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Groundwater and Intruder Radionuclide Screening

S. E. Aleman

L. L. Hamm

August 2020

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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 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 has been tasked to update the facility's PA. 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 disposal units[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-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 of 97 elements. This database is the critical starting point for developing a consistent inventory limit system.

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.

The groundwater and inadvertent intruder screening analyses presented in this report start with this 1,252 radionuclide list and reduces it down to more manageable lists that are applicable to the various disposal unit 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 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.

[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).

In this new 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/y performance measure x 0.001 = 0.004 mrem/yr) over the entire period of performance.

Bullet one ensures that no inconsistencies creep 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.

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/models the overall costs are greatly reduced. The overall structure of the E-Area tiered inventory limit system is:

- Tier-0 – Establishment of an upper closure inventory projection
- Tier-1 - "NCRP-like" groundwater and intruder screening (very conservative)
- Tier-2 – Simple, but bounding, 1D transport modeling (conservative)
- Tier-3 - Generic waste (multi-D, no credit taken for any possible engineering barriers)
- Tier-4 - Special waste form (multi-D, credit taken for certain engineered 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 Tier3 or Tier-4. Within this revision of the report only Tier-0 and Tier-1 results are presented. Tier-2 results will be added in a later revision.

In the 2021 PA revision there will be a total of 33 disposal units (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)
- **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, 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 disposal units were represented by the following five screening models:

- **Trench** [represents all ETs, STs, and former Component-in-Grout (CIG) trenches]
- **LAWV**
- **ILV**
- **NRCDA** [represented by two models: a model for generic Naval Reactor waste (NRCDAG) and a model for special waste forms (NRCDAS)]

The resulting Tier-0 screening results are listed in Table ES-1, along with the recommended Tier-1 groundwater and inadvertent intruder screening results for each disposal unit model. In Table ES-1 the number of "parent" radionuclides remaining (highlighted in orange) after the "NCRP-like" groundwater and intruder screening are shown for each disposal unit model (i.e., parent implies the first member in a decay chain and the total dose associated with that decay chain is the rolled-up contributions from that parent and its progeny). These lists will be employed as input into upcoming Tier-2 processing. The number of radionuclides failing the screening process by pathway (i.e., who's maximum SOF exceeds the 0.1% screening criterion) has also been provided.

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

Tier	Pathway	ILV	LAWV	NRCDAG	NRCDAS	Trench
ICRP-107	-	1,252	1,252	1,252	1,252	1,252
Tier-0	-	271	271	295	295	271
Tier-1	Beta-Gamma	86	86	101	66	106
	Gross Alpha	68	63	63	55	67
	Radium	9	6	4	5	7
	Uranium	9	10	11	7	10
	All-Pathways	117	110	111	96	108
	Acute Intruder	24	7	26	30	54
	Chronic Intruder	27	20	29	71	80
Tier-2	Groundwater	121	116	133	98	136
Input	Intruder	27	20	29	71	80

[1] The number of parent radionuclides remaining (highlighted in orange) represent the union of the sets of radionuclides passing the Tier-1 screening (i.e., inclusive of the complete set of unique radionuclides from all the above Tier 1 pathways).

Based on the recommended (i.e., the "NCRP-like") 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 (Section 4) for each of the disposal unit screening models. These are the actual parent radionuclides that fail the Tier-1 groundwater and inadvertent intruder screening processes and will be subjected to a follow-on Tier-2 screening process.

Revision 1 of this report addresses Department of Energy (DOE) Savannah River review comments.

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LIST OF ABBREVIATIONS

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
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
PA	Performance Assessment
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
ST	Slit Trench
SWM	Solid Waste Management
US	United States
VZ	Vadose Zone
WAC	Waste Acceptance Criteria
WITS	Waste Information Tracking System
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). A number of 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 are imposed on all radionuclides being buried in E-Area. 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.

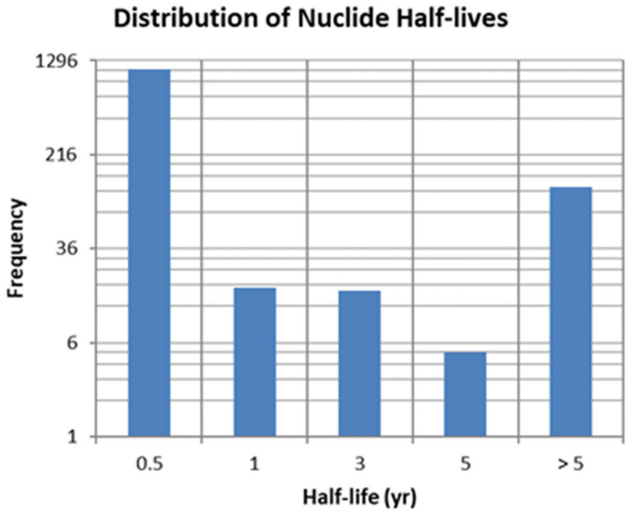
There are over 3,000 known radionuclides and only a subset of these are of any potential concern to E-Area operations. Screening criteria are established based on regulatory Performance Objectives (PO) and a suite of bounding analyses is performed to reduce this large list of radionuclides down to a 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. This report describes these screening analyses, the basis behind the screening analysis approach, and the resulting list of radionuclides requiring further detailed analyses.

1.1 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). 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 826 radionuclides employed in the 2008 Performance Assessment (PA) (referred to as PA2008) screening process (list taken from NCRP 1996). 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.



	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 this 1,252 radionuclide list 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 due to 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 – Establishment of an upper closure inventory projection
  - 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 engineering 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 and performance margins)

As listed in the last bullet a 4- or 5-tiered approach is being considered, depending on the need for Tier-2, where the first three tiers encompass the overall GW and II screening efforts. Tier 2 would incorporate 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.

Those radionuclides whose estimated doses exceed a screening criterion (as laid out in subsequent sections of this report) for either Tier-0, 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. These deterministic analyses were referred to as Tier-3 and Tier-4 processes that handle generic and special waste forms, respectively.

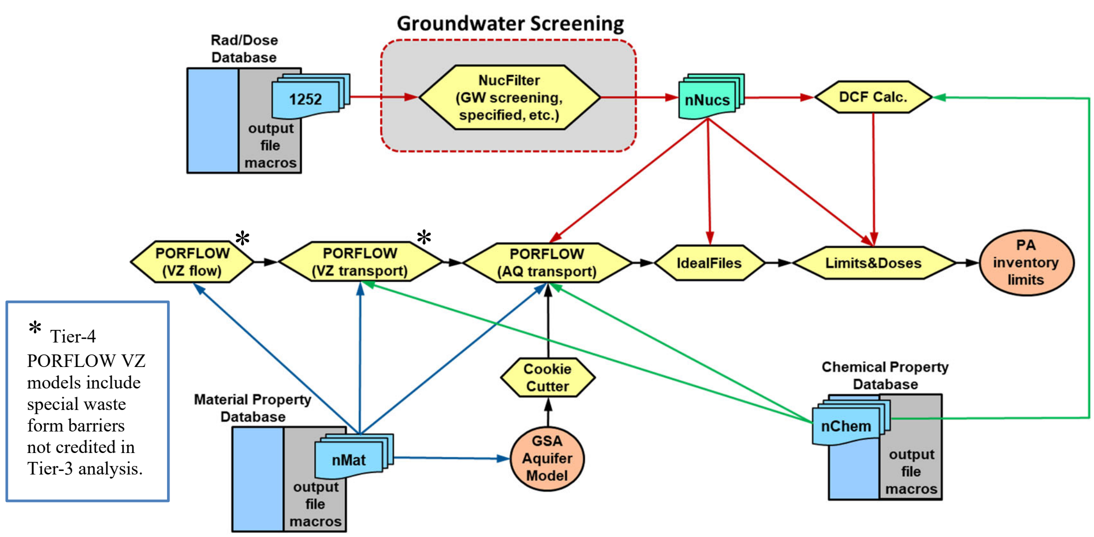


Figure 1-2. Tier-3 and Tier-4 candidate flowchart for 2021 PA analyses (deterministic aspects only).

A high-level overview of the multi-tiered 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. 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.

In Figure 1-3 the recommended lists of radionuclides are provided for each of the DU types for Tier-0 and Tier-1. Given the number of radionuclides remaining in the Tier-1 list for each DU model, a Tier-2 step is likely warranted and will be added in an update to this report upon consultation with SWM.

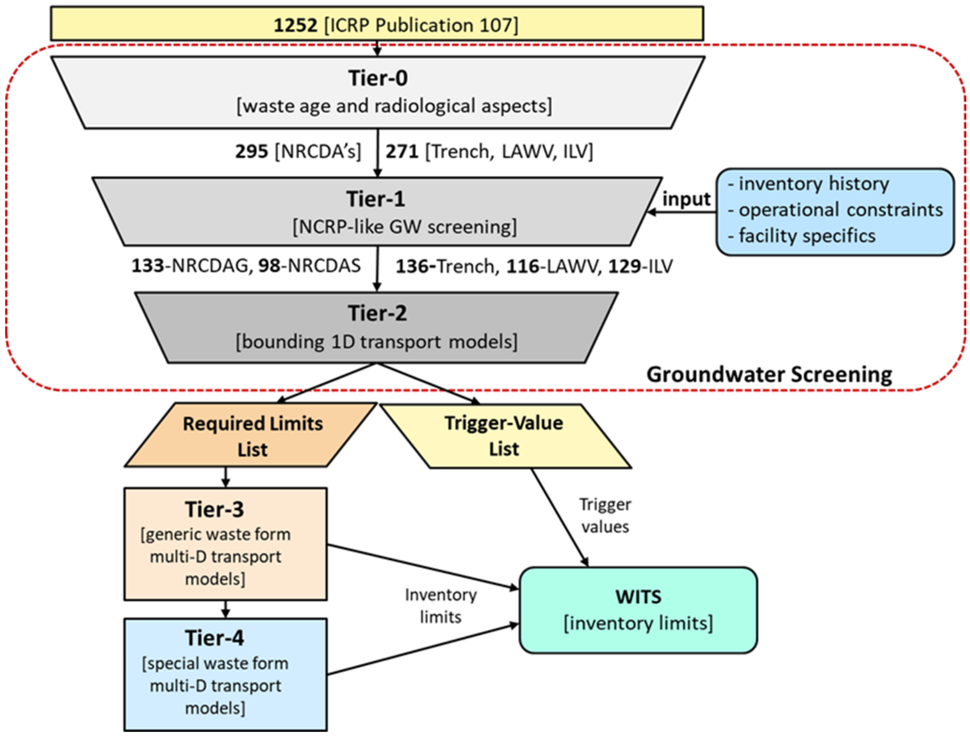


Figure 1-3. Schematic overview of the multi-tiered approach to establishing E-Area inventory limits.

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 groundwater 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, well below a SOF of 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 projected closure inventory 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 136 radionuclides requiring additional analyses in either a Tier-2 or beyond effort.

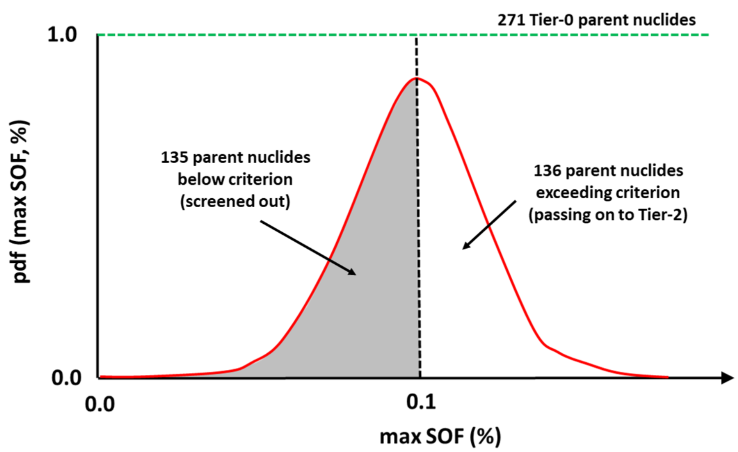


Figure 1-4. Example of a screening out of parent nuclides for a Trench DU.

Thus, for the Trench example we see that the initial 1,252 radionuclides can be reduced to 136 parent nuclides that will require some level of traditional fate and transport analyses.

1.2 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:

- **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.

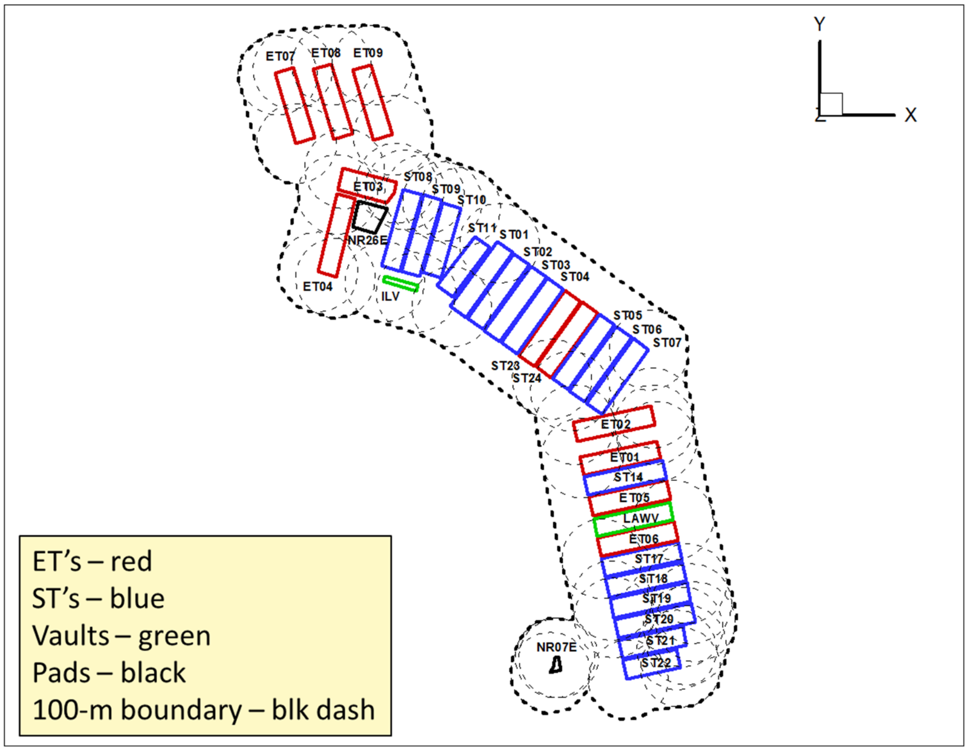


Figure 1-5. New E-Area footprints (33 DU's) and 100-m boundary.

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**
- **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. In most cases, modeling parameters are set in a bounding manner with respect to the population of DUs being represented by each screening model.

1.3 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 groundwater 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 groundwater inventory limit system. Consistency implies higher inventory limits are achieved in each subsequent tier.
- Consider a four-tiered system of groundwater 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 is to get a dozen or so parent nuclides going into the detailed PORFLOW flow and transport analysis.
- Ensure consistency in the groundwater 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 groundwater 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 groundwater 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 groundwater 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 base 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 Groundwater and Intruder Screening report addresses the "screening" and "bounding" tiers of the four-tiered system described above. The screening tier consists of Tier 0 and Tier 1 steps. The bounding tier 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), by investigation of the full-chain parent and progeny half-lives and activities. The parent radionuclides not screened by Tier 0 are then analyzed using the Tier 1 groundwater leaching models and intruder screening. The Tier 1 screening step utilizes the NRCP screening methodology (NCRP 1996) or the Nuclear Regulatory Commission Drinking Water Screening Model (NRCDWSM) (Kennedy and Strenge 1992). These models are described later in this report. The parent radionuclides not screened by Tier 1 are then analyzed using the Tier 2 analyses.

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 and aquifer transport models that take into account, to some degree, both decay and transport aspects (excluding physical dispersive aspects). The ultimate radionuclide lists resulting from these multi-Tiered 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 unit (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 results provided within Revision 0 of this report only pertain to Tier-0 and Tier-1 results. These results strongly indicate that a Tier-2 step would be beneficial, and a later Revision will include the results of this Tier-2 effort. Note that the potential need for a trigger-value list will also be assessed during the Tier-2 effort.

1.4 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 groundwater 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 groundwater 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 (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 groundwater 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 groundwater 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 groundwater 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 PA of the ELLWF. 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. The list of radionuclides remaining after Tier-0 screening, are then analyzed and further screened using conservative GW leaching models developed by the NCRP and the NRC. This step is known as Tier-1 screening. The list of radionuclides remaining after Tier-1 screening, are then analyzed and screened using PORFLOW 1D vadose/aquifer zone flow and transport models. This step is known as the Tier-2 or bounding screening approach. The final list of radionuclides generated from Tier-2 screening is used in the next PA of ELLWF.

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);
- Forecasted 2040 projected inventories for all active and future DUs (Sink 2016a);
- Maximum estimated inventories derived from worker gamma-ray factor exposure limits for B-25 boxes (WAC procedures);
- 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 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 the approximate 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.

Details regarding the above closure inventory aspects are discussed in Appendices C through H.

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., 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 the 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).
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 will address all of the 1,252 radionuclides and either keep them for further evaluation in Tier-1 or screen them out for no further evaluation. The Tier-0 screening process development is complete at this point and be applied to the radionuclides of interest.

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).

2.2 Tier-1: Groundwater and Intruder Radionuclide Screening

The RadScreen computer algorithm implements the Tier-1 level of groundwater and intruder radionuclide screening. The Tier-1 screening process involves three levels of execution [Steps 1 and 3 are 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 groundwater scenarios (various infiltration rates and release times) are processed for the ICRP-07 and Tier-0 list of radionuclides through each of the NCRP123 or the NRC Drinking Water Scenario models. The waste zone represents the areal footprint and nominal waste height of each disposal unit model. 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 groundwater scenario (release time and infiltration rate). The short chain activities in the aquifer zone are converted to concentrations for the groundwater pathways dose calculations using the volume of infiltration in a year. Aquifer dilution factors, mixing with regional groundwater, at the 100-m compliance well are futher applied to the radionuclide screening doses. The short chain concentrations (pCi/m3 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 groundwater 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 groundwater 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 groundwater and intruder pathway. Each radionuclide's inventory is multiplied by each of the groundwater and intruder screening factors and then compared to the corresponding screening criteria. If any of the groundwater 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 groundwater 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 groundwater and from agricultural activity in a garden using contaminated soil. The NCRP123 method for determining the radionuclide concentration in the groundwater is to elute radionuclides from the disposed waste directly into the groundwater 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. 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 3.3.

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 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 2-1 (extracted from Smith 2016).

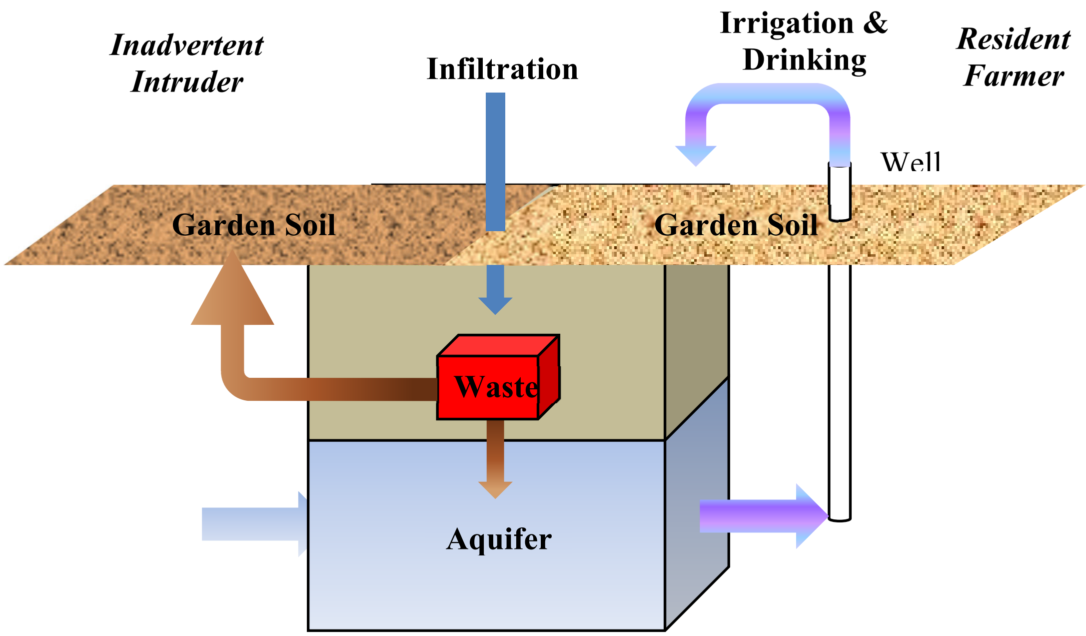


Figure 2-1. Illustration of RadScreen NCRP123 screening dose model.

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:

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

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:

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

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 waste and aquifer zone 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)

2.2.2 NRC Drinking Water Scenario Model

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

For the soil scenarios, a conservative method of estimating the concentration of radionuclides in a groundwater 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 water movement. For this water-use model, it is assumed that radionuclides migrate to the groundwater 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 groundwater aquifer over time.

A conceptual representation of the three-box water-use model for the drinking water scenario is shown in Figure 2-2. 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 groundwater 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 groundwater aquifer (box 3) are initially free of contamination.
- The vertical saturated hydraulic conductivity is greater than the infiltration rate (no ponding or perched water is allowed).

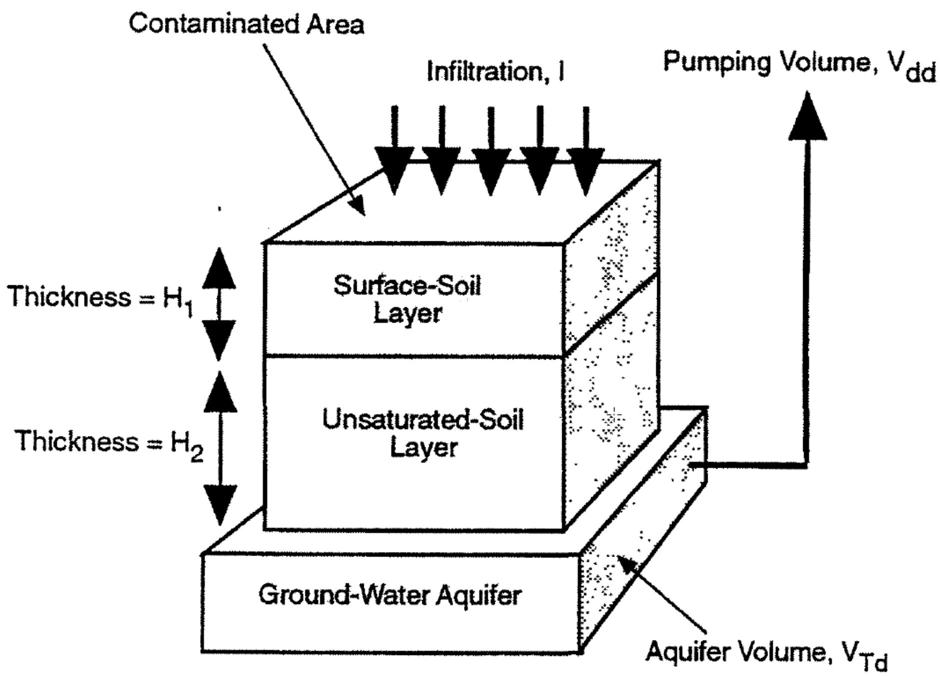


Figure 2-2. Conceptual representation of the drinking water scenario water-use model.

- There is no retardation in 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.
- Water is removed from the aquifer at a constant rate during all years of interest in the analysis.

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 more vertically downward at least as fast as the infiltration rate.

Figure 2-3 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 groundwater 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 groundwater system.

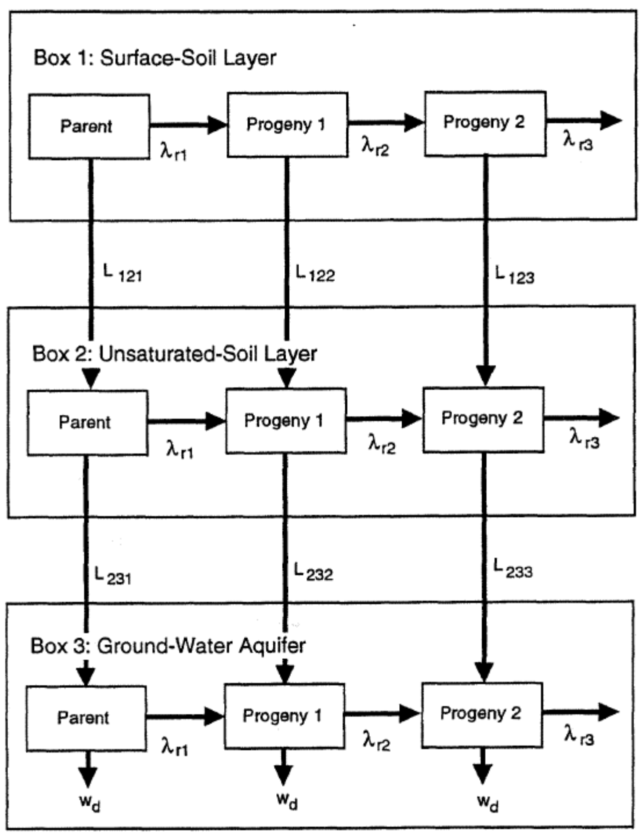


Figure 2-3. Three-box water-use model for the drinking water scenario.

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

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

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

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:

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

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.

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

$$\frac{dN_{3j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{3i} + L_{23j}N_{2j} - \lambda_j N_{3j} - w_p N_{3j} \tag{2-7}$$

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_p ....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)

2.3 Tier-2: PORFLOW 1D Groundwater Screening Model

The advective and dispersive effects of contaminant transport within a porous media are not explicitly taken into account during the Tier-1 screening. These effects result in reduced concentration values at the downstream 100-m Point-of-Assessment (POA). Thus, yielding additional conservatism in the Tier-1 process.

The Tier-2 bounding screening approach improves the Tier-1 leaching models by utilizing PORFLOW 1D vadose and aquifer flow and transport models. 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 will be varied along with multiple infiltration rates which simulate uncovered and covered DU operations. Transient contaminant fluxes of the short chain leaving the water table are post-processed to determine a single "worst" case where the transient maximum contaminant flux of each short chain radionuclide is written out and used as sources to a PORFLOW 1D aquifer transport model. The PORFLOW 1D aquifer transport model includes regional aquifer flows and soil properties from the General Separations Area flow model (Flach 2018). The footprint of the aquifer transport is sufficient in size to compute maximum transient short chain concentrations at the 100-m POA. The maximum transient short chain concentrations are then processed through the SRNL Dose Toolkit (PreDose and PA/CA Limits and Doses) to compute GW pathway doses. The doses are then compared to the same screening criteria used in the Tier-1 screening.

3.0 Screening Analysis and Discussion

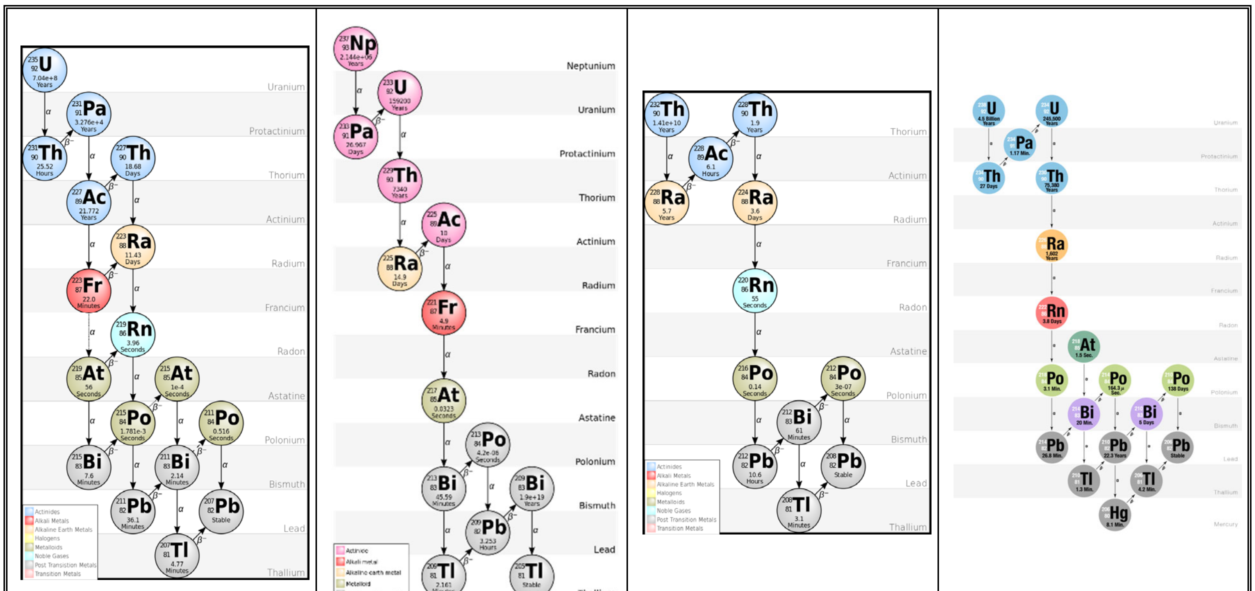
The results obtained from the first tiers of screening analyses (i.e., Tier-0, and Tier-1) are presented within this section. The basis behind the models employed, the parameter settings chosen, and results obtained is provided. Key sensitivity results are also provided in Appendix I. Since stable nuclides (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 reduced listing as well.

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" (i.e., potentially adds members to the list), while the last four are "exclusive" (i.e., 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.

<u>Step 1. Member of Actinium, Neptunium, Thorium or Uranium decay series (Inclusion)</u>

HLW sludge is known to contain the first member of each of four 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 this step, 62 radionuclides have been screened (all for inclusion) and 1190 remain.

<u>Step 2. Radionuclides characterized in residual sludge material estimate (inclusion)</u>

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 HLW

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 this step 112 radionuclides have been screened (all for inclusion) and 1140 remain.

<u>Step 3. Radionuclides which are not in waste due to their physical state (exclusion)</u>

Some elements exist only as gases. Argon, krypton, neon and xenon are in this category and have 24 radionuclides as shown in Table 3-3. 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 this step, 136 radionuclides have been screened (112 for inclusion and 24 for exclusion) and 1116 remain.

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 decay series (they have no ongoing source of formation) with a half-life below 0.23 years which decay 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 this step, 616 radionuclides have been screened (112 for inclusion and 504 for exclusion) and 636 remain.

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 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.

Step 6. Radionuclides with precursors which ingrow 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 which ingrow 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.

At the end of Tier-0 screening, 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. List of radionuclides for Tier-1 screening

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.

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. 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

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 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.

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

Inadvertent intruder analysis was performed for the five disposal unit models using the ICRP-07 and Tier-0 list of radionuclides and radionuclide inventories projected at the closure of E-Area, inventories based on gamma-ray dose limits for handling B-25 boxes (LAWV and Trench DUs), weight-based inventories in B-25 boxes (0.01 wt% of pure radionuclide in each B-25 box estimated from WITS data) or the default historical screening inventory of 10^7 Ci (see Appendices C through H for details). The minimum (limiting) radionuclide inventories from the above estimates are used in the screening process. The default historical screening inventory is ignored for H-3 in the ILV and LAWV since the projected closure inventory exceeds this value.

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 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 an 1171-year period. The short chain is solved numerically using the matrix exponential method in lieu of solving the full chain, because using 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. Transient full chain activities are produced for each parent nuclide as uniformly distributed waste zone soil concentrations (pCi/m^3 per Ci of parent) for intruder dose calculations.

The transient full chain waste zone 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 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).

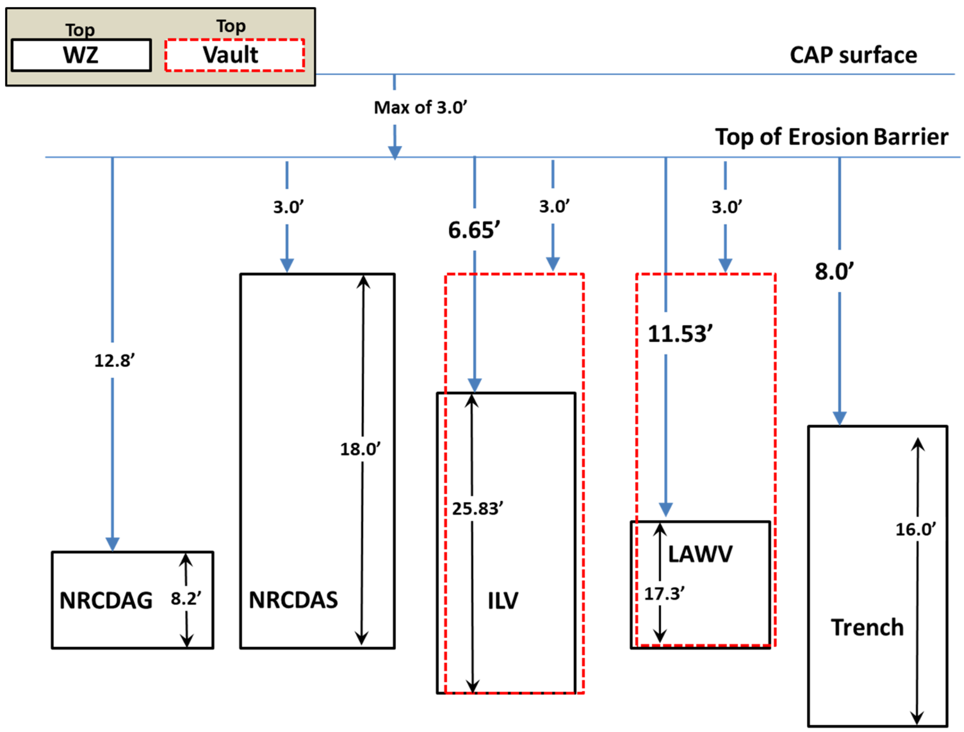


Figure 3-2. Critical dimensions for inadvertent intruder analysis.

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 inventories at closure 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.

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 ICRP07 and Tier-0 radionuclides. The starting lists studied for each DU model were:

- Tier-0 (271) for Trench, ILV, and LAWV models;
- Tier-0 (295) for NRCDA models; and
- ICRP07 (1,252) for all five models.

3.2.1 Tier-1 ILV Inadvertent Intruder Screening

The Intermediate Level Vault 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.

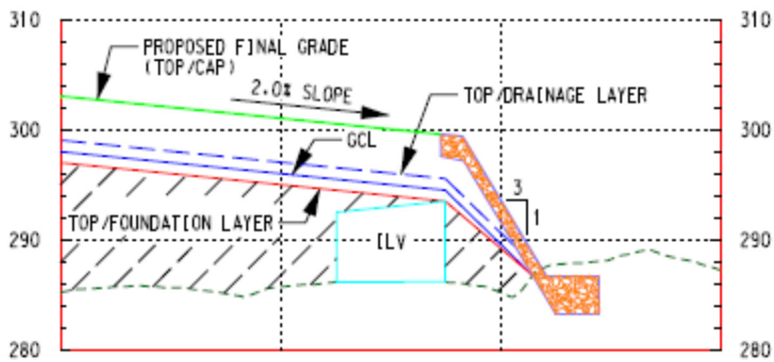


Figure 3-3. ILV cross-section through short axis of the vault.

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.

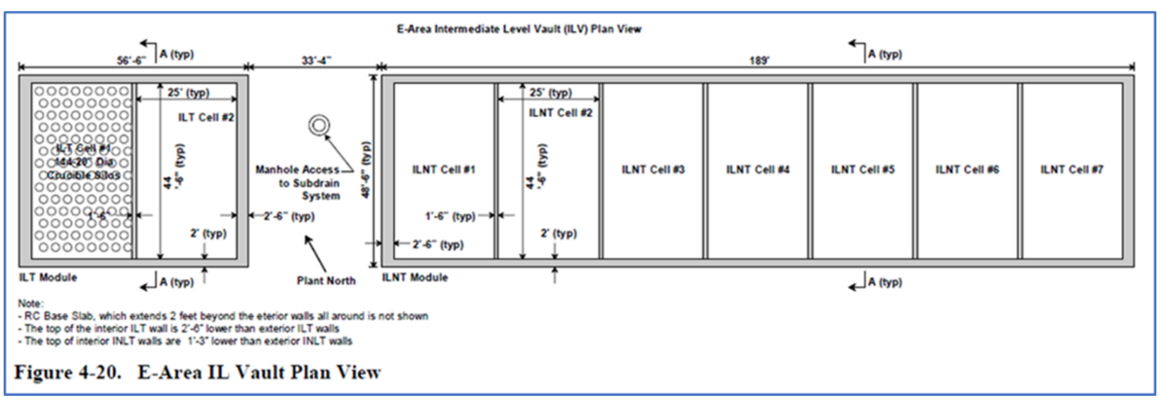


Figure 3-4. ILV plan view of the vault.

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 36 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	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	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 271 to 27 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	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	Re-186m	Tb-158	Tc-98
Th-229	Ti-44	V-50					

3.2.2 Tier-1 LAWV Inadvertent Intruder Screening

The Low-Activity Waste Vault 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.

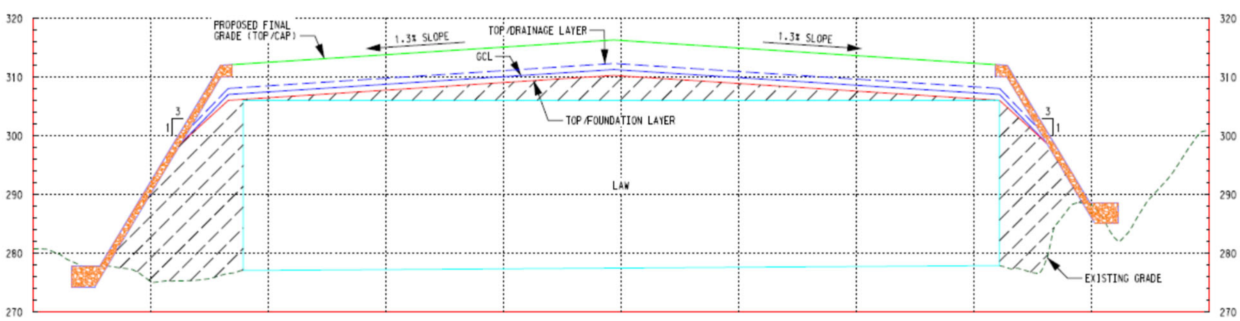


Figure 3-5. LAWV cross-section through long axis of the vault.

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.

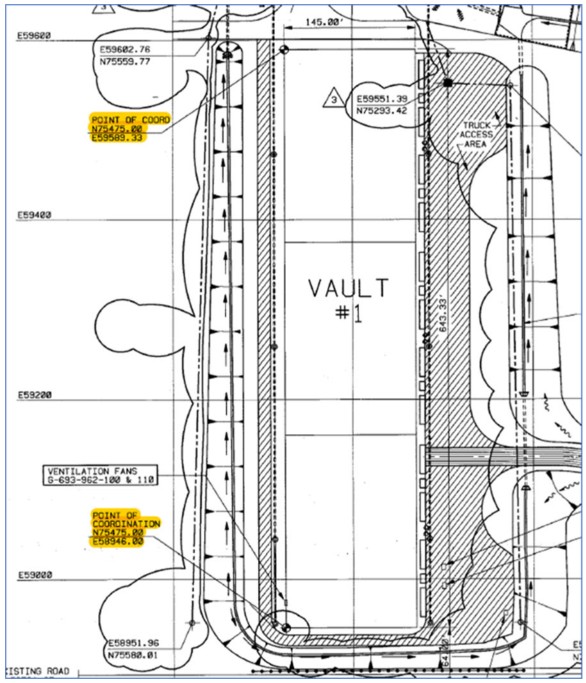


Figure 3-6. LAWV plan view of the vault.

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)
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				

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

Naval Reactor Component Disposal Areas 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.

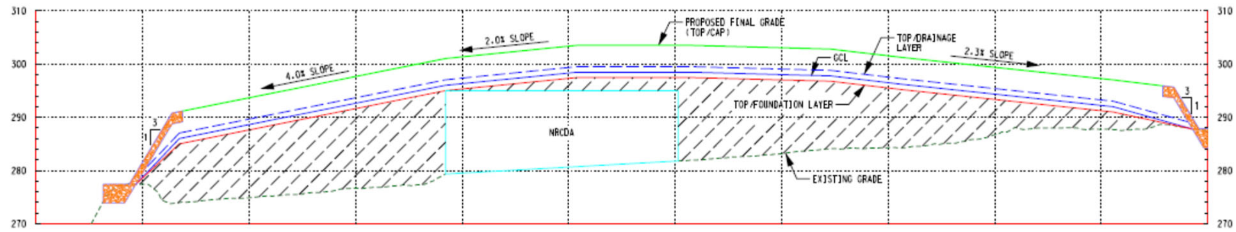


Figure 3-7. 643-26E NRCDA cross-section looking east.

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)
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 144 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	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	Nb-91	Nb-91m	Nb-92
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	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 71 as shown in Table 3-25

Table 3-25. Tier-0 radionuclides that failed Tier-1 NRCDAG 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	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	Nb-91	Nb-92	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	Sr-90	Tb-157	Tb-158	Tc-97
Tc-98	Te-123	Th-229	Th-230	Ti-44	V-50	Zr-93	

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

Slit Trenches are below-grade earthen disposal units 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 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 disposal units 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 disposal unit 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 disposal unit 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
(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 120 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-243	Ar-42	At-207	At-209	At-211
Bi-202	Bi-208	Bi-210m	Bk-245	Bk-249	C-14	Ca-41	Cf-244
Cf-247	Cf-248	Cf-249	Cf-251	Cf-253	Cf-254	Cf-255	Cm-240
Cm-241	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	In-115	Ir-192n	Kr-81
La-137	La-138	Lu-176	Mn-53	Nb-91	Nb-91m	Nb-92	Nb-94
Nd-144	Np-232	Np-235	Np-236	Np-236m	Np-237	Os-186	Pa-229
Pa-230	Pa-232	Pb-194	Pb-202	Pb-202m	Pb-205	Pm-145	Po-208
Po-209	Pt-190	Pu-232	Pu-236	Pu-237	Pu-239	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	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-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 80 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-243	Bi-208	Bi-210m	Bk-249	C-14	Ca-41
Cf-248	Cf-249	Cf-251	Cf-253	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	In-115	Ir-192n
Kr-81	La-137	La-138	Lu-176	Mn-53	Nb-91	Nb-92	Nb-94
Nd-144	Np-235	Np-236	Np-237	Os-186	Pa-232	Pb-202	Pb-205
Pm-145	Po-208	Po-209	Pt-190	Pu-236	Pu-239	Pu-241	Pu-243
Ra-226	Re-186m	Re-187	Si-32	Sm-146	Sm-147	Sm-148	Sn-126
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-238	V-50

3.3 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.

NCRP123 groundwater radionuclide screening was performed for the five DU models using the following sources of inventories:

- ICRP-07 and Tier-0 list of radionuclides and radionuclide inventories projected at the closure of E-Area,
- inventories based on gamma-ray dose limits for handling B-25 boxes (LAWV and Trench DUs),
- weight-based inventories in B-25 boxes (assuming 0.01 wt% of pure radionuclide in each B-25 box estimated from WITS data) or
- the default historical screening inventory of 10^7 Ci (see Appendices C through H for details).

The minimum radionuclide inventories from the above estimates are used in the screening process. The default historical screening inventory is ignored for H-3 in the ILV and LAWV since the projected closure inventory exceeds this value.

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 nominal 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 groundwater scenario (for unique combinations of release time and infiltration rate). The short chain activities in the aquifer zone are converted to concentrations for the groundwater pathway dose calculations using the volume of infiltration in a year. Aquifer dilution factors, mixing with regional groundwater, at the 100-m POA are further applied to the radionuclide screening doses (see Appendix G for details). 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 groundwater 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 groundwater protection and PA AP human receptors. The EPA groundwater 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 groundwater 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 groundwater 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 groundwater protection spans 1171 years from the time of waste burial to 1171 years during the screening period. The PA groundwater 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 groundwater protection and PA AP with progeny contributions rolled up for each radionuclide parent. The screening factors are multiplied by the radionuclide inventories (i.e., projected closure inventories) to produce maximum expected EPA groundwater protection and PA AP doses. The radionuclide is screened out for PORFLOW PA analysis if the EPA groundwater protection or PA AP doses do not exceed its screening criterion.

A discussion of NCRP123 groundwater 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.

3.3.1 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 groundwater 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
Aquifer dilution factor	1/1378 (7.2569E-4)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NCRP123 groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 237 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	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-39	Ar-42	At-207	At-209	At-211
Au-193	Ba-133	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-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
Cm-238	Cm-239	Cm-240	Cm-241	Cm-244	Cm-245	Cm-247	Cm-249
Cm-250	Cm-251	Cs-135	Cs-135m	Cs-137	Cu-59	Dy-148	Dy-152
Dy-154	Dy-157	Es-249	Es-250	Es-250m	Es-251	Es-253	Es-254
Es-254m	Es-255	Eu-146	Eu-150	Eu-150m	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	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-93m	Mo-99
Nb-91	Nb-91m	Nb-92	Nb-94	Nb-94m	Nb-99m	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-237	Pb-194	Pb-202	Pb-202m
Pb-205	Pb-210	Pd-107	Pm-145	Pm-146	Pm-151	Po-206	Po-207
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-244	Pu-245
Pu-246	Ra-226	Ra-227	Ra-230	Rb-87	Rb-90	Rb-90m	Re-186m
Re-187	Rh-97m	Rn-209	Rn-210	Rn-211	Ru-97	Sb-129	Si-32
Sm-145	Sm-146	Sm-147	Sm-148	Sn-129	Sr-90	Tb-148	Tb-148m
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-226	Th-229	Th-230
Th-232	Th-233	Ti-44	Tl-194	Tl-194m	Tl-210	U-230	U-231
U-233	U-234	U-235	U-236	U-237	U-238	U-239	U-240
U-242	V-50	Xe-135	Xe-137	Y-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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 121 as shown in Table 3-33.

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

Ac-227	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-244	Cm-245	Cm-247	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	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-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
Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sr-90	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232	Ti-44
Tl-210	U-233	U-234	U-235	U-236	U-237	U-238	U-240
V-50							

3.3.2 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 groundwater 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
Aquifer dilution factor	1/157 (6.3694E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NCRP123 groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 209 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	Ar-39	Ar-42	At-206	At-207	At-209	At-211
Au-193	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-253	Cf-254	Cf-255	Cl-36
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	Fr-227	Gd-148	Gd-150	Gd-152	H-3	Hf-174

Hf-178m	Hf-182	Hg-193m	Hg-194	Ho-154	Ho-163	Ho-166m	I-129
In-115	Ir-192n	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-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-237	Pb-194	Pb-202	Pb-202m	Pb-205	Pb-210	Pd-107	Pm-145
Pm-146	Po-209	Po-218	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-230	Rb-87	Re-186m	Re-187	Rh-97	Rh-97m
Rn-207	Rn-209	Rn-210	Rn-211	Rn-222	Sb-129	Se-79	Si-32
Sm-145	Sm-146	Sm-147	Sm-148	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-226	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-237	U-238	U-239	U-240	U-242	V-50
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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 116 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
Ar-39	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Ca-41	Cd-113	Cf-248	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
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	Pb-210	Pd-107
Pm-145	Pm-146	Po-209	Po-218	Pt-190	Pu-236	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Pu-243	Pu-246	Rb-87	Re-186m	Re-187
Rn-222	Se-79	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	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-237
U-238	U-240	V-50	Zr-93				

3.3.3 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 groundwater 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
Aquifer dilution factor	1/372 (2.6882E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NCRP123 groundwater 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 groundwater 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
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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 297 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-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
Cm-238	Cm-239	Cm-240	Cm-241	Cm-242	Cm-244	Cm-249	Cm-250
Cm-251	Co-55	Co-60	Co-60m	Cs-134m	Cs-135m	Cs-137	Cu-59
Dy-148	Dy-150	Dy-152	Dy-154	Dy-157	Er-154	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-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-145	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-157	Ho-163	Ho-166m	I-129	I-135	In-109
In-115	Ir-192n	K-40	Kr-81	La-133	La-137	La-138	Lu-173
Lu-174	Lu-174m	Lu-176	Mn-53	Mo-91	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-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-237	Pb-194	Pb-202	Pb-202m	Pb-205
Pb-210	Pd-101	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-243
Pu-245	Pu-246	Ra-222	Ra-227	Ra-228	Ra-230	Rb-87	Rb-90
Rb-90m	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	Ru-97	Sb-125
Sb-129	Se-79m	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sm-155
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	Ti-44	Tl-194	Tl-194m	Tl-204	Tl-210

Tm-163	Tm-171	U-230	U-231	U-234	U-235	U-237	U-238
U-239	U-240	U-242	V-50	W-179	Xe-135	Xe-135m	Xe-137
Y-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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 295 to 133 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-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	Cm-242	Cm-244	Cm-249	Cm-250	Co-60	Co-60m	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-173	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-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-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-237	U-238	U-240	V-50			

3.3.4 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 groundwater 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

Parameter	Setting	Comment
Waste zone thickness	18 ft (5.4864 m)	Height of welded casks
Aquifer dilution factor	1/372 (2.6882E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NCRP123 groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP07 radionuclides from 1,252 to 202 as shown in Table 3-44.

Table 3-44. ICRP07 radionuclides that failed Tier 1 NRCDAS NCRP123 groundwater screening

Ac-226	Ac-230	Ac-231	Ac-233	Al-26	Am-237	Am-238	Am-239
Am-240	Am-241	Am-243	Am-244	Am-244m	Am-245	Am-246	Am-246m
Ar-39	Ar-42	At-206	At-209	Au-193	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	Cm-238	Cm-239
Cm-240	Cm-241	Cm-244	Cm-249	Cm-250	Cm-251	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-237	Pb-194	Pb-202
Pb-202m	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-87	Re-186m
Re-187	Rh-97	Rh-97m	Rn-209	Rn-210	Ru-97	Sb-129	Si-32
Sm-146	Sm-147	Sm-148	Sn-129	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	Ti-44	Tl-194	Tl-194m
U-231	U-238	U-239	U-240	U-242	V-50	Xe-135	Xe-135m
Y-93	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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 295 to 98 as shown in Table 3-45.

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

Al-26	Am-241	Am-243	Am-245	Am-246m	Ar-39	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-244	Cm-249	Cm-250	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	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	Si-32	Sm-146	Sm-147	Sm-148	Tb-157	Tb-158	Tc-97
Tc-98	Tc-99	Te-123	Th-229	Th-230	Ti-44	U-238	U-240
V-50	Zr-93						

3.3.5 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 groundwater 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
Aquifer dilution factor	1/107 (9.3458E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NCRP123 groundwater 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 groundwater 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
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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 279 as shown in Table 3-48.

Table 3-48. ICRP-07 radionuclides that failed Tier-1 Generic Trench NCRP123 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
At-218	Au-193	Au-193m	Ba-133m	Bi-202	Bi-208	Bi-210m	Bk-245
Bk-246	Bk-248m	Bk-249	Bk-250	Bk-251	C-14	Ca-41	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	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-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-145	Eu-150
Eu-150m	Eu-152	Eu-152n	Eu-154	Eu-154m	Eu-155	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-146	Gd-148	Gd-150	Gd-152	Ge-68
H-3	Hf-172	Hf-174	Hf-178m	Hf-182	Hg-193	Hg-193m	Hg-194
Ho-154	Ho-154m	Ho-157	Ho-163	I-129	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	Mo-93	Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92
Nb-94	Nb-94m	Nd-144	Nd-147	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-228	Pa-229	Pa-230
Pa-232	Pa-237	Pb-194	Pb-202	Pb-202m	Pb-205	Pb-210	Pm-145
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-245	Pu-246	Ra-222	Ra-226	Ra-227
Ra-228	Ra-230	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
Rn-218	Ru-97	Ru-106	Sb-129	Se-79	Si-32	Sm-145	Sm-146
Sm-147	Sm-148	Sm-151	Sn-109	Sn-125	Sn-126	Sr-90	Ta-172
Ta-179	Tb-148	Tb-148m	Tb-149	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-232	Th-233
Ti-44	Tl-194	Tl-194m	Tl-204	Tm-163	U-228	U-230	U-231

U-232	U-233	U-234	U-235	U-236	U-238	U-239	U-240
U-242	V-49	V-50	W-179	W-179m	Xe-137	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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 136 as shown in Table 3-49.

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

Ag-108m	Am-241	Am-242m	Am-243	Am-245	Am-246m	At-218	Bi-208
Bi-210m	Bk-249	Bk-250	C-14	Ca-41	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-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	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	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
Os-194	Pa-232	Pb-202	Pb-205	Pb-210	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	Re-186m	Re-187	Rh-101	Rh-102m	Rn-218
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-232	Ti-44	Tl-204	U-232	U-233
U-234	U-235	U-236	U-238	U-240	V-49	V-50	Zr-93

3.4 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 groundwater radionuclide screening was performed for the five DU models using the ICRP-07 and Tier-0 list of radionuclides and radionuclide inventories projected at the closure of E-Area, inventories based on gamma-ray dose limits for handling B-25 boxes (LAWV and Trench DUs), weight-based inventories in B-25 boxes (0.01 wt% of pure radionuclide in each B-25 box estimated from WITS data) or the default historical screening inventory of 10^7 Ci (see Appendices C through H for details). The minimum radionuclide inventories from the above estimates is used in the screening process. The default historical screening inventory is ignored for H-3 in the ILV and LAWV since the projected closure inventory exceeds this value.

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 groundwater 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 groundwater 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 groundwater 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 nominal or 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 groundwater scenario (release time and infiltration rate). The short chain activities in the aquifer zone are converted to concentrations for the groundwater pathways dose calculations using the volume of infiltration in a year. Aquifer dilution factors, mixing with regional groundwater, at the 100-m POA (compliance well) are further applied to the radionuclide screening doses. The short chain concentrations (pCi/m^3 per Ci of parent) in the groundwater 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 groundwater 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 groundwater protection and PA AP human receptors. The EPA groundwater 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 groundwater 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 groundwater 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 groundwater protection spans 1171 years from the time of waste burial to 1171 years during the screening period. The PA groundwater 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 groundwater 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 groundwater protection and PA AP doses. The radionuclide is screened out for PORFLOW PA analysis if the EPA groundwater protection or PA AP doses do not exceed its screening criterion.

A discussion of NRCDWSM groundwater 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.

3.4.1 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 groundwater model is identical to the intruder waste zone with the exception of using the collapsed state of the ILV waste. The ILV NCRP123 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
Unsaturated-soil layer thickness	53.5 ft (16.307 m)	53.5 ft depth from waste zone bottom to water table
Aquifer dilution factor	1/1378 (7.2569E-4)	Table G-2, Eq. (B-15) concentration

Parameter	Setting	Comment
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 groundwater scenarios were simulated using the NRCDWSM groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 183 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	Al-26	Am-237	Am-238	Am-239
Am-240	Am-241	Am-242	Am-244	Am-244m	Am-245	Am-246	Am-246m
Ar-39	Ar-42	At-209	Au-193	Ba-133	Be-10	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-252	Cf-253	Cf-254	Cf-255	Cl-36	Cm-238	Cm-239	Cm-240
Cm-241	Cm-247	Cm-249	Cm-250	Cm-251	Cs-135	Cs-137	Cu-59
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	H-3	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-93m
Mo-99	Nb-91	Nb-91m	Nb-92	Nb-99m	Nd-144	Ni-59	Ni-63
Np-232	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238	Np-240
Np-240m	Np-241	Os-186	Pa-229	Pa-230	Pa-231	Pa-232	Pa-237
Pb-202	Pb-205	Pd-107	Pm-146	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-244	Pu-245	Pu-246	Ra-226	Ra-230
Rb-87	Rb-90	Rb-90m	Re-186m	Re-187	Ru-97	Sb-129	Si-32
Sm-146	Sm-147	Sm-148	Sn-129	Sr-90	Tb-157	Tb-158	Tc-93
Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123	Te-129	Te-129m
Th-229	Th-230	Ti-44	U-230	U-231	U-233	U-234	U-235
U-237	U-238	U-239	U-240	V-50	Xe-135	Xe-137	

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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 108 as shown in Table 3-53.

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

Ac-227	Al-26	Am-241	Am-242	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-250	Cf-252	Cf-253	Cl-36	Cm-247
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	Nb-91	Nb-92
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	Pd-107	Pm-146
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	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
0U-237	U-238	U-240	V-50				

3.4.2 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 groundwater 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
Aquifer dilution factor	1/157 (6.3694E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NRCDWSM groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 152 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	Al-26	Am-237	Am-238	Am-241
Am-242	Am-243	Ar-39	Ar-42	At-209	Au-193	Be-10	Bi-208
Bi-210m	Bk-245	Bk-247	Bk-248m	Bk-249	C-14	Ca-41	Cd-113
Cf-244	Cf-246	Cf-247	Cf-248	Cf-253	Cf-254	Cf-255	Cl-36
Cm-238	Cm-239	Cm-240	Cm-241	Cm-244	Cm-245	Cm-246	Cm-250
Cs-137	Cu-59	Dy-154	Es-249	Es-250	Es-250m	Es-251	Es-253
Es-254	Es-254m	Es-255	Fe-60	Fm-251	Fm-252	Fm-253	Fm-254
Fm-255	Fm-257	Gd-148	Gd-150	Gd-152	H-3	Hf-174	Hf-182
Hg-193m	Hg-194	Ho-163	Ho-166m	I-129	In-115	Ir-192n	Kr-81
La-137	La-138	Lu-176	Mn-53	Mo-99	Nb-91	Nb-92	Nb-94
Nd-144	Ni-59	Ni-63	Np-232	Np-233	Np-235	Np-236	Np-236m
Np-237	Os-186	Pa-229	Pa-230	Pa-231	Pa-237	Pb-202	Pb-202m
Pb-205	Pb-210	Pd-107	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-246	Ra-230	Rb-87	Re-186m	Re-187	Rn-209	Rn-222
Se-79	Si-32	Sm-146	Sm-147	Sm-148	Sr-90	Tb-148	Tb-157
Tb-158	Tc-93m	Tc-97	Tc-97m	Tc-98	Tc-99	Te-123	Te-129
Te-129m	Th-230	Th-232	Ti-44	Tl-194	Tl-194m	U-230	U-231
U-233	U-234	U-235	U-236	U-237	U-238	U-240	V-50

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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 97 as shown in Table 3-57.

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

Ac-227	Al-26	Am-241	Am-242	Am-243	Ar-39	Be-10	Bi-208
Bi-210m	Bk-247	Bk-249	C-14	Ca-41	Cd-113	Cf-248	Cf-253
Cl-36	Cm-244	Cm-245	Cm-246	Cm-250	Cs-137	Dy-154	Es-253
Es-254	Fe-60	Fm-254	Fm-257	Gd-148	Gd-150	Gd-152	H-3
Hf-174	Hf-182	Hg-194	Ho-163	Ho-166m	I-129	In-115	Ir-192n
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-231
Pb-202	Pb-205	Pb-210	Pd-107	Po-209	Pt-190	Pu-236	Pu-238
Pu-239	Pu-240	Pu-241	Pu-242	Pu-243	Pu-246	Rb-87	Re-186m
Re-187	Rn-222	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-230	Th-232
Ti-44	U-233	U-234	U-235	U-236	U-237	U-238	U-240
V-50							

3.4.3 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 groundwater 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 depth from waste zone bottom to water table
Aquifer dilution factor	1/372 (2.6882E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NRCDWSM groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 227 as shown in Table 3-60.

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

Ac-226	Ac-230	Ac-231	Ag-113	Al-26	Am-237	Am-238	Am-239
Am-240	Am-242	Am-243	Am-244	Am-244m	Am-245	Am-246	Am-246m
Ar-39	Ar-42	At-207	At-209	At-211	Au-193	Au-193m	Ba-133
Ba-133m	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-109	Cd-113
Cd-113m	Ce-133	Ce-133m	Cf-244	Cf-246	Cf-247	Cf-248	Cf-250
Cf-252	Cf-253	Cf-254	Cf-255	Cm-238	Cm-239	Cm-240	Cm-241
Cm-249	Cm-250	Cm-251	Co-60	Co-60m	Cs-134m	Cs-135m	Cs-137
Cu-59	Dy-148	Dy-154	Es-249	Es-250	Es-250m	Es-251	Es-253
Es-254	Es-254m	Es-255	Eu-150	Eu-150m	Eu-152	Fe-60	Fm-251
Fm-252	Fm-253	Fm-254	Fm-255	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-163	Ho-166m	I-129	I-135	In-115	Ir-192n	K-40
Kr-81	La-133	La-137	La-138	Lu-174	Lu-176	Mn-53	Mo-93
Mo-93m	Mo-99	Na-22	Nb-91	Nb-91m	Nb-92	Nb-93m	Nb-94

Nb-99	Nb-99m	Nd-144	Ni-59	Ni-63	Np-232	Np-233	Np-234
Np-235	Np-236	Np-236m	Np-238	Np-239	Np-240	Np-240m	Np-241
Os-186	Os-194	Pa-229	Pa-230	Pa-232	Pa-233	Pa-237	Pb-194
Pb-202	Pb-202m	Pb-205	Pb-210	Pd-107	Pm-145	Pm-146	Pm-151
Po-206	Po-207	Po-208	Po-209	Pt-190	Pt-193	Pt-193m	Pu-232
Pu-234	Pu-235	Pu-236	Pu-237	Pu-239	Pu-240	Pu-243	Pu-245
Pu-246	Ra-227	Ra-228	Ra-230	Rb-87	Rb-90	Rb-90m	Re-186m
Re-187	Rh-97	Rh-97m	Rh-101	Rh-102m	Rn-209	Rn-211	Ru-97
Sb-129	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sn-129	Sr-90
Ta-179	Tb-148	Tb-148m	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-226	Th-228	Th-229	Th-233	Ti-44	Tl-194	Tl-194m	Tl-204
U-230	U-231	U-237	U-238	U-239	U-240	U-242	V-50
Xe-135	Xe-135m	Xe-137					

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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 295 to 116 as shown in Table 3-61.

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

Al-26	Am-242	Am-243	Am-245	Am-246m	Ar-39	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	Cm-249	Cm-250
Co-60	Co-60m	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-174	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-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-239	Pu-240	Pu-243
Pu-246	Ra-228	Rb-87	Re-186m	Re-187	Rh-101	Rh-102m	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
U-237	U-238	U-240	V-50				

3.4.4 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 groundwater 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 depth from waste zone bottom to water table
Aquifer dilution factor	1/372 (2.6882E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NRCDWSM groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP07 radionuclides from 1,252 to 155 as shown in Table 3-64.

Table 3-64. ICRP07 radionuclides that failed Tier 1 NRCDAS NRCDWSM groundwater screening

Ac-226	Ac-230	Ac-231	Al-26	Am-237	Am-238	Am-239	Am-240
Am-241	Am-244	Am-244m	Am-245	Am-246	Am-246m	Ar-39	Ar-42
Bi-208	Bi-210m	Bk-245	Bk-246	Bk-247	Bk-248m	Bk-250	Bk-251
C-14	Ca-41	Cd-113	Cf-246	Cf-247	Cf-248	Cf-250	Cf-252
Cf-253	Cf-254	Cf-255	Cl-36	Cm-238	Cm-239	Cm-240	Cm-241
Cm-249	Cm-250	Cm-251	Cs-135m	Cu-59	Dy-154	Es-249	Es-250
Es-250m	Es-251	Es-253	Es-254	Es-254m	Es-255	Fe-60	Fm-251
Fm-252	Fm-253	Fm-254	Fm-255	Fm-257	Gd-148	Gd-150	Gd-152
Hf-174	Hf-182	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-93
Mo-93m	Mo-99	Nb-91	Nb-91m	Nb-92	Nb-94	Nb-99m	Nd-144
Ni-59	Ni-63	Np-234	Np-235	Np-236	Np-236m	Np-237	Np-238
Np-240	Np-240m	Np-241	Os-186	Pa-229	Pa-230	Pa-231	Pa-232
Pa-233	Pa-234	Pa-237	Pb-202	Pm-146	Po-209	Pt-190	Pt-193m
Pu-234	Pu-235	Pu-236	Pu-237	Pu-239	Pu-240	Pu-241	Pu-243
Pu-245	Pu-246	Ra-226	Ra-230	Rb-87	Re-186m	Re-187	Rh-97
Rh-97m	Ru-97	Sb-129	Si-32	Sm-146	Sm-147	Sm-148	Sn-129
Tb-157	Tb-158	Tc-97	Tc-97m	Tc-98	Tc-99	Tc-99m	Te-123
Te-129	Te-129m	Th-229	Th-230	Ti-44	U-231	U-239	U-240
V-50	Xe-135	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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 295 to 90 as shown in Table 3-65.

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

Al-26	Am-241	Am-245	Am-246m	Ar-39	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-249	Cm-250	Dy-154	Es-253	Es-254	Fe-60	Fm-254
Fm-257	Gd-148	Gd-150	Gd-152	Hf-174	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	Pm-146	Po-209	Pt-190
Pu-236	Pu-239	Pu-240	Pu-241	Pu-243	Pu-246	Ra-226	Rb-87
Re-186m	Re-187	Si-32	Sm-146	Sm-147	Sm-148	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Ti-44	U-240
V-50	Zr-93						

3.4.5 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 groundwater 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 depth from waste zone bottom to water table
Aquifer dilution factor	1/107 (9.3458E-3)	Table G-2, Eq. (B-15) concentration
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 groundwater scenarios were simulated using the NRCDWSM groundwater 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 groundwater 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 groundwater screening criteria reduce the number of ICRP-07 radionuclides from 1,252 to 192 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	Ag-108m	Ag-113	Am-237	Am-238	Am-239
Am-240	Am-241	Am-242m	Am-243	Am-244	Am-244m	Am-245	Ar-42
At-207	At-209	At-211	Au-193	Au-193m	Ba-133m	Bi-202	Bi-208
Bi-210m	Bk-245	Bk-246	Bk-248m	Bk-249	Bk-251	C-14	Ca-41
Cd-113m	Ce-133	Ce-133m	Cf-244	Cf-246	Cf-247	Cf-248	Cf-249
Cf-251	Cf-253	Cf-254	Cf-255	Cl-36	Cm-238	Cm-239	Cm-240
Cm-241	Cm-244	Cm-245	Cm-247	Cm-249	Cm-250	Co-60m	Cs-134m
Cs-137	Cu-59	Dy-148	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	Fr-227	Gd-148	Gd-150	Gd-152
H-3	Hf-174	Hf-178m	Hf-182	Hg-193	Hg-193m	Hg-194	Ho-163
I-129	In-115	Ir-192n	K-40	Kr-81	La-133	La-137	La-138
Lu-176	Mn-53	Mo-99	Nb-91	Nb-91m	Nb-92	Nb-94	Nd-144
Ni-59	Ni-63	Np-232	Np-233	Np-235	Np-236	Np-236m	Np-237
Np-238	Np-241	Os-186	Os-194	Pa-229	Pa-230	Pa-232	Pa-237
Pb-194	Pb-202	Pb-202m	Pb-205	Pm-145	Po-208	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-90	Rb-90m	Re-186m	Re-187	Rn-209	Rn-211	Sb-129	Si-32

Sm-145	Sm-146	Sm-147	Sm-148	Sr-90	Ta-179	Tb-148	Tb-148m
Tb-150	Tb-157	Tb-158	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-232
Ti-44	Tl-194	Tl-194m	Tl-204	U-230	U-231	U-232	U-233
U-234	U-235	U-236	U-238	U-240	U-242	V-50	Xe-137

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 groundwater screening criteria reduce the number of Tier-0 radionuclides from 271 to 104 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	Bi-208	Bi-210m	Bk-249
C-14	Ca-41	Cd-113m	Cf-248	Cf-249	Cf-251	Cf-253	Cl-36
Cm-244	Cm-245	Cm-247	Cm-249	Cm-250	Co-60m	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	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	Np-238	Os-186	Os-194	Pa-232	Pb-202	Pb-205	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	Re-186m	Re-187	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-229	Th-230	Th-232	Ti-44	Tl-204
U-232	U-233	U-234	U-235	U-236	U-238	U-240	V-50

3.5 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 recommends following up with Tier-2 efforts focusing on 1D vadose zone and 1D aquifer fate and transport analyses. SWM Engineering will be consulted before proceeding to Tier 2.

For inadvertent intruder, the Tier-1 screening results are considered to be an acceptable number of radionuclides. 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.

4.0 Summary and Conclusions

Tier-0 screening analysis was presented in Section 3.1 and reduced the list of ICRP-07 radionuclides from 1,252 to 271. The list of Tier-0 radionuclides was augmented for the NRCDAG and NRCDAS DU screening models to include radionuclides identified in the NRCDA inventories. The NRCDA Tier-0 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) 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.

Tier-1 inadvertent intruder radionuclide screening of the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench are presented in Section 3.2. Site-specific features of existing disposal units were incorporated into generic or composite intruder screening models. The short-chain members of each parent radionuclide with a half-life cutoff of 1 year were modeled in the waste zone with full-chain expansion assuming secular equilibrium. The short-chain atom number ordinary differential equations were solved efficiently using the matrix exponential method with minimal roundoff errors. The intruder screening models were then exercised through the full spectrum of acute and chronic intruder scenarios analyzed in the ELLWF PA. Maximum dose screening factors during the inadvertent intruder POC were computed for all radionuclides. Several methods or sources for estimating inventories were used to obtain a set of limiting radionuclide disposal inventories including: 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, or the historical screening inventory of 10^7 Ci. Screening criteria of 0.1% of performance objectives were used instead of 1% as done in previous screening analyses.

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 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/y performance measure x 0.001 = 0.004 mrem/yr) over the entire period of performance.

Bullet one ensures that no inconsistencies creep 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.

Tier-1 groundwater radionuclide screening of the ILV, LAWV, NRCDAG, NRCDAS and Generic Trench are presented in Section 3.3 and 3.4 for both groundwater screening models. Site-specific features of existing disposal units were incorporated into generic or composite groundwater screening models. The short-chain of each radionuclide with a half-life cutoff of 1 year were modeled in the soil-layers and aquifer with leaching after the minimum release time occurred. The series of coupled ordinary differential equations representing the soil-layer(s) and aquifer were solved efficiently using the matrix exponential method. Aquifer short-chain concentrations were expanded into full-chain concentrations assuming secular equilibrium. A series of groundwater screening scenarios were executed with various infiltration rates and release times. The maximum aquifer concentration time series was computed from the full-chain concentrations of each groundwater screening scenario. The groundwater screening models were then exercised through the EPA groundwater protection and PA AP human receptors analyzed in the ELLWF PA. Maximum dose screening factors during the EPA groundwater and PA AP POC were computed for all radionuclides. The list of radionuclide inventories used in the intruder screening were used for groundwater screening. The screening criterion of 0.1% of the performance objective were used.

Based on the recommended (i.e., the "NCRP-like") groundwater and intruder screening methodologies the list of parent nuclides that fail the screening criterion (i.e., 0.1% SOF) are summarized in Table 4-1 through Table 4-10 for each of the disposal unit screening models. These are the actual parent radionuclides that fail the Tier-1 groundwater and inadvertent intruder screening processes and will be subjected to a follow-on Tier-2 screening process**.**.

Radionuclides that failed Tier-1 ILV intruder and groundwater screening are shown in Table 4-1 and Table 4-2 respectively.

Table 4-1. Radionuclides that failed Tier-1 ILV intruder screening

Ac-227	Al-26	Bi-207	Bi-208	Bi-210m	Cm-250	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	Re-186m	Tb-158	Tc-98
Th-229	Ti-44	V-50					

Table 4-2. Radionuclides that failed Tier-1 ILV groundwater screening

Ac-227	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-244	Cm-245	Cm-247	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	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-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
Si-32	Sm-145	Sm-146	Sm-147	Sm-148	Sr-90	Tb-157	Tb-158
Tc-97	Tc-98	Tc-99	Te-123	Th-229	Th-230	Th-232	Ti-44
Tl-210	U-233	U-234	U-235	U-236	U-237	U-238	U-240
V-50							

Radionuclides that failed Tier-1 LAWV intruder and groundwater screening are shown in Table 4-3 and Table 4-4 respectively.

Table 4-3. 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				

Table 4-4. Radionuclides that failed Tier-1 LAWV groundwater screening

Ac-227	Ag-108m	Al-26	Am-241	Am-242	Am-242m	Am-243	Am-245
Ar-39	Be-10	Bi-207	Bi-208	Bi-210m	Bk-247	Bk-249	Bk-250
C-14	Ca-41	Cd-113	Cf-248	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
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	Pb-210	Pd-107
Pm-145	Pm-146	Po-209	Po-218	Pt-190	Pu-236	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Pu-243	Pu-246	Rb-87	Re-186m	Re-187
Rn-222	Se-79	Si-32	Sm-145	Sm-146	Sm-147	Sm-148	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-237
U-238	U-240	V-50	Zr-93				

Radionuclides that failed Tier-1 Generic NRCDA intruder and groundwater screening are shown in Table 4-5 and Table 4-6 respectively.

Table 4-5. Radionuclides that failed Tier-1 Generic NRCDA 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 4-6. Radionuclides that failed Tier-1 Generic NRCDA 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	Cm-242	Cm-244	Cm-249	Cm-250	Co-60	Co-60m	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-173	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-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-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-237	U-238	U-240	V-50			

Radionuclides that failed Tier-1 NRCDA Special intruder and groundwater screening are shown in Table 4-7 and Table 4-8 respectively.

Table 4-7. Radionuclides that failed Tier-1 Special NRCDA 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	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	Nb-91	Nb-92	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	Sr-90	Tb-157	Tb-158	Tc-97
Tc-98	Te-123	Th-229	Th-230	Ti-44	V-50	Zr-93	

Table 4-8. Radionuclides that failed Tier-1 Special NRCDA groundwater screening

Al-26	Am-241	Am-243	Am-245	Am-246m	Ar-39	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-244	Cm-249	Cm-250	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	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	Si-32	Sm-146	Sm-147	Sm-148	Tb-157	Tb-158	Tc-97
Tc-98	Tc-99	Te-123	Th-229	Th-230	Ti-44	U-238	U-240
V-50	Zr-93						

Radionuclides that failed Tier-1 Generic Trench intruder and groundwater screening are shown in Table 4-9 and Table 4-10, respectively.

Table 4-9. Radionuclides that failed Tier-1 Generic Trench intruder screening

Ag-108m	Am-241	Am-243	Bi-208	Bi-210m	Bk-249	C-14	Ca-41
Cf-248	Cf-249	Cf-251	Cf-253	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	In-115	Ir-192n
Kr-81	La-137	La-138	Lu-176	Mn-53	Nb-91	Nb-92	Nb-94
Nd-144	Np-235	Np-236	Np-237	Os-186	Pa-232	Pb-202	Pb-205
Pm-145	Po-208	Po-209	Pt-190	Pu-236	Pu-239	Pu-241	Pu-243
Ra-226	Re-186m	Re-187	Si-32	Sm-146	Sm-147	Sm-148	Sn-126
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-238	V-50

Table 4-10. Radionuclides that failed Tier-1 Generic Trench groundwater screening

Ag-108m	Am-241	Am-242m	Am-243	Am-245	Am-246m	At-218	Bi-208
Bi-210m	Bk-249	Bk-250	C-14	Ca-41	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-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	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	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
Os-194	Pa-232	Pb-202	Pb-205	Pb-210	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	Re-186m	Re-187	Rh-101	Rh-102m	Rn-218
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-232	Ti-44	Tl-204	U-232	U-233
U-234	U-235	U-236	U-238	U-240	V-49	V-50	Zr-93

5.0 Recommendations, Path Forward, or Future Work

The Tier-0 list of radionuclides are recommended for the Tier-1 inadvertent intruder and groundwater radionuclide screening for all disposal units. 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 is the union of 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 groundwater screening. The NRCDWSM also provides an additional storage and leaching mechanism from an unsaturated-soil zone between the waste and the groundwater aquifer in a manner similar to transport models planned in Tier-2. Therefore, SRNL recommends radionuclides for each disposal unit model that failed Tier-1 groundwater screening be analyzed in Tier-2. The lists of radionuclides that failed groundwater screening in NRCDWSM will be compared to the results of Tier-2.

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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 $\{c_{w,j}(t)\}_{out}$.

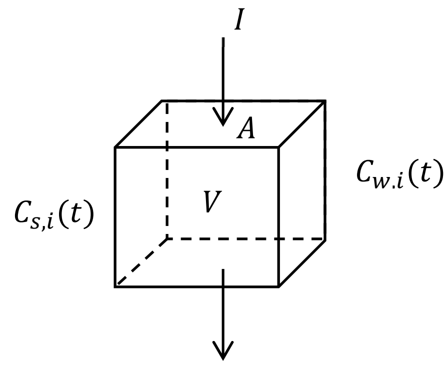

Figure A-1. Volume of contaminated soil.

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:

$$\frac{d(\alpha_w V C_{w,j})}{dt} = \alpha_w V \sum_{i=1}^{j-1} b_{ji}\lambda_i C_{w,i} - \alpha_w V \lambda_j C_{w,j} - IA\{c_{w,j}(t)\}_{out} + F_j \quad \text{(A-1)}$$

$$\frac{d(\alpha_s \rho_s V C_{s,j})}{dt} = \alpha_s \rho_s V \sum_{i=1}^{j-1} b_{ji}\lambda_i C_{s,i} - \alpha_s \rho_s V \lambda_j C_{s,j} - F_j \quad \text{(A-2)}$$

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, $\theta_w = S\phi$, where θ_w is moisture content and S 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 Eq. (A-3) and Eq. (A-4) into Eq. (A-1) and Eq. (A-2) and adding the resulting equations eliminates the solid-water transfer rate and gives a single equation:

$$\frac{d(\{\theta_w + \alpha_s\rho_s k_{d,j}\}VC_{w,j})}{dt} = \sum_{i=1}^{j-1}\{\theta_w + \alpha_s\rho_s k_{d,i}\}Vb_{ji}\lambda_i C_{w,i} - \{\theta_w + \alpha_s\rho_s k_{d,j}\}V\lambda_j C_{w,j} - IAC_{w,j} \tag{A-5}$$

Introducing the retardation factor R_j and defining the effective concentration of radionuclide j in the porous matrix per total volume of soil $C_{e,j}$, Eq. (A-5) can be expressed as:

$$\frac{d(VC_{e,j})}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i VC_{e,i} - \lambda_j VC_{e,j} - IAC_{w,j} \tag{A-6}$$

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 Eq. (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 Eq. (A-8) and Eq. (A-9) as:

$$C_{w,j} = \frac{N_j}{\theta_w R_j V} \tag{A-10}$$

Substituting the expressions in Eq. (A-9) and Eq. (A-10) into Eq. (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 Eq. (A-11) is defined for each radionuclide j as:

$$L_j = \frac{I}{\theta_w R_j H} \tag{A-12}$$

Update of Eq. (A-11) with the expression from Eq. (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 Eq. (A-13). We now designate the overlying soil layer as 1 and the lower soil layer as 2. The new set of radionuclide balance equations for each soil layer are written as:

$$\frac{dN_{1j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{1i} - \lambda_j N_{1j} - L_{12j} N_{1j} \tag{A-14}$$

$$\frac{dN_{2j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{2i} + L_{12j} N_{1j} - \lambda_j N_{2j} - L_{23j} N_{2j} \tag{A-15}$$

$$\frac{dN_{3j}}{dt} = \sum_{i=1}^{j-1} b_{ji}\lambda_i N_{3i} + L_{23j} N_{2j} - \lambda_j N_{3j} - w_p N_{3j} \tag{A-16}$$

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

N_{2i} ....atom count of precursor radionuclide i in 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_p ....rate constant for pumping of water from the aquifer (1/y)

Appendix B. Numerical Solution of Radionuclide Balances in Multilayer Soils

This general radioactive decay problem describes the decay of an initial quantity of 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:

$$\begin{pmatrix} \dot{N}_1(t) \\ \dot{N}_2(t) \\ \dot{N}_3(t) \\ \dot{N}_4(t) \\ \dot{N}_5(t) \end{pmatrix} + \begin{pmatrix} \lambda_1 & 0 & 0 & 0 & 0 \\ -b_{21}\lambda_1 & \lambda_2 & 0 & 0 & 0 \\ -b_{31}\lambda_1 & -b_{32}\lambda_2 & \lambda_3 & 0 & 0 \\ 0 & 0 & -b_{43}\lambda_3 & \lambda_4 & 0 \\ 0 & 0 & 0 & -b_{54}\lambda_4 & \lambda_5 \end{pmatrix} \begin{pmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ N_4(t) \\ N_5(t) \end{pmatrix} = \dot{\vec{N}}(t) + \Lambda\vec{N}(t) = 0 \qquad \text{(B-1)}$$

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 Eq. (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:

$$\tilde{\Lambda}_{12} = \begin{pmatrix} L_{121} & 0 & 0 & 0 & 0 \\ 0 & L_{122} & 0 & 0 & 0 \\ 0 & 0 & L_{123} & 0 & 0 \\ 0 & 0 & 0 & L_{124} & 0 \\ 0 & 0 & 0 & 0 & L_{125} \end{pmatrix} \qquad \text{(B-2)}$$

Adding the contribution of Eq. (B-2) to Eq. (B-1) with leaching yields:

$$\dot{\vec{N}}_1(t) + (\Lambda + \tilde{\Lambda}_{12})\vec{N}_1(t) = 0 \qquad \text{(B-3)}$$

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 Eq. (B-3) that incorporates a delayed start of leaching, t_r, is given by the following set of equations

$$\begin{aligned} \vec{N}_1(t) &= e^{-\Lambda t}\vec{N}_1(0) \qquad t \le t_r \\ \vec{N}_1(t) &= e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \quad t > t_r \\ \vec{N}_1(0) &= \left\{10^{12}\,\text{pCi}/\lambda_1 \quad 0 \quad 0 \quad 0 \quad 0\right\} \end{aligned} \tag{B-4}$$

The matrix exponential method Harr (2007) is used to solve the system of linear first order differential equations with constant coefficients in Eq. (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 Eq. (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 Eq. (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 Eq. (B-5) for $t > t_r$ should have the form of the forcing function on the RHS (leachate source term) as

$$\vec{N}_{2p}(t) = Ae^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \tag{B-8}$$

Substitution of the particular solution, Eq. (B-8), and the leachate source term from Eq. (B-4) into Eq. (B-6) yields

$$\begin{gathered} -A\left(\Lambda+\tilde{\Lambda}_{12}\right)e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ +\Lambda Ae^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) = \tilde{\Lambda}_{12}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ -A\tilde{\Lambda}_{12}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) = \tilde{\Lambda}_{12}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \\ A = -I \end{gathered} \tag{B-9}$$

The general solution of Eq. (B-5) becomes

$$\vec{N}_2(t) = e^{-\Lambda(t-t_r)}\vec{C} - e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \tag{B-10}$$

Applying the initial condition of Eq (B-10) as $\vec{N}_2(t_r) = 0$ yields

$$\vec{C} = \vec{N}_1(t_r) \tag{B-11}$$

The general solution of the nonhomogeneous Eq. (B-5) is

$$\begin{aligned} \vec{N}_2(t) &= 0 & t \le t_r \\ \vec{N}_2(t) &= e^{-\Lambda(t-t_r)}\vec{N}_1(t_r) - e^{-(\Lambda+\tilde{\Lambda}_{12})(t-t_r)}\vec{N}_1(t_r) & t > t_r \end{aligned} \qquad \text{(B-12)}$$

$\vec{N}_1(t)$ 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

$$\vec{A}_1(t) = \vec{\lambda}\vec{N}_1(t),\ \vec{A}_2(t) = \vec{\lambda}\vec{N}_2(t) \qquad \text{(B-13)}$$

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 for the inadvertent intruder pathways dose calculations as

$$\vec{C}_{wz}(t) = \vec{A}_1(t) / V_1 \qquad \text{(B-14)}$$

where

$\vec{C}_{wz}(t)$ ....short chain concentrations in waste zone (pCi/m^3)

V_1 ....volume of waste zone, A×H (m^3)

The short chain activities in the aquifer zone are converted to concentrations for the groundwater pathways dose calculations as

$$\vec{C}_{az}(t) = DF\frac{\vec{A}_2(t)}{I \times A \times 1\,y} \qquad \text{(B-15)}$$

where

$\vec{C}_{az}(t)$ ....short chain concentrations in aquifer zone (pCi/m^3)
A ....cross-sectional or projected area of soil layer (m^2)
DF ....dilution factor for mixing with aquifer regional flow
I ....infiltration rate of clean water, (m/y)

The short chain concentrations in the waste and aquifer zones 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).

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 groundwater aquifer (box 3).

The solution of the surface-soil layer (box 1) atom count in Eq. (B-3) with a delayed start of leaching, t_r , is given by the following set of equations

$$\begin{aligned} \vec{N}_1(t) &= e^{-\Lambda t}\vec{N}_1(0) \qquad t \le t_r \\ \vec{N}_1(t) &= e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \quad t > t_r \\ \vec{N}_1(0) &= \left\{10^{12}\,\text{pCi}/\lambda_1 \quad 0 \quad 0 \quad 0 \quad 0\right\} \end{aligned} \tag{B-16}$$

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

$\tilde{\Lambda}_{23}$ ....leach rate matrix from box 2 to box 3

$\vec{N}_2(t)$ ....atom count of short chain in the unsaturated-soil layer, box 2

The general solution of Eq. (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 Eq. (B-17) is

$$\begin{aligned} \vec{N}_{2h}(t) &= 0 \qquad t \le t_r \\ \vec{N}_{2h}(t) &= Ce^{-(\Lambda+\tilde{\Lambda}_{23})(t-t_r)}\vec{N}_1(t_r) \quad t > t_r \end{aligned} \tag{B-19}$$

The particular solution of Eq. (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, Eq. (B-20), and the leachate source term from Eq. (B-16) into Eq. (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 Eq. (B-17) becomes

$$\vec{N}_2(t) = Ce^{-(\Lambda+\tilde{\Lambda}_{23})(t-t_r)}\vec{N}_1(t_r) - \tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12}-\tilde{\Lambda}_{23}\right)^{-1}e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \tag{B-22}$$

Applying the initial condition of Eq. (B-22) as $\vec{N}_2(t_r) = 0$ yields

$$C = \tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} \tag{B-23}$$

The general solution of the nonhomogeneous Eq. (B-17) is

$$\begin{aligned} &\vec{N}_2(t) = 0 && t \le t_r \\ &\vec{N}_2(t) = \tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} e^{-(\Lambda+\Lambda_{23})(t-t_r)}\vec{N}_1(t_r) && \\ &\quad -\tilde{\Lambda}_{12}\left(\tilde{\Lambda}_{12} - \tilde{\Lambda}_{23}\right)^{-1} e^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) && t > t_r \end{aligned} \tag{B-24}$$

The members of the radionuclide chain formed in the groundwater aquifer (box 3) by leaching from the unsaturated-soil layer satisfy the following nonhomogeneous differential equation

$$\dot{\vec{N}}_3(t) + (\Lambda + W)\vec{N}_3(t) = \tilde{\Lambda}_{23}\vec{N}_2(t) \tag{B-25}$$

where the lambda matrix Λ is augmented on the diagonal by the pumping of water from the aquifer of each radionuclide as

$$W = \begin{pmatrix} w_d & 0 & 0 & 0 & 0 \\ 0 & w_d & 0 & 0 & 0 \\ 0 & 0 & w_d & 0 & 0 \\ 0 & 0 & 0 & w_d & 0 \\ 0 & 0 & 0 & 0 & w_d \end{pmatrix} \tag{B-26}$$

where

$\vec{N}_3(t)$ ....atom count of short chain in the groundwater aquifer, box 3

W..........................rate constant for pumping of water from the aquifer for the drinking water scenario (1/y)

The general solution of Eq. (B-25) consists of a homogeneous and a particular solution as

$$\vec{N}_3(t) = \vec{N}_{3h}(t) + \vec{N}_{3p}(t) \tag{B-27}$$

The homogeneous solution of Eq. (B-25) is

$$\begin{aligned} &\vec{N}_{3h}(t) = 0 && t \le t_r \\ &\vec{N}_{3h}(t) = Ce^{-(\Lambda+W)(t-t_r)}\vec{N}_1(t_r) && t > t_r \end{aligned} \tag{B-28}$$

The particular solution of Eq. (B-25) for $t > t_r$ should have the form of the forcing function on the RHS (leachate source term) as

$$\vec{N}_{3p}(t) = Ae^{-\left(\Lambda+\tilde{\Lambda}_{23}\right)(t-t_r)}\vec{N}_1(t_r) + Be^{-\left(\Lambda+\tilde{\Lambda}_{12}\right)(t-t_r)}\vec{N}_1(t_r) \tag{B-29}$$

Substitution of the particular solution, Eq. (B-29), and the leachate source term from Eq. (B-24) into Eq. (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 Eq. (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 Eq. (B-31) as $\vec{N}_3(t_r)=0$ 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 Eq. (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 pumping, $W = 0$, Eq. (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 groundwater 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 groundwater 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 for the inadvertent intruder pathways dose calculations as

$$\vec{C}_{wz}(t) = \vec{A}_1(t) \big/ V_1 \tag{B-36}$$

where

$\vec{C}_{wz}(t)$ ....short chain concentrations in surface-soil layer (pCi/m^3)

V_1 ....volume of surface-soil layer, A×H (m^3)

The short chain activities in the groundwater aquifer are converted to concentrations for the groundwater pathways dose calculations as

$$\vec{C}_{az}(t) = DF \frac{\vec{A}_3(t)}{I \times A \times 1\,y} \tag{B-37}$$

where

$\vec{C}_{az}(t)$ ....short chain concentrations in aquifer zone (pCi/m^3)
A ....cross-sectional or projected area of soil layer (m^2)
DF ....dilution factor for mixing with aquifer regional flow
I ....infiltration rate of clean water, (m/y)

The short chain concentrations in the surface-soil layer and groundwater 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).

Appendix C. Projected 2040 ELLWF Closure Inventories

Prior to listing the maximum projected 2040 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;
- 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. The listing below includes the locations of these unique radionuclides though 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				

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
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
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

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
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

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
83	**Nb-94**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
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

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
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
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

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
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

	Nuclide List	ST01	ST02	ST03	ST04	ST05	ST06	ST07	ST08	ST09	ST14	ET01	ET02	ET03	CIG01	LAWV	ILV	NR0	NR1
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
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		

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 appendix reflect the value projected out to 2040 and do not incorporate additional increases associated with the updated closure date of 2065.

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;
    - For Ar-37 no inventory for any DU is provided. The only source of Ar-37 is within the TPBARs and as stated above its release from the casks exceeds the CP;
- 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 Appendices D and E and also apply to all 1,252 radionuclides.

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 that workers can be exposed to. 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.

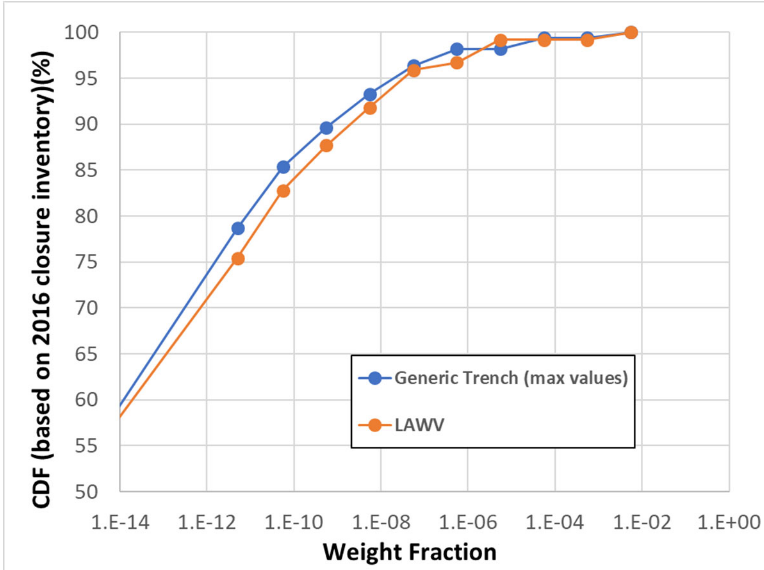

Figure E-1. Histogram plot of weight-based inventory limit versus Sink (2016) 2040 projection.

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.

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.

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
ST17	**ST17**	49.18	29.18	15.84	13.35
ST18	**ST18**	48.13	28.13	15.95	12.18

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)
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 VZ 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
ST22	69709	10727	24	115	13	7.2	29.5
ET02	62743	9634	22	104	11	6.5	11.8

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)**
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.

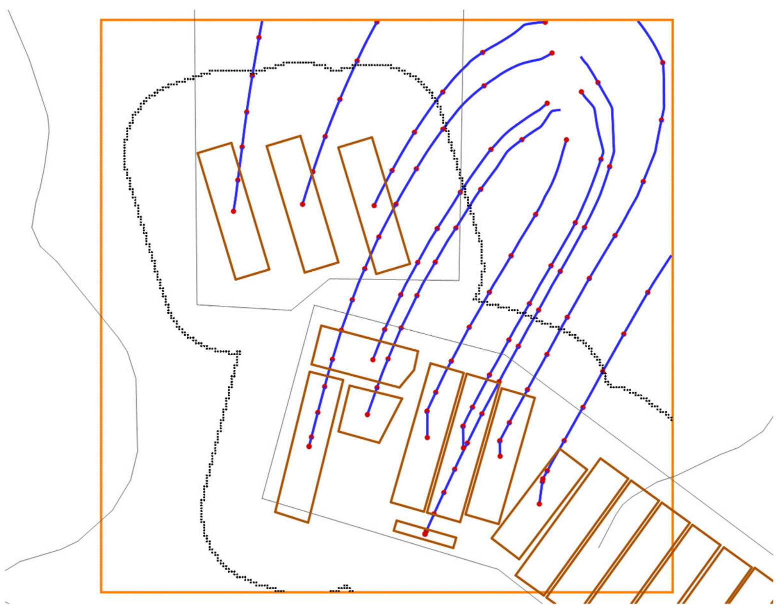

Figure F-4. 3D streamtraces for DUs within the West cutout.

The total travel time to the 100-m POA can be computed based on:

$$\Delta t_{Tot} = \Delta t_{VZ} + \Delta t_{Aq} \qquad \text{(F-3)}$$

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 Factors

Contaminant transport for a specific DU travels essentially downwards through the VZ and ends up reaching the top surface of the water table directly underneath this DU's footprint. 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).

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, or future units) within E-Area. Both uncovered and E-Area covered flow models were considered. PORFLOW-based aquifer steady-state tracer runs were performed for all DUs based on the following GSA aquifer flow cutouts:

- **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** (DU8A, DU8B, DU8C, ET03, ET04, ILV, NRCDA26E, ST08, ST09, ST10, ST11)

For each DU a uniform strength source term was applied (i.e., constant rate of gmole/yr) whose numerical value was set such that the "maximum" tracer concentration reaching the 100-m POA was $1x10^{-8}$ gmole/ft^3). For example, PORFLOW results are shown in Figure G-1 and Figure G-2 for the ET04 and ILV DUs, respectively.

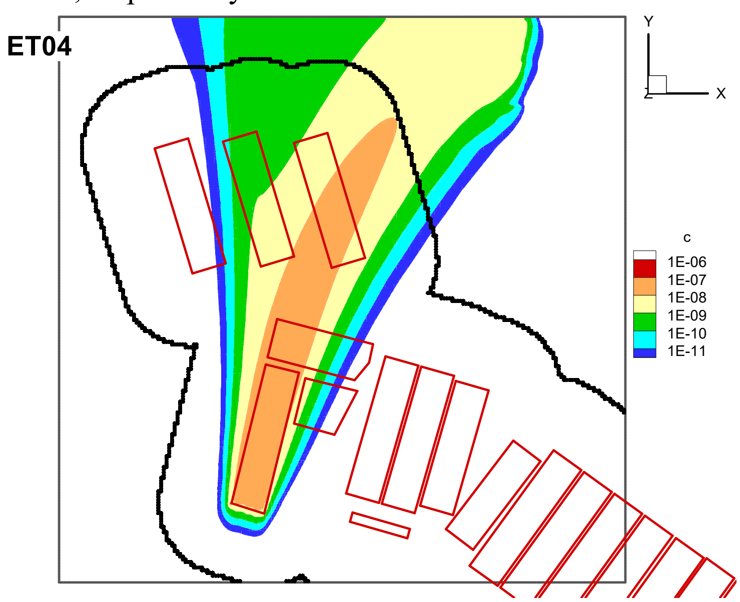

Figure G-1. PORFLOW-based steady-state tracer plume for ET04.

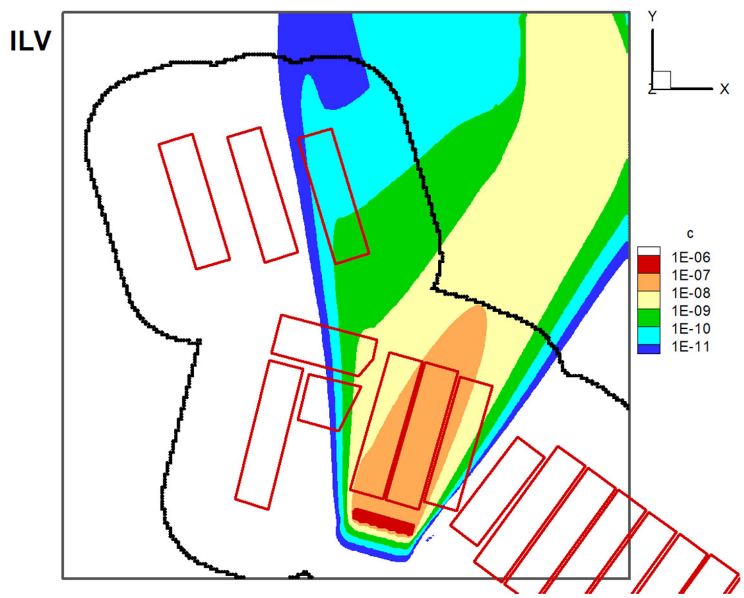

Figure G-2. PORFLOW-based steady-state tracer plume for the ILV.

One-order in magnitude concentration contours are shown where the 1×10^{-8} value seats in between the orange and yellow regions. As both figures indicate, this concentration value just touches the 100-m POA.

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:

$$DF_{DU} = \frac{\langle c \rangle_{DU}}{c_{POA}^{max}} = \frac{\langle c \rangle_{DU}}{1x10^{-8}} \qquad \text{(G-1)}$$

where

DF_{DU} ....Dilution Factor for a specific DU (-)

$\langle c \rangle_{DU}$ ....Average water table surface concentration within the given DU t (gmole/ft^3)

c_{POA}^{max} ....Maximum aquifer concentration along the 100-m POA ($1x10^{-8}$ gmole/ft^3)

Dilution Factors were computed using Eq. (G-1). A summary of these DF values for the uncovered case are listed in Table G-1.

Table G-1. Summary of Dilution Factor values for uncovered E-Area case.

Center DU	Uncovered Dilution Factor
ST01	233
ST02	254
ST03	265
ST04	266
CIG1	240
CIG2	172
ST05	190
ST06	152
ST07	148
ST11	282

East1 DU	Uncovered Dilution Factor
ET01	112
ET02	107
LAWV	157
ST14	113
ST15	115
ST16	146
ST17	147
ST18	140
ST19	134
ST20	125
ST21	149
ST22	159

West DU	Uncovered Dilution Factor
DU8A	207
DU8B	156
DU8C	132
ET03	215
ET04	266
ILV	1378
NRCDA26E	372
ST08	195
ST09	224
ST10	343

East2 DU	Uncovered Dilution Factor
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. Recommended Dilution Factor values for GW screening purposes.

DU	DF
Generic Trench	107
LAWV	157
ILV	1378
NRCDAG	372
NRCDAS	195

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.

Appendix H. NRCDA Inventories and Waste Age

The NRCDA DUs are unique within the E-Area facility since the waste being buried within it all comes 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 is 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. It's 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 is based on the assumption 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:

$$m = \frac{526}{2020 - 1950} = 7.51 \tag{H-2}$$

To compute an average age of decommissioned reactors at some point in time (T), the following integral was developed:

$$\langle T \rangle = \frac{1}{R_d(T_o)T - T_o} \int_{T_o}^{T} (t - T_o) R_d dt = \frac{m}{3}(T - T_o)^2 \tag{H-3}$$

where

$\langle T \rangle$ ....Average age of decommissioned reactors (yr)

As shown in Eq. (H-3), a simple expression results. 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

Key Time	Year	Number of Reactors Built	Number of Reactors Decommissioned	Composite Age of Decommissioned Reactors
	2018	512	248	11.0
	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 99.9% 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%

	NR1 2040 Forecast	Representative Sample Cask	Max Value
Isotope	Fraction Crud (%)	Fraction Crud (%)	Fraction Crud (%)
IN114M	0.0000%	100.0000%	100.0000%
IR192	0.0000%	100.0000%	100.0000%
IR192M	0.0000%	100.0000%	100.0000%
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%

	NR1 2040 Forecast	Representative Sample Cask	Max Value
Isotope	Fraction Crud (%)	Fraction Crud (%)	Fraction Crud (%)
SN119M	0.0000%	0.0000%	0.0000%
SN121	0.0000%	100.0000%	100.0000%
SN121M	0.0000%	100.0000%	100.0000%
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

138 List Nuclide	NRCDAS Max Act. (Ci)	NRCDAG Max Act. (Ci)
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
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

138 List Nuclide	NRCDAS Max Act. (Ci)	NRCDAG Max Act. (Ci)
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
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. Sensitivity Results for Tier-1 Radionuclide Lists

For each of the five DU types a variety of parameters were varied to see their impact on the Tier-1 list of radionuclides passing through this level of filtering. The parameters considered were:

- **GW model** – the traditional NCRP model and the 3-Box model;
- **Starting nuclide list** – Bypassing the Tier-0 process and employing the full list of 1,252 radionuclides, Tier-0 list based on SRS waste (i.e., applies to the Trench, ILV, and LAWV models), and Tier-0 list based on Naval Reactor waste (i.e., applies to the NRCDA-G and NRCDA-S models); and
- **Aquifer dilution factor** – no aquifer dilution, 10% and 100% dilution.

For each DU type two tables are provided below. The first table contains the Tier-1 listing where the dilution factor has been fixed to its recommended value. The second table contains similar results where the dilution factor is varied as defined above. In both tables the radionuclide listings have been aligned.

I.1 Generic Trench Model

Table I-1 and Table I-2 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
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	107	107	107	107	-	-
Tier-1 List	279	136	192	104	120	80
	Ac-226		Ac-226		Ac-226	
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233					
	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m
	Ag-113		Ag-113			
	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-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-246					
	Am-246m	Am-246m				
	Ar-42		Ar-42		Ar-42	
	At-206					
	At-207		At-207		At-207	
	At-208					
	At-209		At-209		At-209	
	At-211		At-211		At-211	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Dilution Factor	**107**	**107**	**107**	**107**	**-**	**-**
Tier-1 List	**279**	**136**	**192**	**104**	**120**	**80**
	At-218	At-218				
	Au-193		Au-193			
	Au-193m		Au-193m			
	Ba-133m		Ba-133m			
	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-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250				
	Bk-251		Bk-251			
	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-113m	Cd-113m	Cd-113m	Cd-113m		
	Ce-133		Ce-133			
	Ce-133m		Ce-133m			
	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-251	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251
	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		
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		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-247	Cm-247	Cm-247	Cm-247		
	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					
	Co-60	Co-60				
	Co-60m	Co-60m	Co-60m	Co-60m		
	Cs-134	Cs-134				
	Cs-134m		Cs-134m			
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-150					
	Dy-152					
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Er-154					
	Es-249		Es-249		Es-249	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	107	107	107	107	-	-
Tier-1 List	279	136	192	104	120	80
	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					
	Eu-145					
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m					
	Eu-152	Eu-152				
	Eu-152n					
	Eu-154	Eu-154				
	Eu-154m					
	Eu-155	Eu-155				
	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-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	Fr-212					
	Fr-222					
	Fr-227		Fr-227			
	Gd-145					
	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
	Ge-68	Ge-68				
	H-3	H-3	H-3	H-3		
	Hf-172	Hf-172				
	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
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-154					
	Ho-154m					
	Ho-157					
	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163
	I-129	I-129	I-129	I-129		
	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		
	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

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	107	107	107	107	-	-
Tier-1 List	279	136	192	104	120	80
	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-173	Lu-173				
	Lu-174	Lu-174				
	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
	Mo-93	Mo-93				
	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-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nb-94m					
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	Nd-147					
	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-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-240	Np-240				
	Np-240m	Np-240m				
	Np-241		Np-241			
	Np-242					
	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	
	Pa-230		Pa-230		Pa-230	
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	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-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205
	Pb-210	Pb-210				
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145
	Pm-151					
	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					
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pt-193m		Pt-193m			
	Pu-232		Pu-232		Pu-232	
	Pu-234		Pu-234			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	107	107	107	107	-	-
Tier-1 List	279	136	192	104	120	80
	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-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-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
	Ra-227					
	Ra-228	Ra-228				
	Ra-230		Ra-230		Ra-230	
	Rb-90		Rb-90			
	Rb-90m		Rb-90m			
	Re-179					
	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-97m					
	Rh-101	Rh-101				
	Rh-102m	Rh-102m				
	Rn-207				Rn-207	
	Rn-209		Rn-209			
	Rn-210					
	Rn-211		Rn-211		Rn-211	
	Rn-212					
	Rn-218	Rn-218				
	Ru-97					
	Ru-106	Ru-106				
	Sb-129		Sb-129			
	Se-79	Se-79				
	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				
	Sn-109					
	Sn-125					
	Sn-126	Sn-126			Sn-126	Sn-126
	Sr-90	Sr-90	Sr-90	Sr-90		
	Ta-172					
	Ta-179	Ta-179	Ta-179	Ta-179		
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-150		Tb-150			
	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-93m		Tc-93m			
	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Dilution Factor	**107**	**107**	**107**	**107**	**-**	**-**
Tier-1 List	**279**	**136**	**192**	**104**	**120**	**80**
	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-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-232	Th-232	Th-232	Th-232
	Th-233					
	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		
	Tm-163					
	U-228					
	U-230		U-230		U-230	
	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-236	U-236	U-236	U-236		
	U-238	U-238	U-238	U-238	U-238	U-238
	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-179m					
	Xe-137		Xe-137			
	Zr-93	Zr-93				

Table I-2. Impact Dilution Factor has on Tier-1 Radionuclide Listing for the Generic Trench Disposal Unit.

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	**271**	**271**	**271**	**271**	**271**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Dilution Factor	**1**	**10.7**	**107**	**1**	**10.7**	**107**
Tier-1 List	**156**	**145**	**136**	**132**	**115**	**104**
	Ac-227	Ac-227				
	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m
	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-245	Am-245	Am-245	Am-245	Am-245	Am-245
	Am-246m	Am-246m	Am-246m	Am-246m		

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	10.7	107	1	10.7	107
Tier-1 List	156	145	136	132	115	104
	At-218	At-218	At-218			
	Au-195					
	Ba-133					
	Be-10			Be-10		
	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-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	
	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-113m	Cd-113m	Cd-113m	Cd-113m	Cd-113m	Cd-113m
	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-250	
	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251
	Cf-252					
	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253
	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36
	Cm-243	Cm-243	Cm-243			
	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244
	Cm-245	Cm-245	Cm-245	Cm-245	Cm-245	Cm-245
	Cm-246	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-249	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Co-60	Co-60	Co-60	Co-60		
	Co-60m	Co-60m	Co-60m	Co-60m	Co-60m	Co-60m
	Cs-134	Cs-134	Cs-134	Cs-134		
	Cs-135			Cs-135		
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-152	Eu-152	Eu-152	Eu-152		
	Eu-154	Eu-154	Eu-154	Eu-154		
	Eu-155	Eu-155	Eu-155			
	Fe-55	Fe-55	Fe-55			
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	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	Ge-68			
	H-3	H-3	H-3	H-3	H-3	H-3
	Hf-172	Hf-172	Hf-172	Hf-172	Hf-172	
	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
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	10.7	107	1	10.7	107
Tier-1 List	156	145	136	132	115	104
	I-129	I-129	I-129	I-129	I-129	I-129
	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-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-173			
	Lu-174	Lu-174	Lu-174	Lu-174	Lu-174	
	Lu-174m	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
	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93	
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	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
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	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-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238
	Np-239	Np-239				
	Np-240	Np-240	Np-240	Np-240	Np-240	
	Np-240m	Np-240m	Np-240m	Np-240m		
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	Os-194	Os-194	Os-194	Os-194	Os-194	Os-194
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205
	Pb-210	Pb-210	Pb-210	Pb-210		
	Pm-144	Pm-144				
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145
	Pm-147	Pm-147				
	Po-208	Po-208	Po-208	Po-208	Po-208	Po-208
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-238	Pu-238	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-242	Pu-242
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	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-228	Ra-228	Ra-228	Ra-228	Ra-228	
	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-101	Rh-101	Rh-101	Rh-101		
	Rh-102m	Rh-102m	Rh-102m	Rh-102m		

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	10.7	107	1	10.7	107
Tier-1 List	156	145	136	132	115	104
	Rn-218	Rn-218	Rn-218			
	Rn-222					
	Ru-106	Ru-106	Ru-106	Ru-106		
	Sb-125					
	Se-79	Se-79	Se-79	Se-79	Se-79	
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	Sm-145	Sm-145	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		
	Sn-121m					
	Sn-126	Sn-126	Sn-126	Sn-126		
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	Ta-179	Ta-179	Ta-179	Ta-179	Ta-179	Ta-179
	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-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	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-232	Th-232	Th-232	Th-232	Th-232	Th-232
	Th-234					
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-204	Tl-204	Tl-204	Tl-204	Tl-204	Tl-204
	Tl-210	Tl-210				
	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-236	U-236	U-236	U-236	U-236	U-236
	U-238	U-238	U-238	U-238	U-238	U-238
	U-240	U-240	U-240	U-240	U-240	U-240
	V-49	V-49	V-49			
	V-50	V-50	V-50	V-50	V-50	V-50
	Zr-93	Zr-93	Zr-93	Zr-93		

I.2 ILV Model

Table I-3 and Table I-4 are the results for the ILV model that apply to only the ILV unit. For ILV an additional dilution factor of 1% was considered.

Table I-3. Tier-1 Radionuclide Listing for the ILV Disposal Unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	1378	1378	1378	1378	-	-
Tier-1 List	237	121	183	108	36	27
	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					
	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-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		
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	At-207					
	At-209		At-209			
	At-211					
	Au-193		Au-193			
	Ba-133	Ba-133	Ba-133	Ba-133		
	Ba-133m					
	Be-10	Be-10	Be-10	Be-10		
	Bi-202					
	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-137					
	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-250	Cf-250	Cf-250	Cf-250		
	Cf-251	Cf-251				
	Cf-252	Cf-252	Cf-252	Cf-252		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	1378	1378	1378	1378	-	-
Tier-1 List	237	121	183	108	36	27
	Cf-253	Cf-253	Cf-253	Cf-253		
	Cf-254		Cf-254			
	Cf-255		Cf-255			
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	Cm-244	Cm-244				
	Cm-245	Cm-245				
	Cm-247	Cm-247	Cm-247	Cm-247		
	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-137	Cs-137	Cs-137	Cs-137		
	Cu-59		Cu-59			
	Dy-148					
	Dy-152					
	Dy-154	Dy-154	Dy-154	Dy-154		
	Dy-157					
	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			
	Eu-146					
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-150m					
	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-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
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	1378	1378	1378	1378	-	-
Tier-1 List	237	121	183	108	36	27
	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		
	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-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-94	Nb-94				
	Nb-94m					
	Nb-99m		Nb-99m			
	Nd-144	Nd-144	Nd-144	Nd-144		
	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-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-242m					
	Os-186	Os-186	Os-186	Os-186		
	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-237		Pa-237			
	Pb-194					
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m					
	Pb-205	Pb-205	Pb-205	Pb-205		
	Pb-210	Pb-210				
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-145	Pm-145				
	Pm-146	Pm-146	Pm-146	Pm-146		
	Pm-151					
	Po-206		Po-206			
	Po-207					

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	1378	1378	1378	1378	-	-
Tier-1 List	237	121	183	108	36	27
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pt-190	Pt-190	Pt-190	Pt-190		
	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-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-97m					
	Rn-209					
	Rn-210					
	Rn-211				Rn-211	
	Ru-97		Ru-97			
	Sb-129		Sb-129			
	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		
	Sn-129		Sn-129			
	Sr-90	Sr-90	Sr-90	Sr-90		
	Tb-148					
	Tb-148m					
	Tb-150					
	Tb-157	Tb-157	Tb-157	Tb-157		
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-93		Tc-93			
	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		
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226					

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	1378	1378	1378	1378	-	-
Tier-1 List	237	121	183	108	36	27
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Th-230	Th-230	Th-230	Th-230		
	Th-232	Th-232				
	Th-233					
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194					
	Tl-194m					
	Tl-210	Tl-210				
	U-230		U-230			
	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-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					
	V-50	V-50	V-50	V-50	V-50	V-50
	Xe-135		Xe-135			
	Xe-137		Xe-137			
	Y-93					

Table I-4. Impact Dilution Factor has on Tier-1 Radionuclide Listing for the ILV Disposal Unit.

Model	NCRP	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW	GW	GW
Dilution Factor	1	13.78	137.8	1378	1	13.78	137.8	1378
Tier-1 List	138	135	129	121	127	119	114	108
	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
	Ag-108m	Ag-108m	Ag-108m		Ag-108m	Ag-108m		
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
	Am-242	Am-242	Am-242	Am-242	Am-242	Am-242	Am-242	Am-242
	Am-242m	Am-242m	Am-242m	Am-242m	Am-242m			
	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243	
	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245
	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m
	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39
	At-218	At-218						
	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133
	Be-10	Be-10	Be-10	Be-10	Be-10	Be-10	Be-10	Be-10
	Bi-207	Bi-207	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-208	Bi-208
	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m	Bi-210m
	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250

Model	NCRP	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box	3-Box
Starting List	**271**	**271**	**271**	**271**	**271**	**271**	**271**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Dilution Factor	**1**	**13.78**	**137.8**	**1378**	**1**	**13.78**	**137.8**	**1378**
Tier-1 List	**138**	**135**	**129**	**121**	**127**	**119**	**114**	**108**
	C-14	C-14	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113
	Cf-248	Cf-248	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-250	Cf-250	Cf-250	Cf-250
	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251	Cf-251		
	Cf-252	Cf-252	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-253	Cf-253
	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36
	Cm-243	Cm-243	Cm-243		Cm-243			
	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	
	Cm-245	Cm-245	Cm-245	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-247	Cm-247
	Cm-248	Cm-248						
	Cm-249	Cm-249	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-250	Cm-250
	Cs-135	Cs-135	Cs-135	Cs-135	Cs-135	Cs-135	Cs-135	Cs-135
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Es-253	Es-253	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-254	Es-254
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	Gd-148	Gd-148	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-150	Gd-150
	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152
	H-3	H-3	H-3	H-3	H-3	H-3	H-3	H-3
	Hf-174	Hf-174	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-178m	Hf-178m
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163	Ho-163
	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m	Ho-166m
	I-129	I-129	I-129	I-129	I-129	I-129	I-129	I-129
	In-115	In-115	In-115	In-115	In-115	In-115	In-115	In-115
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	K-40	K-40	K-40	K-40	K-40	K-40	K-40	K-40
	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81
	La-137	La-137	La-137	La-137	La-137	La-137	La-137	La-137
	La-138	La-138	La-138	La-138	La-138	La-138	La-138	La-138
	Lu-176	Lu-176	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-53	Mn-53
	Mo-93	Mo-93	Mo-93		Mo-93			
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m							
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59	Ni-59
	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63	Ni-63

Model	NCRP	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW	GW	GW
Dilution Factor	1	13.78	137.8	1378	1	13.78	137.8	1378
Tier-1 List	138	135	129	121	127	119	114	108
	Np-235	Np-235	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-236	Np-236
	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238
	Np-240	Np-240	Np-240	Np-240	Np-240	Np-240	Np-240	Np-240
	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	Os-194	Os-194						
	Pa-231	Pa-231	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-232	Pa-232
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205
	Pb-210	Pb-210	Pb-210	Pb-210				
	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	
	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146
	Po-208	Po-208	Po-208		Po-208			
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238
	Pu-239	Pu-239	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-240	Pu-240
	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241	Pu-241
	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	Pu-244	Pu-244	Pu-244	Pu-244	Pu-244	Pu-244	Pu-244	Pu-244
	Pu-246	Pu-246	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-226	Ra-226
	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187
	Rn-222							
	Se-79	Se-79	Se-79		Se-79			
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	Sm-145	Sm-145	Sm-145	Sm-145	Sm-145			
	Sm-146	Sm-146	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-147	Sm-147
	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148	Sm-148
	Sm-151	Sm-151						
	Sn-126	Sn-126	Sn-126		Sn-126			
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157	Tb-157
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-98	Tc-98	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-99	Tc-99
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	Th-229	Th-229	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-230	Th-230
	Th-231							
	Th-232	Th-232	Th-232	Th-232	Th-232	Th-232		
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-210	Tl-210	Tl-210	Tl-210				

Model	NCRP	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW	GW	GW
Dilution Factor	1	13.78	137.8	1378	1	13.78	137.8	1378
Tier-1 List	138	135	129	121	127	119	114	108
	U-232	U-232	U-232					
	U-233	U-233	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-234	U-234
	U-235	U-235	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-236	
	U-237	U-237	U-237	U-237	U-237	U-237	U-237	U-237
	U-238	U-238	U-238	U-238	U-238	U-238	U-238	U-238
	U-240	U-240	U-240	U-240	U-240	U-240	U-240	U-240
	V-50	V-50	V-50	V-50	V-50	V-50	V-50	V-50
	Zr-93	Zr-93						

I.3 LAWV Model

Table I-5 and Table I-6 are the results for the LAWV model that apply to only the LAWV unit.

Table I-5. Tier-1 Radionuclide Listing for the LAWV Disposal Unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	157	157	157	157	-	-
Tier-1 List	209	116	152	97	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					
	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-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-244m					
	Am-245	Am-245				
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	At-206					
	At-207					
	At-209		At-209			
	At-211					
	Au-193		Au-193			
	Be-10	Be-10	Be-10	Be-10		
	Bi-202					
	Bi-207	Bi-207				

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	157	157	157	157	-	-
Tier-1 List	209	116	152	97	22	20
	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-247	Bk-247	Bk-247	Bk-247		
	Bk-248m		Bk-248m			
	Bk-249	Bk-249	Bk-249	Bk-249		
	Bk-250	Bk-250				
	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		
	Cf-244		Cf-244			
	Cf-246		Cf-246			
	Cf-247		Cf-247			
	Cf-248	Cf-248	Cf-248	Cf-248		
	Cf-253	Cf-253	Cf-253	Cf-253		
	Cf-254		Cf-254			
	Cf-255		Cf-255			
	Cl-36	Cl-36	Cl-36	Cl-36		
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	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-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cm-251					
	Cs-137	Cs-137	Cs-137	Cs-137		
	Cu-59		Cu-59			
	Dy-148					
	Dy-150					
	Dy-152					
	Dy-154	Dy-154	Dy-154	Dy-154		
	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					
	Eu-150	Eu-150				
	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-257	Fm-257	Fm-257	Fm-257		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	157	157	157	157	-	-
Tier-1 List	209	116	152	97	22	20
	Fr-227					
	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-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-154					
	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		
	In-115	In-115	In-115	In-115		
	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n	Ir-192n
	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-93	Mo-93				
	Mo-99		Mo-99			
	Nb-91	Nb-91	Nb-91	Nb-91		
	Nb-91m					
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-94	Nb-94	Nb-94	Nb-94		
	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-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-240	Np-240				
	Np-241					
	Np-242					
	Np-242m					
	Os-186	Os-186	Os-186	Os-186		
	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-237		Pa-237			
	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-107	Pd-107	Pd-107	Pd-107		
	Pm-145	Pm-145				

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	271	1,252	271	1,252	271
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	157	157	157	157	-	-
Tier-1 List	209	116	152	97	22	20
	Pm-146	Pm-146				
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Po-218	Po-218				
	Pt-190	Pt-190	Pt-190	Pt-190		
	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-246	Pu-246	Pu-246	Pu-246		
	Ra-230		Ra-230			
	Rb-87	Rb-87	Rb-87	Rb-87		
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187		
	Rh-97					
	Rh-97m					
	Rn-207					
	Rn-209		Rn-209			
	Rn-210					
	Rn-211					
	Rn-222	Rn-222	Rn-222	Rn-222		
	Sb-129					
	Se-79	Se-79	Se-79	Se-79		
	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		
	Sr-90	Sr-90	Sr-90	Sr-90		
	Tb-148		Tb-148			
	Tb-148m					
	Tb-150					
	Tb-150m					
	Tb-157	Tb-157	Tb-157	Tb-157		
	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158	Tb-158
	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					
	Te-123	Te-123	Te-123	Te-123		
	Te-129		Te-129			
	Te-129m		Te-129m			
	Th-226					
	Th-229	Th-229				

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	**1,252**	**271**	**1,252**	**271**	**1,252**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Dilution Factor	**157**	**157**	**157**	**157**	**-**	**-**
Tier-1 List	**209**	**116**	**152**	**97**	**22**	**20**
	Th-230	Th-230	Th-230	Th-230		
	Th-232	Th-232	Th-232	Th-232		
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194		Tl-194			
	Tl-194m		Tl-194m			
	U-230		U-230			
	U-231		U-231			
	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-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-240	U-240	U-240	U-240		
	U-242					
	V-50	V-50	V-50	V-50		
	Zr-93	Zr-93				

Table I-6. Impact Dilution Factor has on Tier-1 Radionuclide Listing for the LAWV Disposal Unit.

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	**271**	**271**	**271**	**271**	**271**	**271**
Pathway	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Dilution Factor	**1**	**15.7**	**157**	**1**	**15.7**	**157**
Tier-1 List	**133**	**124**	**116**	**118**	**108**	**97**
	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
	Ag-108m	Ag-108m	Ag-108m	Ag-108m	Ag-108m	
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
	Am-242	Am-242	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-243	Am-243
	Am-245	Am-245	Am-245	Am-245	Am-245	
	Am-246m	Am-246m				
	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39
	Be-10	Be-10	Be-10	Be-10	Be-10	Be-10
	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
	Bi-214					
	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250	Bk-250	Bk-250		
	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113
	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248	Cf-248
	Cf-249					

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	15.7	157	1	15.7	157
Tier-1 List	133	124	116	118	108	97
	Cf-250	Cf-250				
	Cf-251	Cf-251				
	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253	Cf-253
	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36
	Cm-243					
	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244
	Cm-245	Cm-245	Cm-245	Cm-245	Cm-245	Cm-245
	Cm-246	Cm-246	Cm-246	Cm-246	Cm-246	Cm-246
	Cm-249	Cm-249	Cm-249	Cm-249	Cm-249	
	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250	Cm-250
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	
	Eu-152					
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	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
	H-3	H-3	H-3	H-3	H-3	H-3
	Hf-174	Hf-174	Hf-174	Hf-174	Hf-174	Hf-174
	Hf-178m	Hf-178m	Hf-178m	Hf-178m	Hf-178m	
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-163	Ho-163	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-129	I-129
	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		
	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81	Kr-81
	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
	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53
	Mo-93	Mo-93	Mo-93	Mo-93		
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m					
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	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-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
	Np-238	Np-238	Np-238	Np-238	Np-238	
	Np-240	Np-240	Np-240	Np-240		
	Np-240m	Np-240m				
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	Os-194					

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	15.7	157	1	15.7	157
Tier-1 List	133	124	116	118	108	97
	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205
	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210
	Pb-214					
	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	
	Pm-146	Pm-146	Pm-146	Pm-146		
	Po-208	Po-208		Po-208		
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Po-218	Po-218	Po-218			
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pt-193					
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	Pu-238	Pu-238	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-242	Pu-242
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246
	Ra-226	Ra-226		Ra-226		
	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187
	Rn-222	Rn-222	Rn-222	Rn-222	Rn-222	Rn-222
	Se-79	Se-79	Se-79	Se-79	Se-79	Se-79
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	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
	Sn-126	Sn-126				
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	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-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	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-232	Th-232	Th-232	Th-232
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	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-236	U-236	U-236	U-236	U-236	U-236
	U-237	U-237	U-237	U-237	U-237	U-237
	U-238	U-238	U-238	U-238	U-238	U-238
	U-240	U-240	U-240	U-240	U-240	U-240

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	271	271	271	271	271	271
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	15.7	157	1	15.7	157
Tier-1 List	133	124	116	118	108	97
	V-50	V-50	V-50	V-50	V-50	V-50
	Zr-93	Zr-93	Zr-93	Zr-93		

I.4 NRCDAG Model

Table I-7 and Table I-8 are the results for the NRCDAG model that apply to only the NRCDAG unit.

Table I-7. Tier-1 Radionuclide Listing for the NRCDAG Disposal Unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	297	133	227	116	44	29
	Ac-226		Ac-226		Ac-226	
	Ac-228	Ac-228				
	Ac-230		Ac-230			
	Ac-231		Ac-231			
	Ac-233					
	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-242	Am-242	Am-242	Am-242		
	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					
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	As-79					
	At-206					
	At-207		At-207		At-207	
	At-208					
	At-209		At-209			
	At-211		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			
	Bi-202		Bi-202			
	Bi-205					

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	297	133	227	116	44	29
	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-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-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			
	Cm-238		Cm-238			
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241			
	Cm-242	Cm-242				
	Cm-244	Cm-244				
	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-60	Co-60	Co-60	Co-60		
	Co-60m	Co-60m	Co-60m	Co-60m		
	Cs-134m		Cs-134m			
	Cs-135m		Cs-135m			
	Cs-137	Cs-137	Cs-137	Cs-137		
	Cu-59		Cu-59			
	Dy-148		Dy-148			
	Dy-150					
	Dy-152					
	Dy-154	Dy-154	Dy-154	Dy-154		
	Dy-157					
	Er-154					
	Er-171					
	Es-249		Es-249			
	Es-250		Es-250			
	Es-250m		Es-250m			
	Es-251		Es-251			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	297	133	227	116	44	29
	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					
	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-152	Eu-152
	Eu-152n					
	Eu-154m					
	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-257	Fm-257	Fm-257	Fm-257		
	Fr-212					
	Fr-222		Fr-222			
	Fr-227					
	Gd-145					
	Gd-146		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-172	Hf-172				
	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
	Hg-193		Hg-193			
	Hg-193m		Hg-193m			
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	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-109					
	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		
	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				

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	**1,252**	**295**	**1,252**	**295**	**1,252**	**295**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Dilution Factor	**372**	**372**	**372**	**372**	**-**	**-**
Tier-1 List	**297**	**133**	**227**	**116**	**44**	**29**
	Lu-176	Lu-176	Lu-176	Lu-176		
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mo-91					
	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-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-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-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-242m					
	Os-186	Os-186	Os-186	Os-186		
	Os-194	Os-194	Os-194	Os-194		
	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-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-101					
	Pd-107	Pd-107	Pd-107	Pd-107		
	Pm-145	Pm-145	Pm-145	Pm-145		
	Pm-146	Pm-146	Pm-146	Pm-146		
	Pm-151		Pm-151			
	Po-206		Po-206			
	Po-207		Po-207		Po-207	
	Po-208	Po-208	Po-208	Po-208		

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	297	133	227	116	44	29
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pr-137					
	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-239	Pu-239	Pu-239	Pu-239		
	Pu-240	Pu-240	Pu-240	Pu-240		
	Pu-241	Pu-241				
	Pu-243	Pu-243	Pu-243	Pu-243		
	Pu-245		Pu-245			
	Pu-246	Pu-246	Pu-246	Pu-246		
	Ra-222					
	Ra-227		Ra-227			
	Ra-228	Ra-228	Ra-228	Ra-228		
	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			
	Rh-101	Rh-101	Rh-101	Rh-101		
	Rh-101m					
	Rh-102m	Rh-102m	Rh-102m	Rh-102m		
	Rn-207					
	Rn-209		Rn-209			
	Rn-210					
	Rn-211		Rn-211		Rn-211	
	Rn-212					
	Rn-218	Rn-218				
	Ru-97		Ru-97			
	Sb-125	Sb-125				
	Sb-129		Sb-129			
	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-155					
	Sn-125					
	Sn-129		Sn-129			
	Sr-90	Sr-90	Sr-90	Sr-90		
	Ta-179	Ta-179	Ta-179	Ta-179		
	Tb-148		Tb-148			
	Tb-148m		Tb-148m			
	Tb-149					
	Tb-150		Tb-150			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	297	133	227	116	44	29
	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-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		
	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			
	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-171	Tm-171				
	U-230		U-230			
	U-231		U-231			
	U-234	U-234				
	U-235	U-235				
	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-179					
	Xe-135		Xe-135			
	Xe-135m		Xe-135m			
	Xe-137		Xe-137			
	Y-93					

Table I-8. Impact Dilution Factor has on Tier-1 Radionuclide Listing for the NRCDAG Disposal Unit.

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	152	139	133	137	124	116
	Ac-228	Ac-228	Ac-228	Ac-228		
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-241	Am-241	Am-241	Am-241	Am-241	
	Am-242	Am-242	Am-242	Am-242	Am-242	Am-242
	Am-242m					
	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243
	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245
	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m
	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39
	At-218	At-218	At-218	At-218		
	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133	Ba-133
	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-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249	Bk-249
	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250
	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-109	Cd-109	Cd-109	Cd-109	Cd-109	Cd-109
	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113
	Cd-113m	Cd-113m	Cd-113m	Cd-113m	Cd-113m	Cd-113m
	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
	Cl-36			Cl-36		
	Cm-242	Cm-242	Cm-242	Cm-242		
	Cm-244	Cm-244	Cm-244	Cm-244	Cm-244	
	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
	Co-57	Co-57				
	Co-60	Co-60	Co-60	Co-60	Co-60	Co-60
	Co-60m	Co-60m	Co-60m	Co-60m	Co-60m	Co-60m
	Cs-134					
	Cs-135			Cs-135		
	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150	Eu-150
	Eu-152	Eu-152	Eu-152	Eu-152	Eu-152	Eu-152
	Eu-154					
	Fe-55	Fe-55	Fe-55			
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	Gd-148	Gd-148	Gd-148	Gd-148	Gd-148	Gd-148
	Gd-150	Gd-150	Gd-150	Gd-150	Gd-150	Gd-150

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	152	139	133	137	124	116
	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152	Gd-152
	Ge-68					
	H-3	H-3	H-3	H-3	H-3	H-3
	Hf-172	Hf-172	Hf-172	Hf-172	Hf-172	
	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
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-163	Ho-163	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-129	I-129
	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-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-173			
	Lu-174	Lu-174	Lu-174	Lu-174	Lu-174	Lu-174
	Lu-174m	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					
	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93
	Na-22	Na-22	Na-22	Na-22	Na-22	Na-22
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-93m	Nb-93m	Nb-93m	Nb-93m	Nb-93m	Nb-93m
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	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-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-237			Np-237		
	Np-238	Np-238	Np-238	Np-238	Np-238	Np-238
	Np-239	Np-239	Np-239	Np-239	Np-239	Np-239
	Np-240	Np-240	Np-240	Np-240	Np-240	Np-240
	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	Os-194	Os-194	Os-194	Os-194	Os-194	Os-194
	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232	Pa-232
	Pa-233	Pa-233	Pa-233	Pa-233	Pa-233	Pa-233
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205	Pb-205
	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210
	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107	Pd-107
	Pm-144	Pm-144				
	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145	Pm-145
	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146
	Pm-147					
	Po-208	Po-208	Po-208	Po-208	Po-208	Po-208
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	152	139	133	137	124	116
	Pt-193	Pt-193	Pt-193	Pt-193	Pt-193	Pt-193
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	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-242	Pu-242		Pu-242		
	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243	Pu-243
	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246
	Ra-228	Ra-228	Ra-228	Ra-228	Ra-228	Ra-228
	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87
	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-101	Rh-101	Rh-101	Rh-101	Rh-101	Rh-101
	Rh-102m	Rh-102m	Rh-102m	Rh-102m	Rh-102m	Rh-102m
	Rn-218	Rn-218	Rn-218	Rn-218		
	Ru-106					
	Sb-125	Sb-125	Sb-125	Sb-125		
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	Sm-145	Sm-145	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
	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
	Ta-179	Ta-179	Ta-179	Ta-179	Ta-179	Ta-179
	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-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	Th-228	Th-228	Th-228	Th-228	Th-228	Th-228
	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-204	Tl-204	Tl-204	Tl-204	Tl-204	Tl-204
	Tl-210	Tl-210	Tl-210	Tl-210	Tl-210	
	Tm-171	Tm-171	Tm-171	Tm-171		
	U-232					
	U-234	U-234	U-234	U-234	U-234	
	U-235	U-235	U-235	U-235	U-235	
	U-235m	U-235m		U-235m		
	U-237	U-237	U-237	U-237	U-237	U-237
	U-238	U-238	U-238	U-238	U-238	U-238
	U-240	U-240	U-240	U-240	U-240	U-240
	V-49					
	V-50	V-50	V-50	V-50	V-50	V-50
	Zr-93	Zr-93		Zr-93		

I.5 NRCDAS Model

Table I-9 and Table I-10 are the results for the NRCDAS model that apply to only the NRCDAS unit.

Table I-9. Tier-1 Radionuclide Listing for the NRCDAS Disposal Unit.

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	202	98	155	90	144	71
	Ac-226		Ac-226		Ac-226	
					Ac-227	Ac-227
	Ac-230		Ac-230		Ac-230	
	Ac-231		Ac-231		Ac-231	
	Ac-233					
	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-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
	Ar-39	Ar-39	Ar-39	Ar-39		
	Ar-42		Ar-42		Ar-42	
	At-206				At-206	
					At-207	
	At-209				At-209	
					At-211	
	Au-193					
					Ba-133m	
	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	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-137m				Ce-137m	
	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		
	Cm-238		Cm-238			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	202	98	155	90	144	71
	Cm-239		Cm-239			
	Cm-240		Cm-240		Cm-240	
	Cm-241		Cm-241		Cm-241	
	Cm-244	Cm-244				
	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	
	Cs-135m		Cs-135m			
					Cs-137	Cs-137
	Cu-59		Cu-59			
	Dy-154	Dy-154	Dy-154	Dy-154		
					Dy-157	
	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					
					Eu-145	
	Eu-146					
	Eu-150	Eu-150			Eu-150	Eu-150
	Eu-150m					
					Eu-152n	
	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-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
					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		
	Hf-174	Hf-174	Hf-174	Hf-174		
	Hf-178m	Hf-178m				
	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182	Hf-182
	Hg-193					
	Hg-193m					
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
					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	

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	**1,252**	**295**	**1,252**	**295**	**1,252**	**295**
Pathway	**GW**	**GW**	**GW**	**GW**	**II**	**II**
Dilution Factor	**372**	**372**	**372**	**372**	**-**	**-**
Tier-1 List	**202**	**98**	**155**	**90**	**144**	**71**
	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
	Mn-53	Mn-53	Mn-53	Mn-53		
	Mo-91				Mo-91	
	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-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nb-94m				Nb-94m	
	Nb-99					
	Nb-99m		Nb-99m			
	Nd-144	Nd-144	Nd-144	Nd-144		
	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-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-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-237		Pa-237			
	Pb-194				Pb-194	
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-202m				Pb-202m	
					Pb-210	Pb-210
					Pm-145	Pm-145
	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146
	Pm-151					
	Po-206				Po-206	
					Po-207	
					Po-208	Po-208
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209
	Pt-190	Pt-190	Pt-190	Pt-190		
	Pt-193m		Pt-193m			
	Pu-232				Pu-232	
	Pu-234		Pu-234			

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	202	98	155	90	144	71
	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-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-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-87	Rb-87	Rb-87	Rb-87		
					Rb-90	
					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-222	Rn-222
	Ru-97		Ru-97			
	Sb-129		Sb-129			
	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		
					Sn-121m	Sn-121m
	Sn-129		Sn-129			
					Sr-90	Sr-90
	Tb-148					
					Tb-149	
	Tb-150					
	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-93					
	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		
	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-233					

Model	NCRP	NCRP	3-Box	3-Box	RadScreen	RadScreen
Starting List	1,252	295	1,252	295	1,252	295
Pathway	GW	GW	GW	GW	II	II
Dilution Factor	372	372	372	372	-	-
Tier-1 List	202	98	155	90	144	71
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	Tl-194				Tl-194	
	Tl-194m				Tl-194m	
					U-230	
	U-231		U-231		U-231	
	U-238	U-238				
	U-239		U-239			
	U-240	U-240	U-240	U-240		
	U-242					
	V-50	V-50	V-50	V-50	V-50	V-50
	Xe-135		Xe-135			
	Xe-135m					
					Xe-137	
	Y-93					
	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93

Table I-10. Impact Dilution Factor has on Tier-1 Radionuclide Listing for the NRCDAS Disposal Unit.

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	120	111	98	104	92	90
	Ac-227	Ac-227				
	Ag-108m					
	Al-26	Al-26	Al-26	Al-26	Al-26	Al-26
	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
	Am-242m	Am-242m				
	Am-243	Am-243	Am-243	Am-243		
	Am-245	Am-245	Am-245	Am-245	Am-245	Am-245
	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m	Am-246m
	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39	Ar-39
	Be-10	Be-10		Be-10	Be-10	
	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-247	Bk-247	Bk-247	Bk-247	Bk-247	Bk-247
	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250	Bk-250
	C-14	C-14	C-14	C-14	C-14	C-14
	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41	Ca-41
	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113	Cd-113
	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
	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36	Cl-36
	Cm-242	Cm-242		Cm-242		
	Cm-243					
	Cm-244	Cm-244	Cm-244	Cm-244		

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	120	111	98	104	92	90
	Cm-245	Cm-245				
	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
	Cs-135	Cs-135		Cs-135	Cs-135	
	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154	Dy-154
	Es-253	Es-253	Es-253	Es-253	Es-253	Es-253
	Es-254	Es-254	Es-254	Es-254	Es-254	Es-254
	Eu-150	Eu-150	Eu-150	Eu-150		
	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60	Fe-60
	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254	Fm-254
	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257	Fm-257
	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
	Hf-174	Hf-174	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
	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194	Hg-194
	Ho-163	Ho-163	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-129	I-129
	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-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
	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53	Mn-53
	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93	Mo-93
	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91	Nb-91
	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92	Nb-92
	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94	Nb-94
	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144	Nd-144
	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-235	Np-235	Np-235	Np-235	Np-235	Np-235
	Np-236	Np-236	Np-236	Np-236	Np-236	Np-236
	Np-237	Np-237	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-240	Np-240
	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m	Np-240m
	Os-186	Os-186	Os-186	Os-186	Os-186	Os-186
	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-234	Pa-234
	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202	Pb-202
	Pb-210	Pb-210				
	Pd-107					
	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146	Pm-146
	Po-208	Po-208				
	Po-209	Po-209	Po-209	Po-209	Po-209	Po-209

Model	NCRP	NCRP	NCRP	3-Box	3-Box	3-Box
Starting List	295	295	295	295	295	295
Pathway	GW	GW	GW	GW	GW	GW
Dilution Factor	1	37.2	372	1	37.2	372
Tier-1 List	120	111	98	104	92	90
	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190	Pt-190
	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236	Pu-236
	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-246	Pu-246	Pu-246	Pu-246	Pu-246	Pu-246
	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87	Rb-87
	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m	Re-186m
	Re-187	Re-187	Re-187	Re-187	Re-187	Re-187
	Se-79	Se-79				
	Si-32	Si-32	Si-32	Si-32	Si-32	Si-32
	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					
	Sn-126					
	Sr-90					
	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-97	Tc-97	Tc-97	Tc-97	Tc-97	Tc-97
	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98	Tc-98
	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
	Te-123	Te-123	Te-123	Te-123	Te-123	Te-123
	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					
	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44	Ti-44
	U-233					
	U-234	U-234		U-234		
	U-235	U-235		U-235		
	U-235m	U-235m		U-235m		
	U-236	U-236				
	U-238	U-238	U-238	U-238		
	U-240	U-240	U-240	U-240	U-240	U-240
	V-50	V-50	V-50	V-50	V-50	V-50
	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93	Zr-93

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