										1.45E-70	2.86E+00	1.00E+07	4
Pu-238				Pu-238							7.56E-04	8.77E+01	2.54E+02	2
Pu-239						Pu-239					1.28E-02	2.41E+04	8.60E+01	2
Pu-240	Pu-240										3.78E-46	6.56E+03	1.95E+01	2
Pu-241									Pu-241		5.86E+01	1.44E+01	3.09E+02	2
Pu-242	Pu-242										3.78E-14	3.75E+05	1.35E+00	2
Pu-243	Pu-243										6.30E-08	5.65E-04	5.83E+05	1
Pu-246	Pu-246										7.86E-19	2.97E-02	6.26E+04	1
Ra-226										Ra-226	8.63E+02	1.60E+03	4.61E-01	2
Ra-228	Ra-228										9.68E-40	5.75E+00	1.25E-01	2
Rb-87							Rb-87				1.17E-01	4.92E+10	1.73E-04	2
Re-184m	Re-184m										2.24E-20	4.63E-01	1.76E+04	1
Re-186m										Re-186m	1.54E+10	2.00E+05	3.50E+06	1
Re-187										Re-187	9.09E+08	4.12E+10	1.00E+07	4
Rh-101	Rh-101										1.43E-206	3.30E+00	2.49E+04	1
Rh-102m	Rh-102m										2.79E-201	3.74E+00	2.63E+03	1
Rn-218	Rn-218										2.00E-170	1.11E-09	7.30E+06	1
Rn-222	Rn-222										8.17E-108	1.05E-02	4.60E-01	2
Ru-106	Ru-106										3.32E-10	1.02E+00	3.54E+00	2
Sb-125	Sb-125										5.23E-253	2.76E+00	7.87E+00	2
Se-79	Se-79										1.11E-123	2.95E+05	9.92E-02	2
Si-32										Si-32	1.92E+11	1.32E+02	1.00E+07	4
Sm-145	Sm-145										1.22E-143	9.31E-01	6.14E+06	1
Sm-146	Sm-146										1.94E-118	1.03E+08	1.00E+07	4
Sm-147	Sm-147										1.94E-118	1.06E+11	1.00E+07	4
Sm-148	Sm-148										1.94E-118	7.00E+15	1.00E+07	4
Sm-151	Sm-151										2.44E-130	9.00E+01	1.29E+01	2
Sn-121m	Sn-121m										8.29E-163	4.39E+01	1.22E-01	2
Sn-126	Sn-126										2.67E-154	2.30E+05	1.24E-02	2
Sr-90										Sr-90	4.57E+04	2.88E+01	1.44E+03	2
Ta-179	Ta-179										6.99E-17	1.82E+00	2.87E+06	1
Tb-157	Tb-157										5.17E-127	7.10E+01	1.00E+07	4
Tb-158	Tb-158										1.75E-125	1.80E+02	7.69E+03	1
Tc-97										Tc-97	1.36E+09	2.60E+06	1.00E+07	4
Tc-98										Tc-98	5.39E+06	4.20E+06	4.01E+03	1
Tc-99										Tc-99	8.21E+02	2.11E+05	9.03E-01	2
Te-123	Te-123										3.57E-116	6.00E+14	1.00E+07	4
Th-228	Th-228										6.56E-224	1.91E+00	1.10E+00	2
Th-229	Th-229										7.82E-117	7.34E+03	2.32E-01	2
Th-230									Th-230		2.69E+01	7.54E+04	4.63E-01	2
Th-231					Th-231						5.78E-03	2.91E-03	1.14E+00	2
Th-232	Th-232										1.29E-36	1.41E+10	1.25E-01	2
Th-234	Th-234										9.52E-07	6.60E-02	1.19E+02	2
Ti-44	Ti-44										5.65E-119	6.00E+01	1.72E+05	1
Tl-204	Tl-204										3.94E-46	3.78E+00	1.00E+07	4
Tl-210	Tl-210										1.49E-170	2.47E-06	2.44E+03	1
U-232	U-232										3.60E-76	6.89E+01	1.06E+00	2
U-233	U-233										2.95E-70	1.59E+05	8.28E+01	2
U-234								U-234			1.27E+00	2.46E+05	4.25E+01	2
U-235										U-235	2.53E+03	7.04E+08	4.31E+00	2
U-235m				U-235m							4.12E-04	4.94E-05	1.00E+07	4
U-236	U-236										6.13E-42	2.34E+07	1.53E+00	2
U-238				U-238							4.95E-04	4.47E+09	1.19E+02	2
U-240	U-240										3.21E-47	1.61E-03	6.76E+06	1
V-49	V-49										4.67E-160	9.03E-01	1.00E+07	4
V-50	V-50										1.32E-31	1.50E+17	2.46E-01	3
Zr-93	Zr-93										3.08E-120	1.53E+06	2.17E-02	2

Note that an inventory flag of 4 is where no inventory information was available, and the historical screening value of 10^7 Ci was considered to be an upper bound.

In Sections 3.3 and 3.7 of the main body, the final Inadvertent Intruder Tier-1 and Groundwater Tier-2 radionuclide listings for each DU type are provided. Those listings can potentially be further reduced based on employing additional "process knowledge" where available. For example (see Table L-2), the following aspects should be considered:

- **Noble Gases** – (shaded in blue) Noble gases predominately are outgassed from the waste forms; however, there remains a residual amount of the noble gas within the liquid-phase due to having a finite solubility value (i.e., Henry's Law constants);
- **Heavy Elements** – (shaded in yellow) Production of very heavy elements is generally limited since SRS production reactor operations typically were focused on weapons-grade Pu production (i.e., 3% and 6% Pu-240). Thus, reactor core burnup levels were low when compared to power reactor operations. One primary exception here was the Cf campaign that were performed in C-Reactor during the 70's;
- **Fission Products** – (shaded in green) Fission product (and fragments) yields very greatly over the entire range of atomic mass numbers. For some of these very low yields occur;
- **Neutron Activation Products** – (shaded in red) Some neutron activation products result from trace amounts of various impurities within reactor components present during their fabrication processes.

Note that for many of the cases of interest, no WITS inventories have been recorded since the start of E-Area operations. Those potential radionuclides that might be candidates to be eliminated from the final Tier-2 listings are highlighted in Table L-2.

Table L-2. Radionuclides that have potential to be eliminated from Tier-2 listings.

ILV	LAWV	NRCDA(G)	NRCDA(S)	Trench
45	39	38	31	43
Ag-108m	Ag-108m	Am-241	Am-241	Ag-108m
Am-241	Am-241	Am-245	Am-245	Am-241
Am-245	Be-10	Ar-39	Ar-39	Am-245
Ar-39	Bk-249	Bk-247	Be-10	Be-10
Be-10	C-14	Bk-249	Bk-247	Bk-249
Bk-247	Ca-41	C-14	C-14	C-14
Bk-249	Cd-113	Ca-41	Ca-41	Cf-249
C-14	Cf-253	Cd-113	Cf-253	Cf-253
Ca-41	Cl-36	Cf-253	Cl-36	Cl-36
Cd-113	Cm-245	Cl-36	Cm-249	Cm-245
Cf-249	Cs-137	Cm-249	Es-253	Cm-249
Cf-253	Es-253	Cs-135	Fm-257	Cs-135
Cl-36	Fm-257	Es-253	I-129	Cs-137
Cm-245	H-3	Fm-257	K-40	Es-253
Cm-249	I-129	H-3	Kr-81	Fm-257
Cs-135	K-40	I-129	Ni-59	H-3
Cs-137	Kr-81	K-40	Ni-63	I-129
Es-253	Mn-53	Kr-81	Np-235	K-40
Fm-257	Ni-59	Mn-53	Np-236	Kr-81
H-3	Ni-63	Ni-59	Np-237	Mn-53
I-129	Np-235	Ni-63	Pa-231	Ni-59
K-40	Np-236	Np-235	Pt-190	Ni-63
Kr-81	Np-237	Np-236	Pu-241	Np-235
Mn-53	Pa-231	Np-237	Rb-87	Np-236
Ni-59	Pd-107	Pd-107	Re-186m	Np-237
Ni-63	Pt-190	Pt-190	Re-187	Pa-231

ILV	LAWV	NRCDA(G)	NRCDA(S)	Trench
Np-235	Pu-239	Pt-193	Si-32	Pd-107
Np-236	Pu-241	Pu-241	Tc-97	Pt-190
Np-237	Ra-226	Rb-87	Tc-98	Pu-239
Pa-231	Rb-87	Re-186m	Tc-99	Pu-241
Pd-107	Re-186m	Re-187	U-235	Ra-226
Pt-190	Re-187	Si-32		Rb-87
Pu-239	Si-32	Sr-90		Re-186m
Pu-241	Sr-90	Tc-97		Re-187
Ra-226	Tc-97	Tc-98		Si-32
Rb-87	Tc-98	Tc-99		Sr-90
Re-186m	Tc-99	U-235		Tc-97
Re-187	U-235	U-237		Tc-98
Si-32	U-237			Tc-99
Sr-90				Th-230
Tc-97				Th-231
Tc-98				U-234
Tc-99				U-235
U-235				
U-237				

Below each of the categories as listed in the above bullets are addressed.

L.1 Noble Gases

For the GW screening, all of the buried Noble gases were conservatively considered (once released from a waste package) to be retained within the liquid-phase. No outgassing of the species was considered. To see if outgassing is sufficient to change the status of a Noble gas from being screened out, a simple equilibrium partitioning calculation was performed.

As illustrated in Figure L-1, once a species is released from its waste package it will locally partition between the three phases present (i.e., gas, liquid, and solid) and then be transported towards the watertable for the liquid-phase portion, upwards to the groundwater for the gas-phase portion, and remain stationary for the solid-phase portion.

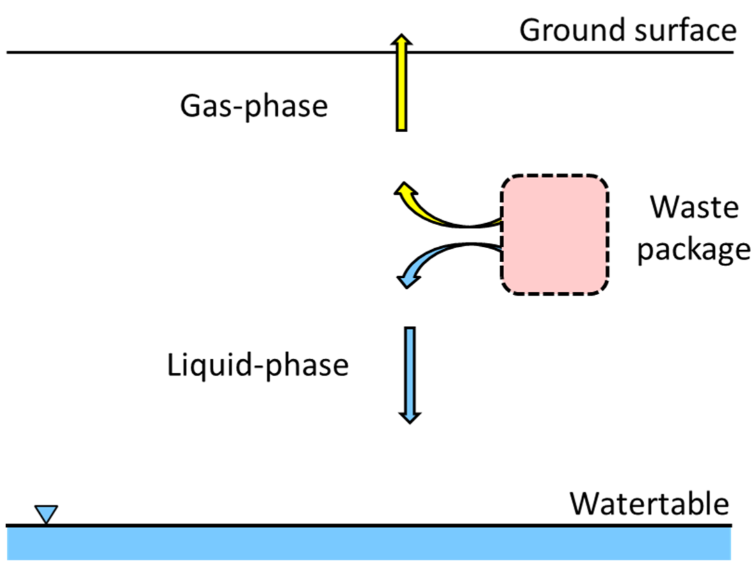


Figure L-1. Liquid and gas-phase partitioning of species released from a waste package.

The K_d values for Noble gases are considered to be very small and zero solid-phase absorption is assumed. The partitioning between the liquid and gas phases is typically measured and report in terms of a Henry's Law constant. Values for the Noble gases under pH conditions representative of the vadose zone soils in E-Area were provided in Dyer (2017) and are listed in Table L-3.

Table L-3. Dimensionless Henry's Law constants for Noble gases within the E-Area vadose zone (pH at 5.4).

Noble Gas	Henry's Constant (molar concs liq/gas)
Ar	29
Kr	17
Xe	9.4

The dimensionless Henry's Law constant is defined here as:

$$H_i = \frac{c_{wi}}{c_{gi}} = \left(\frac{n_{wi}}{V_w}\right)\left(\frac{V_g}{n_{gi}}\right) \tag{L-1}$$

where

- H_i - Henry's Law constant for species i (-)
- c_{wi} - molar (or activity) concentration of species i in liquid phase (gmol/ml or Ci/ml)
- c_{gi} - molar (or activity) concentration of species i in gas phase (gmol/ml or Ci/ml)
- n_{wi} - moles (or activity) of species i in liquid phase (gmol or Ci)
- n_{gi} - moles (or activity) of species i in gas phase (gmol or Ci)
- V_w - volume of liquid phase (ml)
- V_g - volume of gas phase (ml)

Performing a simple mass balance partitioning, assuming equilibrium achieved between both phases, results in the following mole (or activity) fraction are the liquid-phase portion:

$$x_{wi} = \frac{S_w \phi H_i}{S_w \phi H_i + (1 - S_w)\phi} \tag{L-2}$$

where

- x_{wi} - liquid-phase molar (or activity) fraction of species i (-)
- S_w - local vadose zone water saturation (-, set to 85%)
- ϕ - local total porosity of vadose zone (-, set to 38%)

Using the values provided above, the liquid-phase activity fractions for partitioning the Noble gases are listed in Table L-4.

Table L-4. Activity partitioning fractions for Noble gases within the E-Area vadose zone (pH at 5.4).

Noble Gas	Henry's Constant	Liquid Fraction (%)	Gas Fraction (%)
Ar	29	0.994%	99.006%

Kr	17	0.990%	99.010%
Xe	9.4	0.982%	99.018%

As Table L-4 indicates, an approximately two-order magnitude reduction in liquid-phase inventory is observed.

Based on partitioning, the upper bound inventories were updated, along with the computed Max SOF values. Table L-5 shows the updated SOF values for GW Tier-2 screening for each Noble gas that was not screened out by DU type.

Table L-5. Partitioning adjusted Max SOF values for the Noble gases that were not screened out for GW Tier-2 screening.

DU Type	Noble Gas	Original Inventory (Ci)	Original Inventory Basis	Original Max SOF (-)	Partitioned Adjusted Inventory (Ci)	Partitioned Adjusted Max SOF (%)
Trench	Kr-81	6.60E+06	**Gamma weighting**	1.48E+04	6.53E+04	14664.0%
ILV	Ar-39	7.35E+01	**Projected closure**	1.65E-01	7.31E-01	0.2%
LAWV	Kr-81	1.57E+06	**Gamma weighting**	6.74E+02	1.55E+04	666.7%
NRCDAG	Ar-39	1.00E+07	**Initial bounding**	5.28E+04	9.94E+04	52506.1%
	Kr-81	1.00E+07	**Initial bounding**	4.69E+04	9.90E+06	4640341.0%
NRCDAS	Ar-39	1.00E+07	**Initial bounding**	7.57E+03	9.94E+04	7525.5%
	Kr-81	1.00E+07	**Initial bounding**	4.68E+04	9.90E+04	46279.9%

As Table L-5 indicates, partitioning adjustments alone does significantly lower the Max SOF values but does not provided enough reduction for screening any of them out. To screen out some of these will require revisiting the basis for original inventory values.

L.2 Heavy Elements

Heavy elements, sometimes referred to as super-heavy elements, arise within a reactor core during irradiation. The degree of abundance of the super-heavy elements depends upon the neutron flux spectrum, target material of interest, and the burnup level achieved prior to shutting down the reactor. The majority of radionuclides contained within waste streams entering E-Area for disposal originated within the five SRS heavy water reactors during their production years spanning from 1953 through 1988. Some off-site fuel/target materials have also been shipped to SRS where some have been directly buried within E-Area (e.g., Naval reactor fuel components), while others have been stored waiting further processing (i.e., spent nuclear fuel from overseas).

Most irradiated fuel/target assemblies have been reprocessed with the SRS F-Canyon and H-Canyon facilities. Foreign spent fuels and Oak Ridge National Laboratory (ORNL) High-Flux Isotope Reactor (HFIR) targets may be reprocessed in future reprocessing campaigns.

The production of super heavy elements (e.g., Es-Einsteinium and Fm-Fermium) within neutron-based reactors are the direct result of successive capture of neutrons on a source material (see excellent article on this subject by Ferguson 1978). The neuron capture sequence of primary interest here is shown in Figure L-2. This figure traces only the primary path of the neutron capture sequence. Also, Fm-257 is the highest mass number experimentally observed as a result of a neutron capture event.

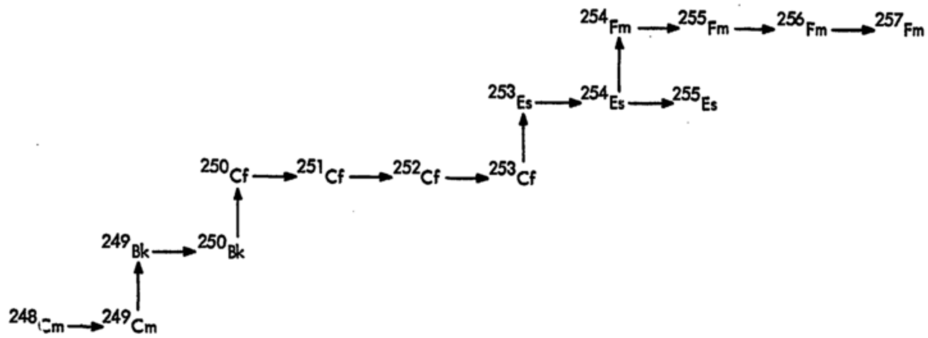


Figure L-2. Neutron capture chain for super heavy element of interest.

In ORNL's High-Flux Isotope Reactor (HFIR), the main objective was the creation of Es and Fm with minimal reactor burnups starting with targets already rich in Cm. Typically, in SRS production reactors the main products of interest were H-3 and Pu-239; however, in a special SRS campaign in the 1969 time period, target assemblies rich in Cm were placed in a small-high flux core within C-Reactor for the direct purpose of creating large quantities of Cf. In this campaign, large quantities of Pu, Am, and Cm were irradiated to produce gram quantities of Cf. Also a significant supply of Cm-248 (i.e., a feed stock) was generated and later used in the ORNL HFIR to make Es and Fm. As stated by Ferguson (1978):

"While it was not possible to recover einsteinium and fermium from the irradiated material because of the necessary long cooling period, a supply of curium rich in the isotope was produced."

The half-lives (in years) and inventory settings for the super heavy elements are listed in Table L-6. The shaded regions highlight:

- **Orange** - half-lives greater than 1 yr are highlighted;
- **Cyan** - those radionuclides that were not screened out during screening process;
- **Green** - those radionuclides that had projected closure inventories; and
- **None** - those radionuclides without projected closure inventories whose values were initially set to 10^7 Ci and then possibly reduced by either gamma-ray factors (Appendix D) or container weight constraints (Appendix E).

Note that projected closure inventories do not exist for the short half-life radionuclides listed in Table L-6.

Table L-6. Decay half-lives (years) for the typically referred to "heavy" elements.

Z	Element	Radionuclide	Half-life (yr)	Trench (Ci)	ILV (Ci)	LAWV (Ci)	NRCDAG (Ci)	NRCDAS (Ci)
97	Berkelium	Bk-245	1.3525E-02					
		Bk-246	4.9281E-03					
		Bk-247	1.3800E+03	3.99E-08				
		Bk-248m	2.7036E-03					
		Bk-249	9.0349E-01				2.07E-08	
		Bk-250	3.6642E-04					
		Bk-251	1.0571E-04					
98	Californium	Cf-244	3.6885E-05					
		Cf-246	4.0726E-03					
		Cf-247	3.5478E-04					
		Cf-248	9.1444E-01					
		Cf-249	3.5100E+02	9.69E-02	2.82E-03	6.05E-06	1.95E-10	9.70E-13

Z	Element	Radionuclide	Half-life (yr)	Trench (Ci)	ILV (Ci)	LAWV (Ci)	NRCDAG (Ci)	NRCDAS (Ci)
		Cf-250	1.3080E+01	7.50E-02		2.13E-03		
		Cf-251	9.0000E+02	8.80E-02	1.63E-03	2.62E-05	4.35E-12	2.62E-14
		Cf-252	2.6450E+00	1.05E-02		1.85E-02		
		Cf-253	4.8761E-02					
		Cf-254	1.6564E-01					
		Cf-255	1.6161E-04					
99	Einsteinium	Es-249	1.9431E-04					
		Es-250	9.8106E-04					
		Es-250m	2.5325E-04					
		Es-251	3.7645E-03					
		Es-253	5.6044E-02					
		Es-254	7.5483E-01					
		Es-254m	4.4832E-03					
		Es-255	1.0897E-01					
		Es-256	4.8293E-05					
100	Fermium	Fm-251	6.0461E-04					
		Fm-252	2.8964E-03					
		Fm-253	8.2136E-03					
		Fm-254	3.6961E-04					
		Fm-255	2.2895E-03					
		Fm-256	2.9964E-04					
		Fm-257	2.7515E-01					

For the heaviest element of interest (i.e., Fm-257) its decay chain is shown in Figure L-3. The blue arrows represent the alpha decay mode while the orange arrows represent the beta-minus (or electron capture) modes. As Figure L-3 illustrates, the majority of heavy elements of interest to us are contained within this decay chain.

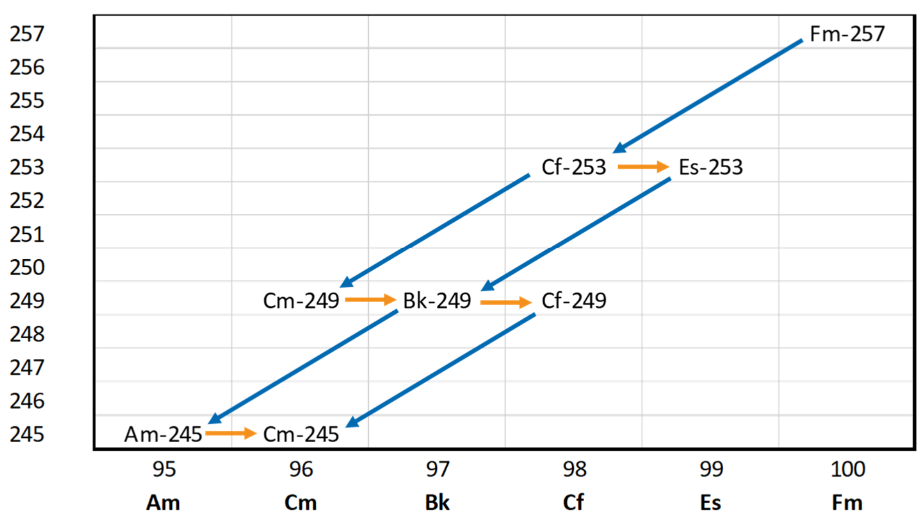


Figure L-3. Decay chain for the radionuclide Fm-257.

For the next heaviest elements of interest (i.e., Fm-254 and Es-254) their decay chains are shown in Figure L-4. The blue arrows represent the alpha decay mode while the orange arrows represent the beta-minus (or isomeric transition) modes. As Figure L-4 illustrates, the two heavy elements of interest to us are contained within this decay chain.

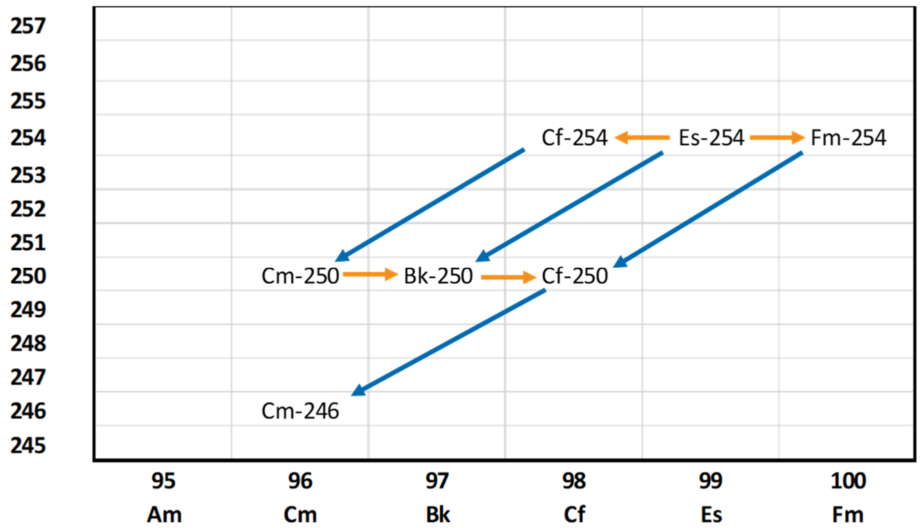


Figure L-4. Decay chains for the radionuclides Fm-254 and Es-254.

To focus attention on which heavy elements should be considered, only those radionuclides that (1) were not screened out and (2) due to lack of inventory knowledge remain at the upper bounding value of 10^7 Ci are addressed. A quick summary of the selection process is provided in Figure L-5.

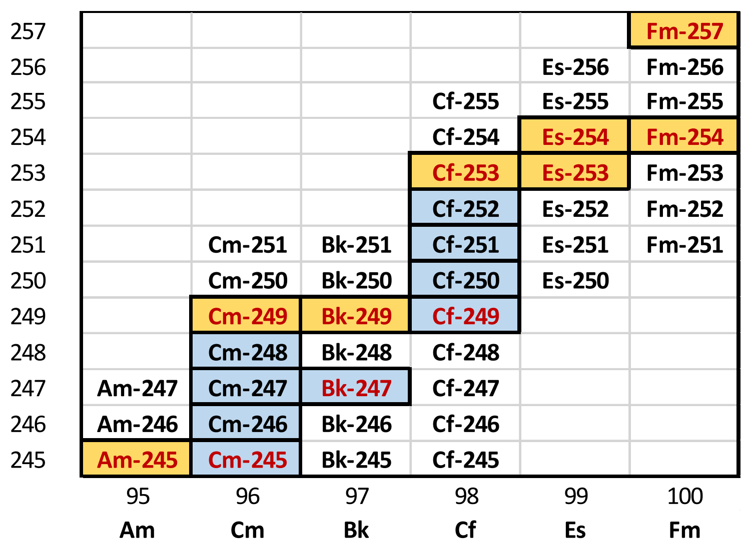


Figure L-5. Heavy elements to be addressed.

This figure is an atomic number versus mass number diagram showing all possible isotopes within an element's family (i.e., cutoff for AMU values below 245). The blue shaded ones have projected closure inventories, the orange shaded ones have the 10^7 Ci bounding value. Isotopes printed in black are accounted for while those printed in red are the ones not screened out and can be potentially eliminated.

Based on the Inadvertent Intruder Tier-1 process and the Groundwater Tier-2 process, the screening status for several of the "heavy" elements is shown in Table L-7.

Table L-7. Status[a,b] of screening results for many of the heavy elements of interest.

Radionuclide[c]	Trench GW	Trench II	ILV GW	ILV II	LAWV GW	LAWV II	NRC-G GW	NRC-G II	NRC-S GW	NRC-S II
Bk-247	out 2	out 2	in 4	out 4	out 1	out 1	in 4	in 4	in 4	in 4
Bk-248m	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0
Bk-249	in 4	in 4	in 4	out 4	in 4	out 4	in 4	out 4	out 0	out 2
Bk-250	out 1	out 1	out 4	out 4	out 1	out 1	out 4	out 4	out 4	in 4
Cf-248	out 4	in 4	out 4	out 4	out 4	out 4	out 4	out 4	out 4	in 4
Cf-249	in 2	in 2	in 2	out 2	out 2	out 2	out 0	out 2	out 0	out 2
Cf-250	out 2	out 2	out 4	out 4	out 2	out 2	out 4	out 4	out 4	in 4
Cf-251	out 2	in 2	out 2	out 2	out 2	out 2	out 0	out 2	out 0	out 2
Cf-252	out 2	out 2	out 4	out 4	out 2	out 2	out 4	out 4	out 4	in 4
Cf-253	in 4	out 4	in 4	out 4	in 4	out 4	in 4	out 4	in 4	in 4
Cf-254	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0	out 0
Es-253	in 4	in 4	in 4	out 4	in 1	out 1	in 4	out 4	in 4	in 4
Es-254	out 1	in 1	out 4	out 4	out 1	out 1	out 4	out 4	out 4	in 4
Fm-254	out 4	in 4	out 4	out 4	out 4	out 4	out 4	out 4	out 4	in 4
Fm-257	in 4	in 4	in 4	out 4	in 4	out 4	in 4	out 4	in 4	in 4

[a] Status implies whether or not a specific parent radionuclide is screened out and its inventory status: 0 - implying being screened out during prior screening step; 1 – gamma-factor inventory basis; 2 – WITS inventory basis; 3 – package weight inventory basis; or 4 – no inventory information available and was set to 10^7 Ci.
[b] Shading indicates those parent radionuclides that have a potential to be removed (i.e., screened out) in a post-processing effort based on estimated projected inventory values associated with heavy element aspects discussed in this appendix.
[c] The radionuclides shaded in grey are screened out of every DU type.

The high-lighted cells represent heavy element parent radionuclides that were not screened out and no inventory information was available within WITS (i.e., in 1 and in 4). The majority of radionuclides presented in Table L-7 have at least one DU type where it has not been screened out. To eliminate these radionuclides their current 10^7 Ci bounding inventory must be significantly reduced. This is accomplished by making use of the following two data sources for predicting better (i.e., more realistic) upper bound inventory estimates:

- **SRS Reactor Neutronic Prediction** – SRS heavy water reactors are unique and neutronic calculations were routinely performed using SRNL developed FORTRAN algorithms (i.e., here specially the GLASS code). GLASS burnup calculations of a typical SRS reactor core were available that track a total of 1,049 radionuclides (i.e., from H-3 through Cf-252). Results for four levels of burnup were available (GLASS results were provided to the authors by Roger Webb a retired SRNL employee). Also, GLASS as been benchmarked numerous times during the years while in use and was considered to be very reliable for heavy water reactor predictions.
- **ORNL HFIR Compositional Measurements** – A special ORNL HFIR campaign (i.e., Campaign 53) was performed in the mid-70s where small quantities of Es and Fm were produced (see Ferguson 1978). Isotopic compositional measurements were made of the assemblies post and prior to irradiation. The prior to irradiation measurements confirmed the Cm enrichment content of an assembly.

Note that the above two sources relate to fairly different reactor situations:

- Heavy water reactor assemblies that are primarily U-235 (fuel) and U-238 (target) based using a soft thermal neutronic spectrum; while
- HFIR assemblies were Cm rich targets in a hard high neutronic spectrum.

As such, large differences could be present and projected compositions between the two could have large differences as well. Therefore, to justify the elimination of one of these elements, predicted SOF values should be significantly below the PM criterion of 0.1% to account for the potentially large uncertainties present.

If we assume that compositional differences are acceptable, then the compositional measurements made in the HFIR assemblies can be scaled to represent compositional behavior within a typical SRS assembly through use of mass ratios. For the scaling process the highest element that was both computed in the GLASS runs and measured in HFIR assemblies was Cf-252. The isotopic mass ratios provided by the measurements made at ORNL are listed in Table L-8, along with listing of some of the other heavy elements being considered.

Table L-8. Measured isotopic mass ratios for "heavy" elements in HFIR assemblies.

Radionuclide[a]	isotopic ratio	HFIR mass ratio (g/g)	Estimated Abundance in SRS assembly (g)	Estimated Abundance in SRS assembly (Ci)	Half-life (yr)	SpAct (Ci/g)
Bk-247	NA	NA	NA	NA	1.380E+03	9.537E+06
Bk-248m	NA	NA	NA	NA	2.704E-03	5.330E+05
Bk-249	Bk-249/Cf-252	1.46E-01	2.71E-22	4.30E-19	9.035E-01	1.589E+03
Bk-250	NA	NA	NA	NA	3.664E-04	3.901E+06
Cf-248	NA	NA	NA	NA	9.144E-01	6.345E+03
Cf-249	NA	NA	NA	NA	3.510E+02	2.370E-01
Cf-250	Cf-250/Cf-252	3.61E+00	6.68E-21	7.31E-19	1.308E+01	1.093E+02
Cf-251	Cf-251/Cf-252	2.37E-02	4.38E-23	6.93E-23	9.000E+02	1.582E+00
Cf-252	Cf-252 (SRS)	1.0 (reference)	1.85E-21	9.93E-19	2.645E+00	5.362E+02
Cf-253	Cf-253/Cf-252	1.72E-02	3.19E-23	9.25E-19	4.876E-02	2.897E+04
Cf-254	Cf-254/Cf-252	6.76E-04	1.25E-24	1.06E-20	1.656E-01	8.494E+03
Es-253	Es-253/Cf-252	7.60E-03	1.41E-23	3.55E-19	5.604E-02	2.520E+04
Es-254	Es-254/Cf-252	NA	NA	NA	7.548E-01	1.864E+03
Fm-254	Fm-254/Cf-252	NA	NA	NA	3.696E-04	3.807E+06
Fm-257	Fm-257/Cf-252	1.94E-09	3.59E-30	1.81E-26	2.752E-01	5.054E+03

[a] The radionuclides shaded in grey are screened out of every DU type..

These mass ratios were then used, along with the computed mass abundance of Cf-252 for the highest burnup runs from GLASS, to estimate the abundances of these five radionuclides within a SRS assembly. Graphically we can compare these abundance predictions as shown in Figure L-6 with the GLASS runs. The labels on the GLASS runs (i.e., 327, 817, 1144, and SRS=1635) represent increasing burnup level in units of MWD/MT of total U. As Figure L-6 indicates the heavy elements of Cf-253, Es-253, and Fm-257 appear to be dropping off consistent with the GLASS runs for elements whose mass number are less than 253.

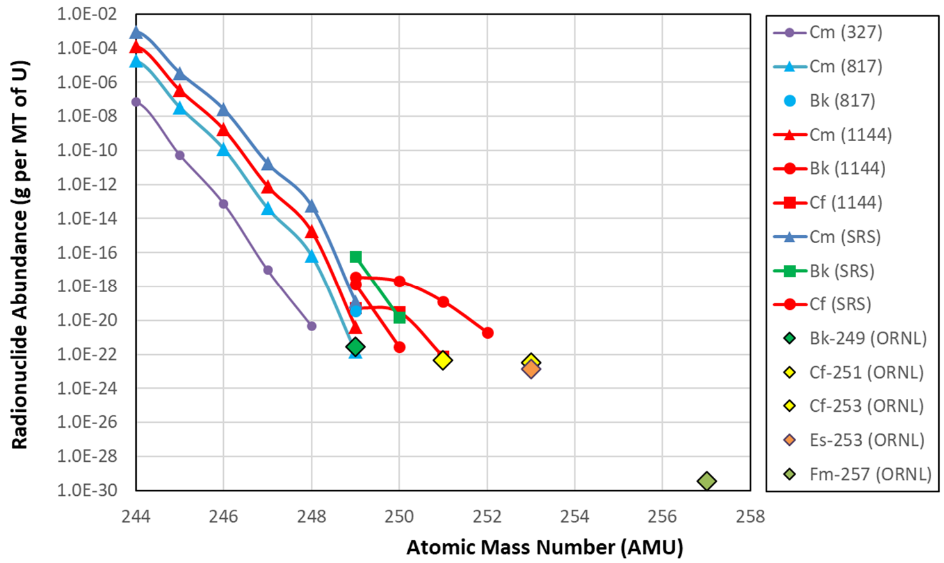


Figure L-6. Heavy element abundances existing in a SRS reactor assembly.

From these results, it is believed that the predictions in relative abundance can be confidently used. These are estimated abundances within assemblies right after irradiation has been terminated. To make use of them for estimating waste stream inventories we must make some sort of assumption associated with their effective separation factors going through the reprocessing facilities. We shall assume that the chemical separation factors for Es and Fm are similar to those for Cf.

Based on the new projected inventories for these heavy elements, updated max SOF values were computed. The Generic Trench GW Tier-2 updated max SOF values are presented in Table L-9.

Table L-9. Estimated max SOF values for the heavy element of interest for the Generic Trench groundwater Tier-2 screening process.

Nuclide	Original SOF	Half-life (yr)	Original Inventory (Ci)	Mass ratio (g/g)	New Inventory (Ci)	New SOF (-)	SOF Ratio (-)
Cf-252	1.73E-61	2.65E+00	1.05E-01	1.00E+00	1.05E-01	1.73E-61	1.00E+00
Bk-249	1.01E+03	9.03E-01	1.00E+07	1.46E-01	4.55E-02	4.61E-06	4.55E-09
Es-253	6.31E+01	5.60E-02	1.00E+07	7.60E-03	3.75E-02	2.37E-07	3.75E-09
Cf-253	5.49E+01	4.88E-02	1.00E+07	1.72E-02	9.78E-02	5.37E-07	9.78E-09
Fm-257	3.09E+02	2.75E-01	1.00E+07	1.94E-09	1.92E-09	5.93E-14	1.92E-16

Assuming that the mass ratios for Es-254 and Fm-254 can be approximated to the value for Es-253, updated SOF estimates can be made for these two heavy elements as well. Based on the new projected inventories for these heavy elements, updated max SOF values were computed. The Generic Trench II Tier-1 updated max SOF values are presented in Table L-10.

Table L-10. Estimated max SOF values for the heavy element of interest for the Generic Trench Inadvertent Intruder Tier-1 screening process.

Nuclide	Original SOF	Half-life (yr)	Original Inventory (Ci)	Mass ratio (g/g)	New Inventory (Ci)	New SOF (-)	SOF Ratio (-)
Cf-252	5.82E-07	2.65E+00	1.05E-01	1.00E+00	1.05E-01	5.82E-07	1.00E+00
Es-254	1.90E+00	7.55E-01	5.54E+06	7.60E-03	2.78E-03	9.50E-10	5.01E-10
Fm-254	1.67E-03	3.70E-04	1.00E+07	7.60E-03	5.67E+00	9.49E-10	5.67E-07

As stated above, two main assumptions were made in updating these max SOF values:

- Potential compositional differences for heavy elements between SRS and HFIR assemblies assumed acceptable; and
- Potential chemical separation factors between Cf and those for Es and Fm assumed acceptable.

Given the fact that the new max SOF values are orders of magnitude lower than the original value, as shown in Table L-9 and Table L-10, it is considered that the following heavy elements can be eliminated from all of the Tier-1 and Tier-2 lists for GW and II, respectively:

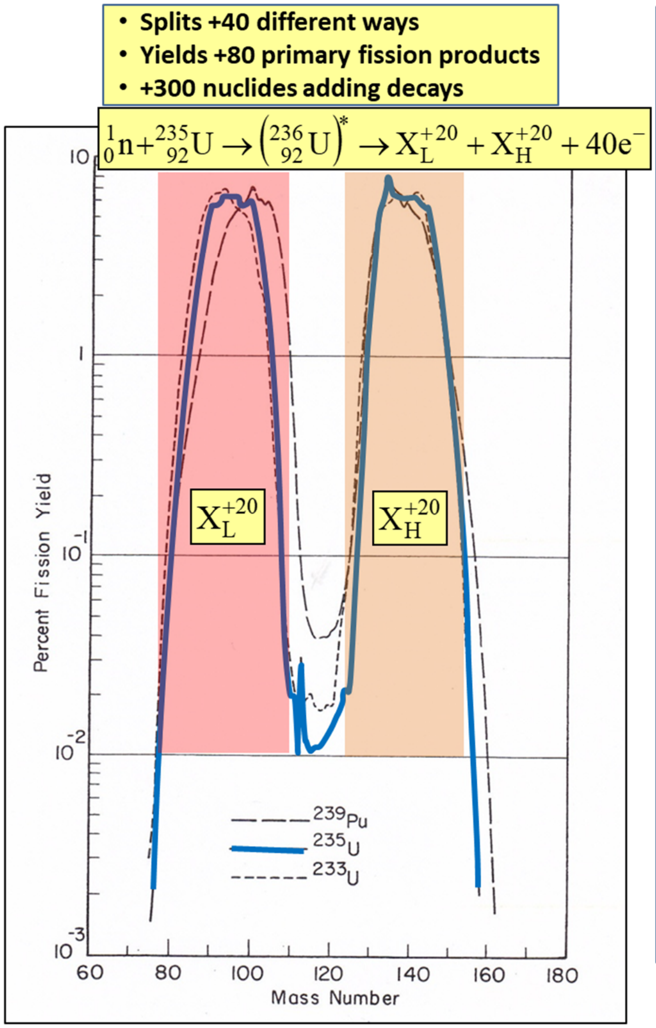
Bk-249, Cf-253, Es-253, Es-254, Fm-254, and Fm-257

L.3 Fission Products

Fission product yields are a function of mass number, neutronic spectrum, and fissioning nuclide. For the SRS production reactors, the primary mode of fission is from slow-neutron (thermal spectrum) induced fission of U-235. Fission yields for this case are shown in Figure L-7,where the light and heavy fragment groups are highlighted. Mass numbers outside these two ranges have low fission yields.

Mass number	Fission by slow neutrons ^{233}U	^{235}U	^{239}Pu
3	2×10^{-4}	1.3×10^{-4}	2.3×10^{-4}
72	0.000200	0.000016	0.000120
73	0.000600	0.000110	0.000200
74	0.00100	0.000350	0.000800
75	0.00301	0.000804	0.000804
76	0.00500	0.00250	0.00300
77	0.0210	0.00830	0.0100
78	0.0600	0.0200	0.0250
79	0.100	0.0560	0.0400
80	0.200	0.100	0.0700
81	0.424	0.140	0.117
82	0.691	0.320	0.200
83	1.17	0.544	0.290
84	1.95	1.00	0.468
85	2.64	1.30	0.539
86	3.27	2.02	0.769
87	4.56	2.49	0.920
88	5.37	3.57	1.42
89	5.86	4.79	1.71
90	6.43	5.77	2.21
91	6.43	5.84	[illegible]
92	6.64	6.03	[illegible]
93	6.98	6.45	[illegible]
94	6.68	6.40	[illegible]
95	6.11	6.27	[illegible]
96	5.59	6.33	5.17
97	5.37	6.09	5.65
98	5.15	5.78	5.89
99	4.80	6.06	6.10
100	4.41	6.30	7.10
101	2.91	5.00	5.91
102	2.22	4.19	5.99
103	1.80	3.00	5.67
104	0.940	1.80	5.93
105	0.480	0.900	5.30
106	0.240	0.380	4.57
107	0.160	0.190	3.50
108	0.0700	0.0650	2.50
109	0.0440	0.0300	1.40
110	0.0300	0.0200	0.500
111	0.0242	0.0192	0.232
112	0.0160	0.0100	0.120
113	0.0180	0.0314	0.0700
114	0.0190	0.0120	0.0520
115	0.0210	0.0104	0.0410
116	0.0180	0.0105	0.0380
117	0.0170	0.0110	0.0390
118	0.0170	0.0110	0.0390
119	0.0170	0.0120	0.0400
120	0.0180	0.0130	0.0400

Light Group



Mass number	Fission by slow neutrons ^{233}U	^{235}U	^{239}Pu
121	0.0180	0.0150	0.0440
122	0.0300	0.0160	0.0450
123	0.0500	0.0173	0.0550
124	0.0700	0.0220	0.0700
125	0.0840	0.0210	0.115
126	0.200	0.0440	0.200
127	0.600	0.130	0.390
128	1.21	0.409	1.21
129	2.00	0.800	2.00
130	2.60	2.00	2.60
131	3.39	2.93	3.78
132	4.54	4.38	5.26
133	5.78	6.61	6.53
134	5.94	8.06	7.46
135	6.16	6.41	7.17
136	6.75	6.47	6.74
137	6.58	6.15	6.03
138	6.31	5.74	6.31
139	6.44	6.55	5.87
140	6.47	6.44	5.64
141	6.49	6.40	[illegible]
142	6.83	6.01	[illegible]
143	5.99	5.73	[illegible]
144	4.61	5.62	[illegible]
145	3.47	3.98	3.13
146	2.63	3.07	2.60
147	1.98	2.36	2.07
148	1.34	1.71	1.73
149	0.760	1.13	1.32
150	0.560	0.670	1.01
151	0.335	0.440	0.800
152	0.220	0.281	0.620
153	0.130	0.169	0.417
154	0.0450	0.0770	0.290
155	0.0230	0.0330	0.230
156	0.0110	0.0140	0.110
157	0.00450	0.00780	0.0800
158	0.00150	0.00200	0.0400
159	0.000800	0.00107	0.0210
160	0.000200	0.000390	0.00980
161	0.000060	0.000180	0.00300
162	0.000027	0.000060	0.00200
163	0.000012		0.000900
164			0.000300
165			0.000130
166			0.000068
Sum	201	200	201

Heavy Group

Figure L-7. Percent fission yields by mass number for slow-neutron fission.

No further investigations are performed on this subject within this revision.

L.4 Neutron Activation Products

No further investigations are performed on this subject within this revision.

Appendix M. Supporting Computer Algorithms

Numerous supporting calculations were placed within FORTRAN-based algorithms and Excel spreadsheets. The algorithms were technically reviewed, one-time calculations and are not under software QA control.

Computer algorithms developed for Tier-0 screening are listed and described below:

- **DecayChain**: This program automates the creation of PORFLOW input files with full chain (or short) chain progeny of each of the 1,252 radionuclides. This program computes the time history of radioactive decay and in-growth of daughter radionuclides over a 1250-year time period (exceeding the compliance period). The initial atom number of each parent radionuclide is set to 1.0E+12 pCi (1 Ci) divided by its decay constant (1/y). The 1,252 PORFLOW input files are executed in the HPC Linux cluster queuing system using the latest 64-bit version of PORFLOW. The time histories for each of the parent radionuclides are then post-processed by the backend of the Decay Chain program. The resulting time histories of full (or short) chain atom numbers are converted to activities using each radionuclide's decay constant and are then written to MS Excel CSV and Tecplot ASCII files. The time histories of the full chain radionuclide activities for each parent nuclide are used by the **InitScreen** program for screening in Tier-0.
- **InitScreen**: This computer algorithm is designed to perform screening in careful, precise steps to ensure that each radionuclide is thoroughly evaluated, and that no radionuclide is screened out by an overly aggressive screening process. The screening process invokes process knowledge where available such as waste stream characterization and screening steps as described in the SRS HLW tank farm closure radionuclide screening report (Hamm 2006). An obvious first level of screening is to focus on radionuclides that have no on-going source of formation (e.g., many activation products) and their progeny.

Computer algorithms developed for Tier-1 screening:

- **RadScreen**: This computer algorithm implements the Tier-1 level of intruder and groundwater radionuclide screening. The "PreScreen" module in RadScreen contains the inadvertent intruder model, NCRP123 and NRCDWSM groundwater models. The output from the "PreScreen" step are maximum full chain waste and aquifer zone concentrations computed every year from all the modeled GW scenarios and intruder as conservative concentrations processed forward to the SRNL Dose Toolkit. The "Screening" module in RadScreen is where maximum concentrations or doses are computed using limiting radionuclide inventories and maximum screening factors (SRNL Dose Toolkit) for each GW and II pathway. These maximum concentrations or doses are then compared to the corresponding screening criteria. If any of the GW or intruder screening criteria are exceeded, then the nuclide is not screened out and is added to the Tier-1 list.

Computer algorithms developed for Tier-2 screening:

- **ShortChain**: This computer algorithm creates input files for the PORFLOW 1D vadose zone transport code for each disposal unit, parent radionuclide and groundwater scenario. The PORFLOW 1D model is used to compute transient fluxes to the watertable.
- **FluxExtraction**: This computer algorithm creates ASCII and Tecplot files of the transient fluxes to the watertable computed by the PORFLOW 1D vadose zone model. For a given

disposal unit and parent radionuclide, the fluxes to the WT for each groundwater scenario are combined into a single file for input to the PorflowPS groundwater model in RadScreen.

- **RadScreen**: This computer algorithm implements the Tier-2 level of groundwater radionuclide screening. The "PorflowPS" module in RadScreen contains the PorflowPS groundwater model. The output from the "PorflowPS" step are maximum full chain aquifer zone concentrations computed every year from all the modeled GW scenarios as conservative concentrations processed forward to the SRNL Dose Toolkit. The "Screening" module in RadScreen is where maximum concentrations or doses are computed using limiting radionuclide inventories and maximum screening factors (SRNL Dose Toolkit) for each GW pathway. These maximum concentrations or doses are then compared to the corresponding screening criteria. If any of the GW screening criteria are exceeded, then the nuclide is not screened out and is added to the Tier-2 list.

Auxiliary computer algorithms developed for postprocessing of screening results:

- **NucList**: This computer algorithm generates side-by-side listings of radionuclides for comparison in the MS Excel csv file format. NucList was used to generate the radionuclide listings in Appendix I and Appendix J.
- **HistoSOF**: This computer algorithm generates SOF histograms for inadvertent intruder or groundwater pathways in the MS Excel csv file format. HistoSOF was used to generate maximum SOF histograms for the inadvertent intruder and groundwater pathway in Appendix I. HistoSOF was used to generate maximum SOF histograms for the groundwater pathway in Appendix J.

All the algorithms developed in this report will be archived in protected directories within the PA2022 directory on the HPC cluster.

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