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7. INADVERTENT HUMAN INTRUDER ANALYSIS

This section describes the IHI analysis and results. Specifically:

- **Section 7.1** introduces the acute and chronic exposure scenarios considered in this PA.
- **Section 7.2** describes the dose estimation conceptual model used in the IHI analysis.
- **Section 7.3** outlines the IHI analysis computational approach.
- **Section 7.4** presents IHI analysis results for STs, ETs, LAWV, ILV, and NRCDAs.
- **Section 7.5** discusses trigger values for 74 radionuclides which could pose a risk to IHIs in the future that are not tracked in CWTS or are not currently present in DUs.
- **Section 7.6** summarizes IHI sensitivity analyses for a 900-year compliance period and a no-dynamic-compaction scenario.

For the GW and air pathways described in Sections 3.5, 3.6, and 3.7, POs are evaluated for MOPs based on a 100-meter POA for all DUs. In this chapter, POs are assessed for the IHI who may physically disrupt the facility at some time after the end of IC and when the POA is at the DUs (Aleman et al., 2021).

The compliance period remains 1,000 years (calendar years 2165 to 3165), commencing after the 100-year IC period, which runs from operational closure in calendar year 2065 to 2165. The applicable performance measures for the IHI analysis are 500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios (U.S. DOE, 2017). The POs for IHI scenarios are radionuclide- and DU-specific inventory limits or trigger values that will be monitored during ELLWF operations based on a SOF approach.

For each DU, the IHI inventory limits are higher (less restrictive) than the GW pathway inventory limits. Given the projected CWTS inventories at closure, expected doses to the IHIs are below DOE POs for all DUs, with

KEY TAKEAWAYS

- ✓ **Compliance period is 1,000 years after 100-year IC period.**
- ✓ **Six IHI exposure scenarios (three acute and three chronic) are considered.**
- ✓ **IHI performance measures are 500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios.**
- ✓ **IHI analysis includes 29 radionuclides for STs and ETs, four for the LAWV, two for the ILV, and 13 for the NRCDAs.**
- ✓ **When the projected inventory at closure is considered, all predicted doses to IHIs are well below performance measures.**
- ✓ **If future disposal of any of the 74 radionuclides identified in Section 2.3 is proposed in an amount that exceeds its IHI trigger value (Table 2-28), formal IHI inventory limits must be identified and documented.**
- ✓ **Among all 33 DUs, only six radionuclides subject to IHI analysis reach their dose maxima (< 10% increase) at Year 1,171 when the compliance period is reduced from 1,000 to 900 years.**
- ✓ **If dynamic compaction does not occur, IHI inventory limits will be much lower; however, predicted IHI doses will still be within performance measures.**
- ✓ **IHI inventory limits are generally two orders of magnitude higher (lower doses) than those calculated for PA2008.**

the highest acute IHI dose being about 1.16 mrem (at ST23) and the highest chronic dose being about 68.3 mrem yr^{-1} (at NR26E). Based on the ratio of projected inventories to 2065 CWTS inventories, on average, the IHI SOFs are approximately 1,000 times lower than the GW SOF values which are limiting.

7.1. SCENARIOS

The following six stylized IHI scenarios are considered (Smith et al., 2019):

- **Acute – Basement Construction**: IHI constructs a basement and encounters waste during excavation.
- **Acute – Well Drilling**: IHI drills a water well through waste and is exposed to drill cuttings.
- **Acute – Discovery**: IHI begins constructing a basement but stops when encountering the riprap in the final closure cap.
- **Chronic – Agriculture**: Resident IHI is exposed to waste from basement excavation and ingests vegetables grown in contaminated soil.
- **Chronic – Post-Drilling:** Resident IHI is exposed to waste from drill cuttings and ingests vegetables grown in contaminated soil.
- **Chronic – Residential**: Resident IHI is exposed to external radiation while in a home located above waste.

These scenarios assume that IC and memory are lost in calendar year 2165 (100 years after operational closure in calendar year 2065) and that the IHI is on site after that time. Waste is assumed to be indistinguishable from, and mistaken for, soil. However, an IHI is assumed to be able to recognize concrete covers and erosion barriers when they are encountered. These scenarios and their associated exposure pathways are summarized in Table 2-25 (Smith et al., 2019).

The total acute dose to an IHI is the sum of individual doses due to the three acute scenarios, as applicable. Therefore, the individual constructing the basement is the same person who drills the well, and who discovers the waste. Likewise, the IHI chronic dose is the sum of the three individual chronic exposure scenarios. Note that these scenarios do not include direct ingestion of contaminated GW or the use of contaminated GW for irrigation (U.S. DOE, 2017; pg. 2-30).

7.1.1. Acute Exposure

Three distinct scenarios resulting in acute exposure of IHIs are commonly applied to LLW disposal facilities and are referred to as the construction, discovery, and drilling scenarios (Kennedy and Peloquin, 1988; Oztunali and Roles, 1986; U.S. NRC, 1981). Parameter assumptions are provided by Smith et al. (2019).

7.1.1.1. Basement Construction

In this scenario, a nonresident IHI builds a home on the disposal site. The IHI spends 160 hours constructing a basement up to 3 meters (9.84 feet) deep, part of which extends into the waste zone. During excavation, waste is inadvertently mixed with clean soil (DU backfill) and somewhat diluted. The IHI acquires dose from the following three pathways: (1) ingestion of excavated material, (2) inhalation of airborne dust, and (3) external exposure to photon radiation from excavated material. The excavator is assumed to penetrate the 12-inch riprap erosion barrier, bentonite, backfill, and other engineered covers but not concrete or steel. The basement scenario is not applicable if waste is roofed by concrete or steel or when the depth to waste is greater than 3 meters because waste will not be excavated. However, the soil cover in the IHI analysis is modeled to begin eroding at a rate of 1.4 mm yr^{-1} at the end of the IC period until exposing the erosion barrier at 0.9144 meters (3 feet) depth after 653 years. Therefore, for some DUs, the basement construction scenario does not apply during the early part of the compliance period but may apply during the latter portion.

7.1.1.2. Well Drilling

In this scenario, a nonresident IHI spends 30 hours drilling a water well, part of which extends into the waste zone. During drilling, cuttings that contain waste mixed with clean soil are brought to the surface. As in the basement construction scenario, the IHI acquires dose from the following three pathways: (1) ingestion of excavated material, (2) inhalation of airborne dust, and (3) external exposure to photon radiation from excavated material. A driller is assumed to be unable to penetrate concrete or steel because the IHI will relocate or abandon the well. However, it is assumed that the driller can penetrate a 12-inch riprap erosion barrier as well as the rusted remains of steel boxes in ETs.

7.1.1.3. Discovery

In this scenario, a nonresident IHI spends 80 hours constructing a basement. During excavation, the IHI encounters the 12-inch riprap erosion barrier and abandons the excavation without penetrating the waste zone. In this scenario, the IHI acquires dose from only one pathway: external exposure to photon radiation from unexcavated material residing in the undisturbed waste zone.

7.1.2. Chronic Exposure

Three distinct scenarios resulting in chronic exposure of IHIs are considered in the dose analysis for the ELLWF PA. They are denoted as the agriculture, post-drilling, and residential scenarios as described below. Parameter assumptions are reported by Smith et al. (2019).

7.1.2.1. Agriculture

In this scenario, a resident IHI lives in a house with a basement that penetrates the waste zone. Waste that was excavated for basement construction is now mixed with native soil in the IHI's vegetable garden. The six exposure pathways are as follows: (1) ingestion of contaminated vegetables, (2) ingestion of garden soil dust, (3) inhalation of airborne garden soil dust, (4) inhalation of airborne house dust, (5) external exposure to radiation from garden soil, and (6) external exposure to photon radiation through the basement floor and walls. Because a basement that penetrates the waste zone is a prerequisite, the agriculture scenario applies only to the same DUs considered for the acute basement construction scenario.

7.1.2.2. Post Drilling

In this scenario, a resident IHI maintains a vegetable garden located in soil where a well was previously drilled through waste. Drill cuttings containing waste are now mixed with native soil and scattered in the garden area. The four exposure pathways are as follows: (1) ingestion of contaminated vegetables, (2) ingestion of garden soil dust, (3) inhalation of airborne garden soil dust, and (4) external exposure to radiation from garden soil. Because a water well that penetrates the waste zone is a prerequisite, the post-drilling scenario applies only to the same DUs considered for the acute well drilling scenario.

7.1.2.3. Residential

In this scenario, a resident IHI lives in a house with a basement located directly above a DU; however, basement construction does not penetrate the waste zone. There is one exposure pathway: external exposure to photon radiation through the basement floor with shielding provided by the 4-inch concrete basement floor and any soil or engineered material remaining between the basement and waste.

7.2. DOSE ESTIMATION CONCEPTUAL MODEL

As discussed in Section 2.3.1, the nature of future waste shipments to the ELLWF over the next 40 years is unknown; therefore, a final radiological inventory cannot be assigned with confidence. Hence, the overall approach for the ELLWF PA is not to estimate future dose but rather to develop operational inventory limits such that future dose to MOPs and IHIs will not exceed U.S. DOE performance measures. The IHI analysis is developed and described by Aleman et al. (2021) and summarized here. Radionuclide-specific inventory limits are calculated in terms of the dose factor in units of mrem yr^{-1} dose per curie of parent radionuclide buried. The U.S. DOE performance measure (e.g., 100 mrem yr^{-1} for IHI chronic exposure scenarios) is divided by the dose factor to obtain the inventory limit in curies for the radionuclide in question. Operationally, the waste activity capacity of a DU at ELLWF applied to a disposed (or proposed) mix of radionuclides is derived from radionuclide-specific inventory limits with a SOF approach.

For each of the 33 DUs, the IHI analysis involves two sets of radionuclide-specific inventory limits: one set for the acute IHI and one set for the chronic IHI. Limits are obtained only for those radionuclides in CWTS that are screened in after the Tier 1 IHI screening (Section 2.3.7.2 and Table 2-27). These include 29 radionuclides for trenches (STs and ETs), four for the LAWV, two for the ILV, and 13 for NRCDAS[1] (i.e., the IHI analysis is not performed for NRCDAG because all generic radionuclides in these DUs are screened out during Tier 1). For radionuclides not currently tracked by CWTS, the trigger values apply as reported in Table 2-28 and undergo no further adjustment in the IHI analysis.

Relative model years 171 to 1,171 (calendar years 2165 to 3165) comprise the compliance period, during which decay and ingrowth occurs. Per the ELLWF closure plan (Phifer et al., 2009), Dynamic compaction of crushable waste containers occurs just before the start of the compliance

[1] The uppercase *S* suffix refers to a welded KAPL CB/TS cask that is treated as a SWF in the nominal PA case. This is not to be confused with a lowercase *s* (NRCDAs) which refers to the two NR pads, NR07E and NR26E.

period. Conservatively, no credit is taken for the leaching of mobile radionuclides (and the resulting time dependent decrease in the waste activity) in calculations.

For most radionuclides and most DUs, dose calculations are performed using the generic waste form model (i.e., no credit is taken for shielding by the waste form material, containers, or other encapsulating material). However, selected radionuclides currently residing in SWFs are treated separately as documented below.

Precise decay and ingrowth calculations for the DUs are complicated because inventory additions occur many times over the life of each DU and decay and ingrowth times are unique for each disposed waste box. (Note that future burial compositions, amounts, and timing are also unknown.) For simplicity and to bound possible outcomes, the IHI analysis is performed twice for two different end-member cases as summarized below and in Table 7-1.

<u>Case 1 Assumptions</u>

DUs opened before 2021:	All waste buried at time of opening
DUs opened 2021 or later:	All waste buried 09/30/2021

<u>Case 2 Assumptions</u>

DUs closed before 2021:	All waste buried at time of closure
DUs planned for closure 2021-2040:	All waste buried 09/30/2040
DUs planned for closure after 2040:	All waste buried 09/30/2065

Conceptually, Case 1 overestimates the amount of decay and ingrowth products in the ground at the time of IHI exposure while Case 2 overestimates the amount of parent radionuclides. Case 1 and Case 2 demonstrate the sensitivity of dose factors to burial time from the start to the end of burial operations, respectively. Calculated inventory limits from Cases 1 and 2 are compared and, for each radionuclide, the lower (more restrictive) of the two limits is adopted. Because inventory limits are radionuclide-specific, it is possible that inventory limits are taken from Case 1 for some radionuclides and Case 2 for others for a given DU.

IHI inventory limits are sensitive to the 3-D geometry of various DUs as well as the overlying material. Critical dimensions of DUs are shown in Figure 7-1. Vertical profiles are presented for the various types of DUs, along with the final depths below backfill and the engineered cover. ST and ET profiles are provided for both the planned compacted state and unplanned uncompacted state for sensitivity modeling. The LAWV, ILV, and NRCDAs are not compacted. Radiological contamination is assumed to be distributed uniformly throughout the waste zone; thus, a parent radionuclide's initial concentration in waste is the DU inventory (nominally one curie at burial) divided by the waste volume within the DU. The initial concentration of progeny in waste is set to 0 curies. The depth to the top of the waste zone determines which acute and chronic exposure scenarios are considered.

Table 7-1. End-Member Cases Considered in Inadvertent Human Intruder Analysis of ELLWF Disposal Units

DU Identification	Case 1 First Waste Package		Case 2 Last Waste Package	
	Calendar	Model Year	Calendar	Model Year
ST01	12/21/1995	1.23	9/19/2003	8.98
ST02	9/20/2001	6.98	8/31/2006	11.93
ST03	10/20/2003	9.06	1/6/2010	15.27
ST04	2/26/2004	9.41	8/19/2010	15.89
ST05	5/27/2004	9.66	10/16/2006	12.05
ST06	4/29/2006	11.59	9/30/2040	46.01
ST07	6/26/2006	11.74	9/30/2040	46.01
ST08	2/6/2007	12.36	9/30/2040	46.01
ST09	3/17/2011	16.47	9/30/2040	46.01
ST10	9/30/2021	27.01	9/30/2040	46.01
ST11	9/30/2021	27.01	9/30/2040	46.01
ST14	3/29/2011	16.50	9/30/2040	46.01
ST17	9/30/2021	27.01	9/30/2065	71.01
ST18	9/30/2021	27.01	9/30/2065	71.01
ST19	9/30/2021	27.01	9/30/2065	71.01
ST20	9/30/2021	27.01	9/30/2065	71.01
ST21	9/30/2021	27.01	9/30/2065	71.01
ST22	9/30/2021	27.01	10/1/2065	71.01
ST23	8/29/2000	5.92	9/30/2065	71.01
ST24	9/30/2021	27.01	9/30/2065	71.01
ET01	2/13/2001	6.38	3/30/2017	22.51
ET02	6/3/2004	9.68	9/30/2040	46.01
ET03	9/19/2013	18.98	9/30/2040	46.01
ET04	9/30/2021	27.01	9/30/2040	46.01
ET05	9/30/2021	27.01	9/30/2065	71.01
ET06	9/30/2021	27.01	9/30/2065	71.01
ET07	9/30/2021	27.01	9/30/2040	46.01
ET08	9/30/2021	27.01	9/30/2040	46.01
ET09	9/30/2021	27.01	9/30/2040	46.01
LAWV	9/28/1994	0.00	9/30/2065	71.01
ILV	9/28/1994	0.00	9/30/2040	46.01
NR07E(S)[a]	1/1/1987	-7.74	5/21/2004	9.65
NR26E(S)[a]	2/6/1997	2.36	9/30/2065	71.01

Notes:

[a] The (S) designation refers to a welded KAPL CB/TS cask that is treated as a SWF in the nominal PA case.

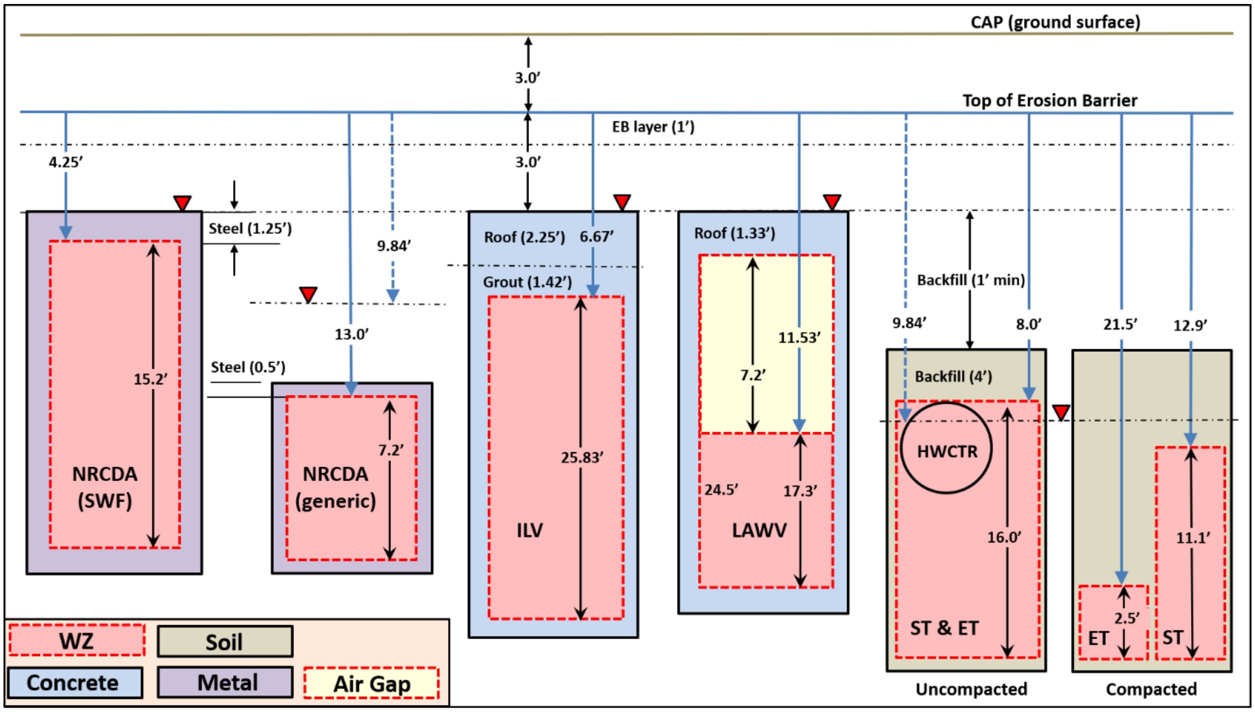


Figure 7-1. Critical Vertical Dimensions of ELLWF Disposal Units for Inadvertent Human Intruder Analysis

Residential basements are assumed to be 3 meters deep; therefore, the acute basement construction and chronic agricultural scenarios do not apply if the top of the waste zone is deeper than 3 meters (9.84 feet) bgs. However, it is also pessimistically assumed that 0.9144 meters (3 feet) of soil in the post-closure cover above the erosion barrier is subject to erosion during the 1,000-year compliance period. As a result, for some DUs, the basement and residential scenarios do not apply initially but are applicable during the latter part of the compliance period when the final closure cap thickness is reduced. Table 7-2 presents site-specific parameters regarding DU geometry.

Table 7-2. ELLWF Disposal Unit Geometric Considerations in Inadvertent Human Intruder Analysis

Type of DU	Parameter	Setting	Comment
ST	Intrusion drilling barrier	No	Drill penetrates erosion barrier and waste
	Depth to top of erosion barrier	3 ft initial, reduces to 0 ft after 653 years of erosion	Thickness of soil cover
	Depth to top of drilling barrier	N/A	N/A
	Depth to top of waste zone	15.9 ft initial, reduces to 12.9 ft after 653 years of erosion	Closure cap (6 ft), backfill (9.9 ft)
	Waste zone thickness	11.1 ft	After dynamic compaction
	Number of modeled radionuclides	29	Section 2.3.7
ET	Intrusion drilling barrier	No	Drill penetrates erosion barrier and waste
	Depth to top of erosion barrier	3 ft initial, reduces to 0 ft after 653 years of erosion	Thickness of soil cover
	Depth to top of drilling barrier	N/A	N/A
	Depth to top of waste zone	24.5 ft initial, reduces to 21.5 ft after 653 years of erosion	Closure cap (6 ft), backfill (18.5 ft)
	Waste zone thickness	2.5 ft	After dynamic compaction
	Number of modeled radionuclides	29	Section 2.3.7
LAWV	Intrusion drilling barrier	Yes	Concrete roof
	Depth to top of erosion barrier	3 ft initial, reduces to 0 ft after 653 years of erosion	Thickness of soil cover
	Depth to top of drilling barrier	6 ft initial, reduces to 3 ft after 653 years of erosion	Top of concrete roof
	Depth to top of waste zone	14.53 ft initial, reduces to 11.53 ft after 653 years of erosion	Closure cap (6 ft), concrete roof (1.33 ft), air gap (7.2 ft)
	Waste zone thickness	17.3 ft	Stacked boxes
	Number of modeled radionuclides	4	Section 2.3.7
ILV	Intrusion drilling barrier	Yes	Concrete roof
	Depth to top of erosion barrier	3 ft initial, reduces to 0 ft after 653 years of erosion	Thickness of soil cover
	Depth to top of drilling barrier	6 ft initial, reduces to 3 ft after 653 years of erosion	Top of concrete roof
	Depth to top of waste zone	9.67 ft initial, reduces to 6.67 ft after 653 years of erosion	Closure cap (6 ft), concrete roof (2.25 ft), grouted air gap (17 in)
	Waste zone thickness	25.83 ft	Interior height of ILNT vault
	Number of modeled radionuclides	2	Section 2.3.7
NRCDAs	Intrusion drilling barrier	Yes	Welded casks
	Depth to top of erosion barrier	3 ft initial, reduces to 0 ft after 653 years of erosion	Thickness of soil cover
	Depth to top of drilling barrier	6 ft initial, reduces to 3 ft after 653 years of erosion	Top of welded casks
	Depth to top of waste zone	7.25 ft initial, reduces to 4.25 ft after 653 years of erosion	Closure cap (6 ft), steel cask (15 in)
	Waste zone thickness	18 ft / 15.2 ft*	Height of waste zone within cask
	Number of modeled radionuclides	13	Section 2.3.7

Notes:

* Conservative value of 18 feet for seven radionuclides; realistic value of 15.2 feet for six gamma-emitting radionuclides

7.3. COMPUTATIONAL APPROACH

Estimating doses to IHIs follows the procedure described by Smith et al. (2019). For each scenario, Smith et al. (2019) document the following in detail:

- Exposure pathways
- Dose equations
- Parameter estimates

Exposure pathways considered for each scenario (ingestion, inhalation, external shine) are presented in Table 2-25. Dose equations relate radionuclide concentration within a DU to dose experienced by the typical person (see Section 3.7.1 for definition and selection rationale) through various intermediate points (e.g., volume of waste brought to surface, radionuclide concentration in soil, radionuclide concentration in garden vegetables). Parameter estimates are assumptions made regarding exposure-related parameters that are variable, speculative, or cannot be easily measured (e.g., ingestion rate of soil while drilling). These estimates and assumptions are documented by Smith et al. (2019) for the typical person (50th percentile); source references for the parameters are recorded in the *Radionuclide, Element, and Dose Parameter Data Package, Ver. 2.0* (Smith et al., 2019; SRNL, 2019b). By example, Table 7-3 lists some general parameter estimates for quantities associated with IHI scenarios.

Table 7-3. Example Parameter Estimates Used in Inadvertent Human Intruder Calculations [compiled by Smith et al. (2019)]

Quantity	Assumed Value	Source
Consumption of garden produce	100 kg yr^{-1}	Jannik and Stagich (2017)
Inadvertent consumption of soil	100 mg d^{-1}	Jannik and Stagich (2017)
Ingestion rate of soil during construction	110 mg d^{-1}	Jannik (2013)
Ingestion rate of soil during well drilling	100 mg d^{-1}	Jannik (2013)
Fraction of produce from local garden	0.308	Jannik and Stagich (2017)
Time spent in garden	88 hr yr^{-1}	Jannik and Stagich (2017)
Time spent constructing basement	160 hr yr^{-1}	Jannik (2013)
Time spent drilling well	30 hr yr^{-1}	Jannik (2013)
Time spent in site discovery	80 hr yr^{-1}	Smith and Phifer (2014)
Time spent in home	6,136 hr yr^{-1}	Jannik and Stagich (2017)
Area of basement	100 m^2	Smith (2015)
Area of garden	2,000 m^2	Smith (2015)
Well depth	50 m	Smith (2015)
Diameter of well borehole	0.178 m	Smith et al. (2019)
Depth of tilled garden soil	0.15 m	Jannik and Stagich (2017)
Bio-transfer factor from soil to vegetable	Radionuclide specific	Smith (2015)
Air inhalation rate (typical)	5,000 m^3 yr^{-1}	Jannik and Stagich (2017)
Air inhalation rate during construction	11,400 m^3 yr^{-1}	Jannik (2013)
Air inhalation rate during well drilling	8,400 m^3 yr^{-1}	Jannik (2013)
Loading of soil in home air	1.0E-8 kg m^{-3}	Lee and Coffield (2008)
Loading of soil in air during gardening	1.0E-7 kg m^{-3}	Lee and Coffield (2008)
Loading of soil in air during construction	6.0E-7 kg m^{-3}	Jannik (2013)
Loading of soil in air during drilling	1.0E-7 kg m^{-3}	Jannik (2013)
Bulk soil density	1.65 kg m^{-3}	Phifer et al. (2006)

Dose calculations are performed using the SRNL Dose Toolkit (Aleman, 2019), which is a FORTRAN-based platform consisting of several modules (see Section 3.9.3). Time-variant radionuclide concentrations within the various DUs, representing Cases 1 and 2, are calculated in the PreDose Module (see Section 3.9.3.1) of the toolkit using decay chains and decay constants reported by Smith et al. (2019) and SRNL (2019b). Dose estimates are derived in another module called the SRNL PA/CA Limits and Doses Tool (see Section 3.9.3.3). Parameters used in calculations are reported by Smith et al. (2019) and SRNL (2019b).

For the HWCTR SWF in ST14, photon dose coefficients are modeled using the Monte-Carlo N-Particle (MCNP) Software, Ver. 6.1 (Pelowitz, 2013). This code was developed by Los Alamos National Laboratory and is documented by an SRNL SQAP (Finfrock, 2021a).

7.4. RESULTS

The radionuclide- and DU-specific, time-variant dose factors represent the dose or dose rate experienced by an IHI, per curie disposed. Each parent radionuclide or progeny is assumed to be uniformly dispersed throughout the waste volume. The relevant methodology for acute and chronic analyses is as follows:

- **Acute**
  For an acute exposure, the IHI dose factor is expressed in terms of mrem per curie disposed. The modeled value is divided into the U.S. DOE performance measure of 500 mrem (U.S. DOE, 2017) to obtain an inventory limit, in curies, for a specific parent radionuclide at a specific DU. Three IHI acute exposure scenarios (basement construction, well drilling, and discovery) may apply to various DUs depending on the DU burial depth and other characteristics (Table 7-4). Two waste burial times (Cases 1 and 2) also apply. For each case, the acute dose is the sum of doses from the applicable acute exposure scenarios. The final acute IHI inventory limit for each radionuclide is the lowest of the two cases. It may be that for a given DU, the limit for one radionuclide is drawn from Case 1, while the limit for a different radionuclide represents Case 2. Acute exposure scenarios appropriate to the various types of DUs are provided in Table 7-4. The basement construction scenario does not apply to ELLWF DUs because of the burial depth (trenches), presence of physical barriers (LAWV, ILV, and NRCDAs), or the nature of the waste form (ST14).
- **Chronic**
  The IHI dose factor for a chronic exposure is expressed in terms of mrem yr^{-1} per curie disposed. The modeled value is divided into the U.S. DOE performance measure of 100 mrem yr^{-1} (U.S. DOE, 2017) to obtain an inventory limit, in curies, for a specific radionuclide at a specific DU. Three IHI chronic exposure scenarios (agriculture, post drilling, and residential) are considered for application to various DUs depending on the DU burial depth and other characteristics (Table 7-4). Because the acute basement construction scenario does not apply to the ELLWF, then neither does the agricultural scenario.

Table 7-4. Applicable Inadvertent Human Intruder Scenarios for Types of ELLWF Disposal Units

Type of DU	IHI Scenario	Applicable?	Comment
ST	Acute – Basement Construction	No*	Waste is not encountered during excavation.*
	Acute – Well Drilling	Yes	No engineered barriers
	Acute – Discovery	Yes	Excavation stops at riprap erosion barrier. Shielding is present between the tops of barrier and waste zone.
	Chronic – Agriculture	No*	Basement does not encounter waste.*
	Chronic – Post Drilling	Yes	No engineered barriers
	Chronic – Residential	Yes	Basement excavated into backfill. Shielding is present between floor and top of waste zone.
ET	Acute – Basement Construction	No	Waste is not encountered during excavation.
	Acute – Well Drilling	Yes	No engineered barriers
	Acute – Discovery	Yes	Excavation stops at riprap erosion barrier. Shielding is present between the tops of barrier and waste zone.
	Chronic – Agriculture	No	Basement does not encounter waste.
	Chronic – Post Drilling	Yes	No engineered barriers.
	Chronic – Residential	Yes	Basement excavated into backfill. Shielding is present between floor and top of waste zone.
LAWV	Acute – Basement Construction	No	Excavation stops at concrete roof.
	Acute – Well Drilling	No	Drilling stops at concrete roof.
	Acute – Discovery	Yes	Excavation stops at riprap erosion barrier. Shielding is present between the tops of the barrier and waste zone.
	Chronic – Agriculture	No	Basement does not encounter waste.
	Chronic – Post Drilling	No	Drilling stops at concrete roof.
	Chronic – Residential	Yes	Basement excavated to top of concrete roof. Shielding is present between floor and top of waste zone.
ILV	Acute – Basement Construction	No	Excavation stops at concrete roof.
	Acute – Well Drilling	No	Drilling stops at concrete roof.
	Acute – Discovery	Yes	Excavation stops at riprap erosion barrier. Shielding is present between the tops of the barrier and waste zone.
	Chronic – Agriculture	No	Basement does not encounter waste.
	Chronic – Post Drilling	No	Drilling stops at concrete roof.
	Chronic – Residential	Yes	Basement excavated to top of concrete roof. Shielding is present between floor and top of waste zone.
NRCDAs	Acute – Basement Construction	No	Excavation stops at steel cask.
	Acute – Well Drilling	No	Drilling stops at steel cask.
	Acute – Discovery	Yes	Excavation stops at riprap erosion barrier. Shielding is present between the tops of barrier and waste zone.
	Chronic – Agriculture	No	Basement does not encounter waste.
	Chronic – Post Drilling	No	Drilling stops at steel cask.
	Chronic – Residential	Yes	Basement excavated to top of cask. Shielding is present between floor and top of waste zone.

Notes:

Applicable scenarios are shaded in light green.

* Except CIG in ST23

IHI analysis results are described fully by Aleman et al. (2021) and summarized in this section. The analysis generates radionuclide-specific dose factors (mrem or mrem yr^{-1} per disposed curie) and inventory limits (curies) for both IHI acute and chronic exposures for each DU. These results are provided in tables and figures for some DUs in this section. Appendix G summarizes information for all DUs, including tables for IHI acute and chronic dose factors and inventory limits and graphs of dose versus time. In all graphs, doses and dose rates are shown only for the top five radionuclides of the given DU.

Waste disposed in the various DUs assumes several different physical forms with differing physical and chemical properties. Using iodine-129 as an example, the generic waste form is designated as “I-129,” while iodine-129 in the various SWFs is differentiated by adding an uppercase letter suffix (e.g., I-129D, I-129E, etc.). The following nomenclature is used for all radionuclides in all DUs: an uppercase letter suffix indicates a SWF, while the absence of an uppercase letter denotes a generic waste form.

The modeled compliance period is from calendar years 2165 to 3165 or relative model years 171 to 1,171 when referenced to calendar year 1994 (start of ELLWF operations).

7.4.1. Engineered Trenches

Nine ETs exist or are planned at the ELLWF (Table 7-1). From an IHI perspective, ETs are like STs. The SWF, U-233D, is planned for disposal in ETs; therefore, waste characteristics are like most of the waste in STs. ET covers are the same as for STs, and the trench areas are similar. Although dynamic compaction results in ET waste being buried more than 8 feet deeper than ST waste (Figure 7-1), the differences in dose factors between ETs and STs are not affected because the shallower ST waste is too deep for the basement construction and agricultural scenarios to apply. In general, doses and dose factors are not significantly different between ETs and STs; the values cluster within about a factor of two of each other.

Using ET01 as an example, IHI doses and dose rates during the compliance period are shown in Figure 7-2. Four graphs labelled (a), (b), (c), and (d) are produced for each DU. Graphs (a) and (b) illustrate radionuclide-specific IHI acute and chronic dose rates, respectively, per disposed curie of radionuclide during the 1,000-year compliance period. The maximum values of a radionuclide on these two graphs represent the IHI acute and chronic dose factors for that radionuclide at ET01. Twenty-nine generic waste form radionuclides and seven SWF radionuclides are evaluated, but only the five with the highest dose factors (highest risk per curie) are shown.

As shown in Figure 7-2(a), Sn-126, Ra-226, Nb-94, Cm-248, and Ag-108m have the highest risk per curie in the acute exposure scenario at ET01. Dose approaches 0.06 mrem per disposed curie at the beginning of the compliance period. The 31 radionuclides not shown have lower maximum doses, extending to the least toxic radionuclide (from an IHI acute dose perspective), Ni-63.

IHI chronic dose rates (mrem yr^{-1} per disposed curie) are displayed in Figure 7-2(b). The five radionuclides with the highest chronic dose rates per disposed curie are: Ra-226, U-232, Th-230, Tc-99, and K-40. The highest chronic dose factors are represented by a different group of radionuclides because IHI acute exposure scenarios at the ELLWF are driven by external exposure to gamma radiation, while chronic exposure scenarios are dominated by ingestion and inhalation exposures where alpha-emitters are more toxic. It is important to note that health risks to actual IHIs are not shown because graphs (a) and (b) are on a per disposed curie basis. To assess health risks to IHIs, DU inventories are included in graphs (c) and (d).

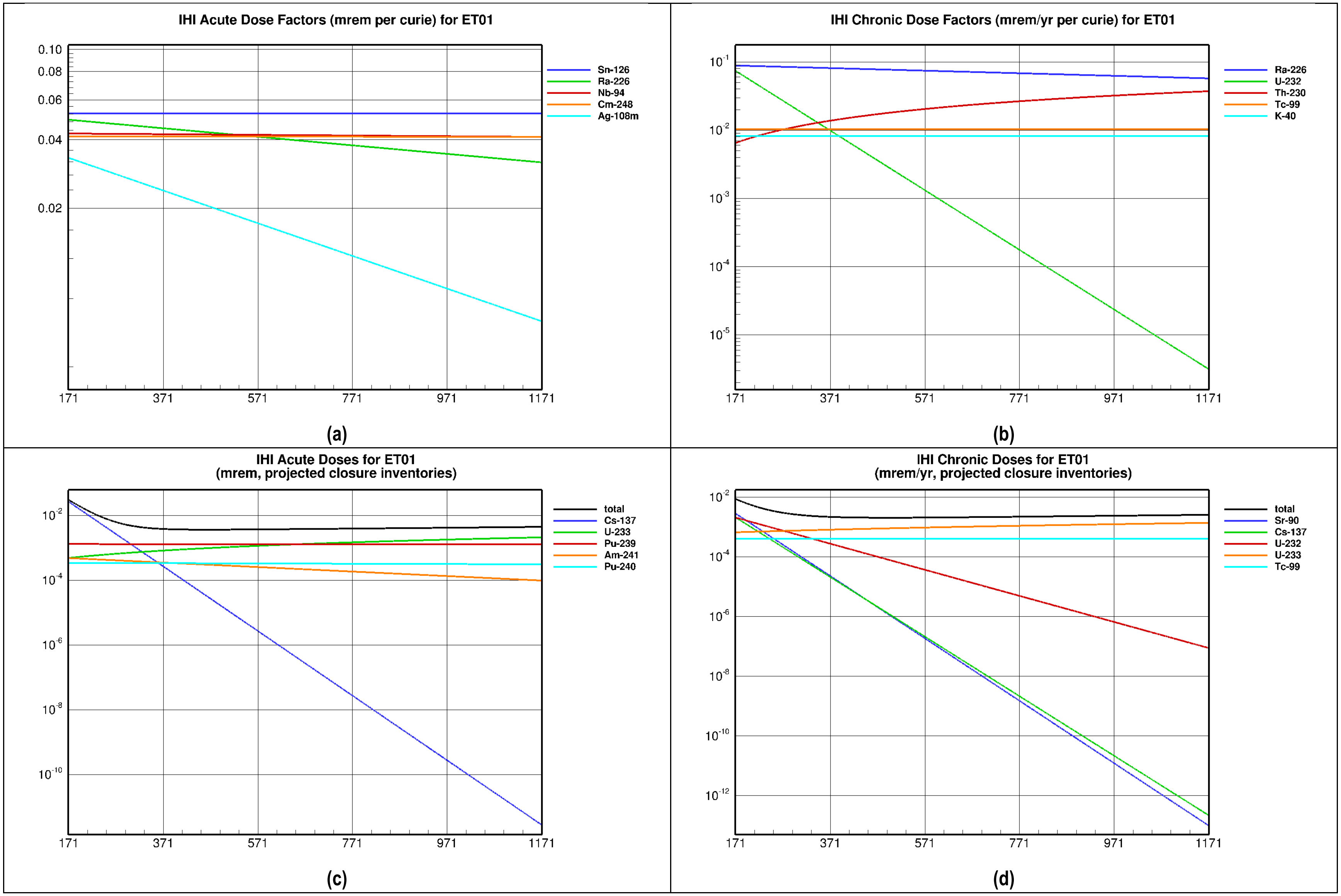
Figure 7-2(c) and Figure 7-2(d) display actual predictions of total doses and dose rates to IHIs using the nominal CWTS inventories projected to 2065 as provided in Section 8.7.1. The curves in graphs (c) and (d) are developed by multiplying curves in graphs (a) and (b) by these projected inventories. The IHI maximum acute dose is 0.0303 mrem and occurs at the start of the compliance period, largely due to Cs-137. Cs-137, which is not one of the top five radionuclides in Figure 7-2(a), is responsible for most of the dose to an actual IHI at ET01 for the first 100 years or more [Figure 7-2(c)] due to its high projected 2065 inventory of 53.2 curies (Section 8.7.1). Like most trenches, most of the dominant radionuclides at ET01 shown in graphs (a) and (b) do not contribute significant doses to actual IHIs because of their low projected 2065 CWTS inventories.

The IHI maximum chronic dose is 0.00865 mrem yr^{-1}, due mostly to Sr-90. ET01 is typical of other ETs (and many STs), with IHI maximum acute doses between 0.0303 and 0.2477 mrem and chronic doses somewhat lower on a yearly basis. All IHI doses for ETs are well below their U.S. DOE performance measures (U.S. DOE, 2017).

Acute and chronic IHI dose factors and inventory limits for ET01 are listed in Table 7-5 and Table 7-6, respectively.[2] The time of maximum dose per disposed curie of Ag-108m for an acute exposure to an IHI occurs at Year 171 (Table 7-5), the first year of the compliance period. Radioactive decay causes the dose to lower in subsequent years. The dose factor is the maximum dose per curie over the time interval of the compliance period, which is 3.33E-02 mrem per disposed curie for Ag-108m. IHI dose factors vary among radionuclides. At ET01, the acute dose factors range from a low of 4.66E-08 for Ni-63 to a high of 5.22E-02 for Sn-126. The inventory limit for acute exposure of Ag-108m at ET01 is the U.S. DOE IHI performance measure (500 mrem) divided by the dose factor. The larger the dose factor, the smaller the inventory limit. A concentration limit is also given as the inventory limit divided by the maximum potential waste volume in the DU. The concentration limit is not administratively or operationally significant; it is provided in tables for comparative purposes only.

All ETs have largely the same geometry, thus most dose factors do not vary between trenches. For example, ET acute dose factors for Sn-126 fall within a relatively narrow range of 0.0483 to 0.0625 mrem per disposed curie, with the differences caused by variations in DU waste volumes. Because of similarities with ET01, other ETs are not discussed individually. Instead, Appendix G provides tables of dose factors and inventory limits and graphs of dose versus time.

[2] In Table 7-5 and those that follow, radionuclides with a capital-letter suffix denote nuclides encapsulated within SWFs that have specified chemical and physical properties that are different from the generic waste form. A DU may have an inventory of a radionuclide in generic waste (e.g., I-129), as well as separate inventories of the same radionuclide in several distinct SWFs (e.g., I-129D and I-129-E).



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 ET01 inventories.

Figure 7-2. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for ET01

Table 7-5. Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for ET01

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (µCi m-3)	Waste Form Limit
Acute	Ag-108m	3.33E-02	171	1.50E+04	2.19E+06	Generic
	Am-241	7.27E-04	171	6.88E+05	1.00E+08	Generic
	Am-242m	8.07E-04	171	6.20E+05	9.04E+07	Generic
	Am-243	4.71E-03	171	1.06E+05	1.55E+07	Generic
	C-14	4.36E-07	171	1.15E+09	1.67E+11	Generic
	Cf-249	6.95E-03	171	7.19E+04	1.05E+07	Generic
	Cf-251	3.14E-03	171	1.59E+05	2.33E+07	Generic
	Cm-247	9.33E-03	1,171	5.36E+04	7.82E+06	Generic
	Cm-248	4.12E-02	171	1.21E+04	1.77E+06	Generic
	Cs-137	4.98E-04	171	1.00E+06	1.46E+08	Generic
	I-129	1.22E-04	171	4.09E+06	5.97E+08	Generic
	K-40	4.84E-03	171	1.03E+05	1.51E+07	Generic
	Nb-94	4.25E-02	171	1.18E+04	1.71E+06	Generic
	Ni-59	4.54E-07	171	1.10E+09	1.61E+11	Generic
	Ni-63	4.66E-08	171	1.07E+10	1.57E+12	Generic
	Np-237	5.53E-03	1,171	9.04E+04	1.32E+07	Generic
	Pu-239	8.93E-04	171	5.60E+05	8.17E+07	Generic
	Pu-240	8.82E-04	171	5.67E+05	8.27E+07	Generic
	Pu-241	2.50E-05	171	2.00E+07	2.92E+09	Generic
	Ra-226	4.89E-02	171	1.02E+04	1.49E+06	Generic
	Sn-126	5.22E-02	171	9.58E+03	1.40E+06	Generic
	Sr-90	6.72E-06	171	7.44E+07	1.08E+10	Generic
	Tc-99	1.14E-06	171	4.38E+08	6.39E+10	Generic
	Th-229	8.58E-03	171	5.83E+04	8.50E+06	Generic
	Th-230	2.09E-02	1,171	2.39E+04	3.49E+06	Generic
	U-232	1.16E-02	171	4.32E+04	6.31E+06	Generic
	U-233	1.00E-03	1,171	5.00E+05	7.29E+07	Generic
	U-234	2.15E-04	1,171	2.33E+06	3.40E+08	Generic
	U-236	8.44E-05	1,171	5.93E+06	8.65E+08	Generic
	U-233D	1.00E-03	1,171	5.00E+05	7.29E+07	Generic
	I-129D	1.22E-04	171	4.09E+06	5.97E+08	Generic
	I-129E	1.22E-04	171	4.09E+06	5.97E+08	Generic
	I-129G	1.22E-04	171	4.09E+06	5.97E+08	Generic
	I-129H	1.22E-04	171	4.09E+06	5.97E+08	Generic
	I-129I	1.22E-04	171	4.09E+06	5.97E+08	Generic
	I-129J	1.22E-04	171	4.09E+06	5.97E+08	Generic

Notes:

SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

Table 7-6. Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for ET01

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Ag-108m	2.20E-03	171	4.55E+04	6.64E+06	Generic
	Am-241	1.53E-05	171	6.53E+06	9.53E+08	Generic
	Am-242m	2.68E-05	171	3.73E+06	5.44E+08	Generic
	Am-243	6.69E-05	171	1.50E+06	2.18E+08	Generic
	C-14	5.42E-05	171	1.84E+06	2.69E+08	Generic
	Cf-249	8.91E-05	171	1.12E+06	1.64E+08	Generic
	Cf-251	4.89E-05	171	2.04E+06	2.98E+08	Generic
	Cm-247	1.23E-04	1,171	8.14E+05	1.19E+08	Generic
	Cm-248	4.82E-04	171	2.08E+05	3.03E+07	Generic
	Cs-137	3.92E-05	171	2.55E+06	3.72E+08	Generic
	I-129	1.02E-03	171	9.82E+04	1.43E+07	Generic
	K-40	8.12E-03	171	1.23E+04	1.80E+06	Generic
	Nb-94	7.10E-03	171	1.41E+04	2.06E+06	Generic
	Ni-59	1.11E-06	171	8.98E+07	1.31E+10	Generic
	Ni-63	9.83E-07	171	1.02E+08	1.48E+10	Generic
	Np-237	3.76E-04	1,171	2.66E+05	3.88E+07	Generic
	Pu-239	1.10E-05	171	9.12E+06	1.33E+09	Generic
	Pu-240	1.08E-05	171	9.23E+06	1.35E+09	Generic
	Pu-241	5.25E-07	171	1.90E+08	2.78E+10	Generic
	Ra-226	8.81E-02	171	1.14E+03	1.66E+05	Generic
	Sn-126	4.38E-03	171	2.28E+04	3.33E+06	Generic
	Sr-90	1.12E-04	171	8.89E+05	1.30E+08	Generic
	Tc-99	1.03E-02	171	9.75E+03	1.42E+06	Generic
	Th-229	3.79E-03	171	2.64E+04	3.85E+06	Generic
	Th-230	3.70E-02	1,171	2.70E+03	3.94E+05	Generic
	U-232	7.38E-02	171	1.36E+03	1.98E+05	Generic
	U-233	6.55E-04	1,171	1.53E+05	2.23E+07	Generic
	U-234	4.63E-04	1,171	2.16E+05	3.15E+07	Generic
	U-236	2.34E-04	1,171	4.28E+05	6.24E+07	Generic
	U-233D	6.55E-04	1,171	1.53E+05	2.23E+07	Generic
	I-129D	1.02E-03	171	9.82E+04	1.43E+07	Generic
	I-129E	1.02E-03	171	9.82E+04	1.43E+07	Generic
	I-129G	1.02E-03	171	9.82E+04	1.43E+07	Generic
	I-129H	1.02E-03	171	9.82E+04	1.43E+07	Generic
	I-129I	1.02E-03	171	9.82E+04	1.43E+07	Generic
	I-129J	1.02E-03	171	9.82E+04	1.43E+07	Generic

Notes:
SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

7.4.2. Slit Trenches

Twenty STs are listed in Table 7-1. Except for ST14 and ST23, all waste is buried 15.9 feet bgs after dynamic compaction (Figure 7-1) and erosion subsequently reduces this thickness to 12.9 feet (Figure 7-1) during the compliance period. All STs have the same geometry with slight variations in footprints, and most are treated as containing generic waste forms (i.e., the waste can be modeled as having the same physical properties as soil in every trench). Therefore, acute and chronic doses and dose factors are similar in each trench except for ST14 and ST23, which are described in Sections 7.4.2.1 and 7.4.2.2, respectively.

After screening (Section 2.3.7), 29 radionuclides remain and are included in the IHI analysis. For the nominal PA case employed for setting inventory limits, dynamic compaction is assumed to be successful. Because waste remains deeper than 9.84 feet throughout the 1,171 years, the acute basement construction and chronic agriculture scenarios do not apply. The well drilling scenario is more important than discovery for the IHI acute pathway because the discovery scenario involves only a short period of IHI involvement.

IHI acute and chronic doses typical of STs are plotted for the 1,000-year compliance period in Figure 7-3 using ST01 as a representative example. (Information for the remaining STs is provided in Appendix G.) In each of the four graphs in Figure 7-3, only the five radionuclides with the highest dose factors are shown.

In ST01, the radionuclides with the highest acute dose factors (and lowest inventory limits) are Sn-126, Ra-226, Nb-94, Cm-248, and Ag-108m [Figure 7-3(a)]. These five also represent the highest acute dose factors in all other STs as well as in ETs (Section 7.4.1). Sn-126, Ag-108m, and Nb-94 are strong gamma emitters, Ra-226 is a parent to short-lived strong gamma emitters, and Cm-248 has a significant spontaneous fission branching ratio. External exposure is the primary IHI acute dose pathway on a per disposed curie basis. These five radionuclides each contribute no more than 0.1 mrem per disposed curie to an IHI's acute dose; the other 28 radionuclides that are not shown contribute less. For example, Cs-137 contributes a maximum of 5.35E-04 mrem per disposed curie.

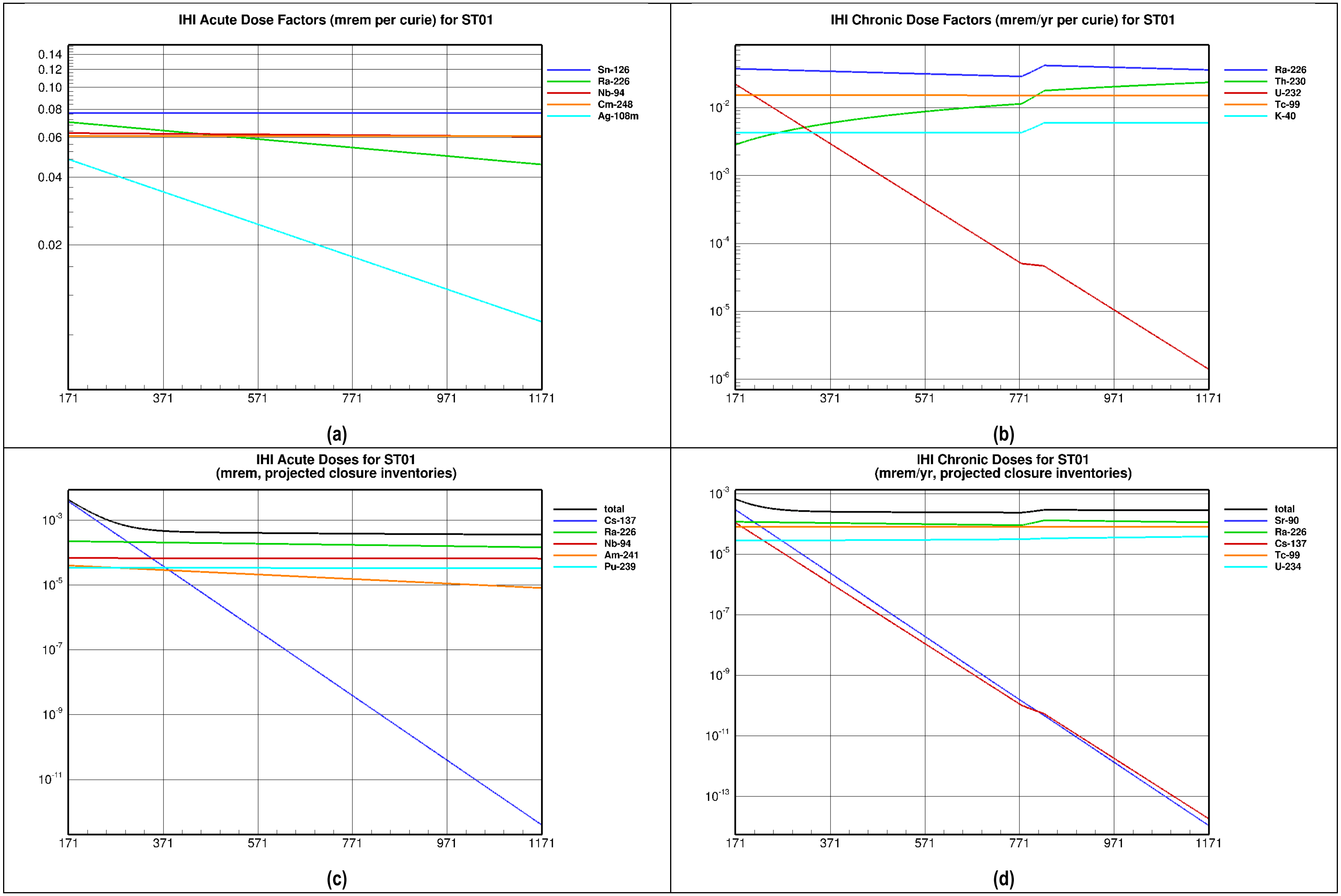
Dose factors and inventory limits for all ST01 radionuclides for the acute and chronic exposure scenarios are presented in Table 7-7 and Table 7-8, respectively; see Appendix G for information on other STs.

The five radionuclides with the highest chronic dose factors in ST01 are shown in Figure 7-3(b): Ra-226, Th-230, U-232, Tc-99, and K-40. The first three radionuclides listed are parents to short-lived, strong gamma emitters with the residential scenario of primary importance. Tc-99 is a pure beta emitter without radioactive progeny, but it has a large soil-to-vegetation bio-transfer factor. These five radionuclides are also the primary chronic dose contributors for other STs as well as ETs (Section 7.4.1). Individually, each of these radionuclides contributes peak dose between 6.0E-03 and 4.2E-02 mrem yr^{-1} per disposed curie. Other radionuclides, not shown, contribute less dose per disposed curie.

A discontinuity in chronic dose rate is evident in Figure 7-3(b), occurring between Years 776 and 824. This feature is a modeling artifact that affects all gamma-emitting decay chains (e.g., Ra-226, U-232, Th-230) in the chronic residential model. Prior to Year 776, the basement floor is over one meter from the waste. Because the SRNL Dose Toolkit model uses a constant gamma-shielding factor for distances greater than 1 meter, dose rate changes are related strictly to decay and ingrowth. Because a distance-variant shielding factor is used between Years 776 and 824, dose increases with continued erosion. At Year 824, all backfill is removed, erosion ceases, the erosion barrier is exposed, and the distance to the waste remains constant to the end of the compliance period. This modeling artifact affects all IHI chronic analyses for STs.

Graphs (c) and (d) in Figure 7-3 show time-variant estimates of actual doses experienced by IHIs at ST01, considering its projected 2065 CWTS inventory. The maximum IHI acute dose considering all 33 modeled radionuclides is 0.00427 mrem, mostly due to Cs-137 (Figure 7-3a). This result is less than the U.S. DOE performance measure of 500 mrem. The IHI chronic dose is 0.000670 mrem yr^{-1}, mostly due to Sr-90 (Figure 7-3d). This result is below the performance measure of 100 mrem yr^{-1}. The ST with the highest dose is ST23 (see Section 7.4.2.1 and Figure 7-4), with acute and chronic doses equal to 1.0 mrem and 3.74 mrem yr^{-1}, respectively. Radionuclides in all STs are predicted to be well within U.S. DOE IHI dose limits considering their projected 2065 CWTS inventories.

ST01 is broadly comparable to most of the other STs; therefore, the other STs are not discussed individually in this chapter. IHI analysis results for all STs are documented in Appendix G. ST14 and ST23 are discussed individually because they contain SWFs.



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 ST01 inventories.

Figure 7-3. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for ST01

Table 7-7. Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for ST01

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	Ag-108m	4.79E-02	171	1.04E+04	5.06E+05	Generic
	Am-241	1.05E-03	171	4.77E+05	2.31E+07	Generic
	Am-242m	1.14E-03	171	4.38E+05	2.12E+07	Generic
	Am-243	6.93E-03	171	7.21E+04	3.49E+06	Generic
	C-14	6.42E-07	171	7.79E+08	3.77E+10	Generic
	Cf-249	9.98E-03	171	5.01E+04	2.43E+06	Generic
	Cf-251	4.58E-03	171	1.09E+05	5.29E+06	Generic
	Cm-247	1.38E-02	1,171	3.63E+04	1.76E+06	Generic
	Cm-248	6.08E-02	171	8.22E+03	3.98E+05	Generic
	Cs-137	5.35E-04	171	9.34E+05	4.53E+07	Generic
	I-129	1.80E-04	171	2.77E+06	1.34E+08	Generic
	K-40	7.00E-03	171	7.14E+04	3.46E+06	Generic
	Nb-94	6.26E-02	171	7.99E+03	3.87E+05	Generic
	Ni-59	6.70E-07	171	7.47E+08	3.62E+10	Generic
	Ni-63	6.24E-08	171	8.01E+09	3.88E+11	Generic
	Np-237	8.16E-03	1,171	6.13E+04	2.97E+06	Generic
	Pu-239	1.32E-03	171	3.80E+05	1.84E+07	Generic
	Pu-240	1.30E-03	171	3.85E+05	1.86E+07	Generic
	Pu-241	3.60E-05	171	1.39E+07	6.73E+08	Generic
	Ra-226	7.00E-02	171	7.14E+03	3.46E+05	Generic
	Sn-126	7.69E-02	171	6.50E+03	3.15E+05	Generic
	Sr-90	6.61E-06	171	7.56E+07	3.66E+09	Generic
	Tc-99	1.68E-06	171	2.97E+08	1.44E+10	Generic
	Th-229	1.26E-02	171	3.97E+04	1.92E+06	Generic
	Th-230	3.02E-02	1,171	1.65E+04	8.02E+05	Generic
	U-232	1.35E-02	171	3.70E+04	1.79E+06	Generic
	U-233	1.48E-03	1,171	3.39E+05	1.64E+07	Generic
	U-234	3.14E-04	1,171	1.59E+06	7.72E+07	Generic
	U-236	1.24E-04	1,171	4.02E+06	1.95E+08	Generic
	U-233D	1.48E-03	1,171	3.39E+05	1.64E+07	Generic
	C-14N	6.42E-07	171	7.79E+08	3.77E+10	Generic
	I-129F	1.80E-04	171	2.77E+06	1.34E+08	Generic
	I-129J	1.80E-04	171	2.77E+06	1.34E+08	Generic

Notes:

SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

Table 7-8. Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for ST01

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Ag-108m	1.12E-03	171	8.94E+04	4.33E+06	Generic
	Am-241	2.21E-05	171	4.53E+06	2.19E+08	Generic
	Am-242m	2.35E-05	171	4.25E+06	2.06E+08	Generic
	Am-243	9.85E-05	171	1.02E+06	4.92E+07	Generic
	C-14	7.98E-05	171	1.25E+06	6.07E+07	Generic
	Cf-249	1.28E-04	171	7.82E+05	3.79E+07	Generic
	Cf-251	7.14E-05	171	1.40E+06	6.79E+07	Generic
	Cm-247	1.81E-04	1,171	5.52E+05	2.67E+07	Generic
	Cm-248	7.10E-04	171	1.41E+05	6.82E+06	Generic
	Cs-137	1.56E-05	171	6.42E+06	3.11E+08	Generic
	I-129	1.50E-03	171	6.66E+04	3.23E+06	Generic
	K-40	5.97E-03	824	1.68E+04	8.12E+05	Generic
	Nb-94	5.04E-03	824	1.98E+04	9.61E+05	Generic
	Ni-59	1.64E-06	171	6.11E+07	2.96E+09	Generic
	Ni-63	1.32E-06	171	7.58E+07	3.67E+09	Generic
	Np-237	5.54E-04	1,171	1.80E+05	8.74E+06	Generic
	Pu-239	1.62E-05	171	6.19E+06	3.00E+08	Generic
	Pu-240	1.60E-05	171	6.27E+06	3.04E+08	Generic
	Pu-241	7.58E-07	171	1.32E+08	6.39E+09	Generic
	Ra-226	4.16E-02	824	2.40E+03	1.16E+05	Generic
	Sn-126	3.53E-03	824	2.84E+04	1.37E+06	Generic
	Sr-90	9.17E-05	171	1.09E+06	5.28E+07	Generic
	Tc-99	1.51E-02	171	6.61E+03	3.20E+05	Generic
	Th-229	3.76E-03	824	2.66E+04	1.29E+06	Generic
	Th-230	2.34E-02	1,171	4.27E+03	2.07E+05	Generic
	U-232	2.21E-02	171	4.53E+03	2.20E+05	Generic
	U-233	8.01E-04	1,171	1.25E+05	6.05E+06	Generic
	U-234	5.02E-04	1,171	1.99E+05	9.66E+06	Generic
	U-236	3.45E-04	171	2.90E+05	1.41E+07	Generic
	U-233D	8.01E-04	1,171	1.25E+05	6.05E+06	Generic
	C-14N	7.98E-05	171	1.25E+06	6.07E+07	Generic
	I-129F	1.50E-03	171	6.66E+04	3.23E+06	Generic
	I-129J	1.50E-03	171	6.66E+04	3.23E+06	Generic

Notes:
SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

7.4.2.1. ST14

ST14 is different from the other trenches because it contains a highly activated reactor vessel from the former HWCTR. The reactor vessel is 8-foot in diameter by 30-foot long and was buried lying on its side. The reactor vessel complicates the IHI analysis in two ways. First, for several activation products, nearly all the inventory in ST14 is concentrated in the 15.66 cubic meter volume of the vessel, resulting in a concentrated SWF. Second, the vessel is regarded as non-compactable, so the waste height of the portion of ST14 containing the vessel is greater than the 11.1 feet adopted for compacted trench waste (Figure 7-1) and, therefore, is more accessible to IHIs.

In CWTS, the inventories of certain HWCTR radionuclides are tracked separately from other ST14 radionuclides and denoted with the suffix "H." Therefore, Nb-94 in CWTS refers to inventory in the generic section of ST14, while Nb-94H refers to activity within the steel reactor vessel. To account for the shielding provided by the steel reactor vessel and uncompacted waste height (Figure 7-1), a separate IHI analysis is performed (Verst, 2021a) for Ag-108mH and Nb-94H, two strong gamma emitters with separately tracked HWCTR inventories. The HWCTR reactor vessel is assumed to be located at the top of the uncompacted waste height, with the outer shell of the vessel 8 feet below the top of the erosion barrier. This location is sufficiently shallow so that, unlike most other trenches, the chronic residential scenario includes waste (in this case the HWCTR reactor vessel) in direct contact with the bottom of the concrete basement floor.

Because HWCTR is a large metallic SWF, the acute basement construction and well drilling scenarios are assumed to not apply to HWCTR radionuclides. The 30-foot-long HWCTR SWF is not excavated during basement construction, and well drilling does not penetrate it. Likewise, the chronic agricultural and post-drilling scenarios do not apply. IHI analysis for HWCTR includes the acute discovery and chronic residential scenarios.

Although the ST14 analysis considers HWCTR separately from the rest of ST14, calculated doses are combined for presentation in Figure 7-4. IHI doses per disposed curie during the compliance period are shown for the highest-contributing radionuclides. Acute dose factors are shown in Figure 7-4(a). As with every trench, the strong gamma emitting, long-lived parents Sn-126, Ra-226, and Nb-94 have the highest doses per disposed curie. Cs-137, although a strong gamma emitter, undergoes significant decay before the compliance period and is no longer significant when the compliance period begins in Year 171.

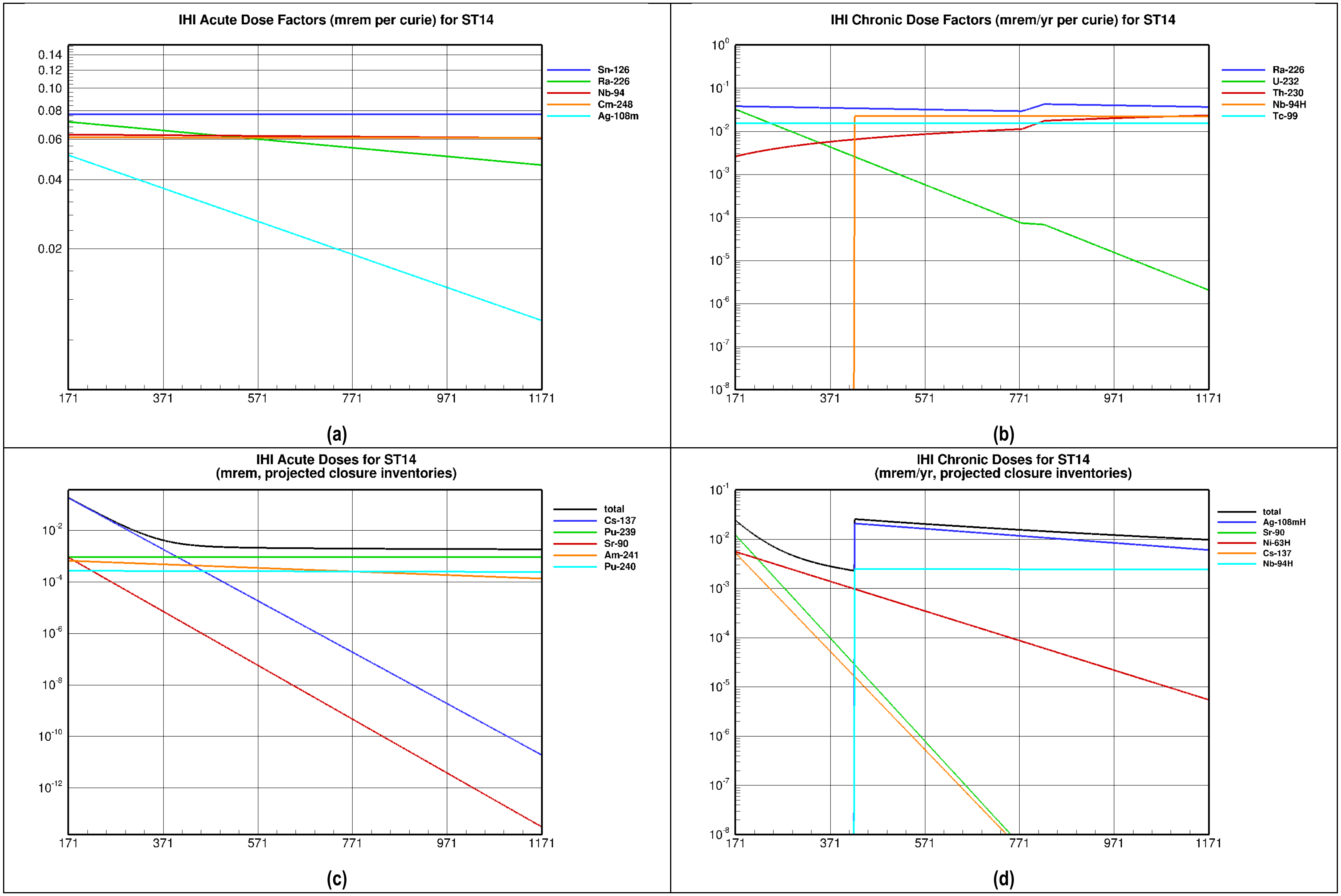
IHI chronic dose factors during the compliance period are shown in Figure 7-4(b). Although strong gamma emitters continue to show high dose rates per curie, Tc-99 (a pure beta emitter) also has a high dose rate because of its high soil-to-vegetation bio-transfer factor (SRNL, 2019b). Nb-94H within HWCTR is an important contributor to chronic dose rate via the residential scenario.

The discontinuity between Years 776 and 824, discussed previously and affecting all gamma emitters, is evident in Figure 7-4(b). A second discontinuity is present, between Years 417 and 423, affecting Nb-94H. Both discontinuities relate to the estimation of external gamma dose within the chronic residential scenario (i.e., the estimated dose to a person living in a house with a basement that overlies waste). The depth of waste below ground varies with time because the soil cover is modeled to pessimistically erode 1.4 mm yr^{-1} until the erosion barrier is reached and further erosion stops. Because the modeling includes the various times at which a basement may be constructed in the future and the doses associated with time-variant distances between basement floor and waste, the scenario can be viewed as a basement floor slowly getting closer and closer to the waste.

The discontinuity between Years 417 and 423 in Figure 7-4(b) and Figure 7-4(d) affects only radionuclides that are specifically modeled for HWCTR. Two different models are used to calculate external gamma dose: the SRNL Dose Toolkit when the basement floor is separated from HWCTR by an interval of clean backfill and MCNP 6.1 (Verst, 2021a) after Year 423 when the basement floor tangentially contacts HWCTR. The two models use different sources for shielding factors. The dose rates are regarded as accurate at Year 171 and after Year 423; however, the real dose rate experiences a gradual climb over the interval between Year 171 and Year 423. This artifact affects only Nb-94H and Ag-108mH, and only in the chronic exposure scenario.

Acute and chronic dose factors, inventory limits, and volumetric concentration limits for ST14 radionuclides are provided in Table 7-9 and Table 7-10, respectively.

Using the projected 2065 radiological CWTS inventory for ST14 (Section 2.3.3), informal, estimated IHI acute doses are provided in Figure 7-4(c), and IHI chronic dose rates are shown in Figure 7-4(d). The 2065 CWTS inventory projection includes all SWF inventories; therefore, the figure represents an upper bound and overestimates dose. Nevertheless, due to the projected ST14 inventory at closure, expected IHI acute and chronic doses are well below performance measures (U.S. DOE, 2017). The acute dose rates are expected to originate predominantly from the strong gamma emitter Cs-137 during the early years and from the alpha emitters Pu-239, Pu-240, and Am-241 after about Year 410. Sr-90 strongly contributes to early chronic dose rates due to its soil-to-vegetation bio-transfer factor before being superseded by HWCTR gamma emitters Ag-108mH and Nb-94H.



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 ST14 inventories.

Figure 7-4. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for ST14

Table 7-9. Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for ST14

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	Ag-108m	5.10E-02	171	9.80E+03	4.75E+05	Generic
	Am-241	1.11E-03	171	4.49E+05	2.18E+07	Generic
	Am-242m	1.28E-03	171	3.91E+05	1.90E+07	Generic
	Am-243	6.97E-03	171	7.18E+04	3.48E+06	Generic
	C-14	6.45E-07	171	7.75E+08	3.76E+10	Generic
	Cf-249	1.07E-02	171	4.65E+04	2.26E+06	Generic
	Cf-251	4.71E-03	171	1.06E+05	5.14E+06	Generic
	Cm-247	1.38E-02	1,171	3.63E+04	1.76E+06	Generic
	Cm-248	6.09E-02	171	8.21E+03	3.98E+05	Generic
	Cs-137	1.26E-03	171	3.97E+05	1.92E+07	Generic
	I-129	1.80E-04	171	2.77E+06	1.34E+08	Generic
	K-40	7.01E-03	171	7.13E+04	3.46E+06	Generic
	Nb-94	6.27E-02	171	7.97E+03	3.87E+05	Generic
	Ni-59	6.71E-07	171	7.46E+08	3.62E+10	Generic
	Ni-63	8.09E-08	171	6.18E+09	3.00E+11	Generic
	Np-237	8.17E-03	1,171	6.12E+04	2.97E+06	Generic
	Pu-239	1.32E-03	171	3.79E+05	1.84E+07	Generic
	Pu-240	1.31E-03	171	3.83E+05	1.86E+07	Generic
	Pu-241	3.82E-05	171	1.31E+07	6.35E+08	Generic
	Ra-226	7.12E-02	171	7.02E+03	3.41E+05	Generic
	Sn-126	7.70E-02	171	6.49E+03	3.15E+05	Generic
	Sr-90	1.62E-05	171	3.08E+07	1.49E+09	Generic
	Tc-99	1.68E-06	171	2.97E+08	1.44E+10	Generic
	Th-229	1.27E-02	171	3.95E+04	1.92E+06	Generic
	Th-230	2.99E-02	1,171	1.67E+04	8.10E+05	Generic
	U-232	1.97E-02	171	2.54E+04	1.23E+06	Generic
	U-233	1.46E-03	1,171	3.42E+05	1.66E+07	Generic
	U-234	3.10E-04	1,171	1.61E+06	7.82E+07	Generic
	U-236	1.25E-04	1,171	4.02E+06	1.95E+08	Generic
	U-233D	1.46E-03	1,171	3.42E+05	1.66E+07	Generic
	C-14N	6.45E-07	171	7.75E+08	3.76E+10	Generic
	Ag-108mH	7.65E-27	171	---	---	Special
	C-14H	6.45E-07	171	7.75E+08	3.76E+10	Generic
	Nb-94H	9.05E-27	171	---	---	Special
	Ni-59H	6.71E-07	171	7.46E+08	3.62E+10	Generic
	Ni-63H	8.09E-08	171	6.18E+09	3.00E+11	Generic
	Tc-99H	1.68E-06	171	2.97E+08	1.44E+10	Generic

Notes:

--- = numerical values exceeding 1 x 10^{20}

SWF radionuclides with future inventory are highlighted in green when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

The SWF model includes explicit gamma ray analyses (Verst, 2021a).

Table 7-10. Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for ST14

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Ag-108m	1.19E-03	171	8.40E+04	4.07E+06	Generic
	Am-241	2.35E-05	171	4.26E+06	2.07E+08	Generic
	Am-242m	2.71E-05	171	3.68E+06	1.79E+08	Generic
	Am-243	9.89E-05	171	1.01E+06	4.90E+07	Generic
	C-14	8.03E-05	171	1.25E+06	6.04E+07	Generic
	Cf-249	1.38E-04	171	7.27E+05	3.53E+07	Generic
	Cf-251	7.35E-05	171	1.36E+06	6.59E+07	Generic
	Cm-247	1.81E-04	1,171	5.52E+05	2.68E+07	Generic
	Cm-248	7.11E-04	171	1.41E+05	6.82E+06	Generic
	Cs-137	3.67E-05	171	2.72E+06	1.32E+08	Generic
	I-129	1.50E-03	171	6.65E+04	3.23E+06	Generic
	K-40	5.98E-03	824	1.67E+04	8.12E+05	Generic
	Nb-94	5.05E-03	824	1.98E+04	9.60E+05	Generic
	Ni-59	1.64E-06	171	6.10E+07	2.96E+09	Generic
	Ni-63	1.71E-06	171	5.85E+07	2.84E+09	Generic
	Np-237	5.55E-04	1,171	1.80E+05	8.74E+06	Generic
	Pu-239	1.62E-05	171	6.17E+06	2.99E+08	Generic
	Pu-240	1.60E-05	171	6.24E+06	3.03E+08	Generic
	Pu-241	8.04E-07	171	1.24E+08	6.03E+09	Generic
	Ra-226	4.23E-02	824	2.36E+03	1.15E+05	Generic
	Sn-126	3.53E-03	824	2.83E+04	1.37E+06	Generic
	Sr-90	2.25E-04	171	4.44E+05	2.15E+07	Generic
	Tc-99	1.51E-02	171	6.61E+03	3.20E+05	Generic
	Th-229	3.77E-03	824	2.65E+04	1.28E+06	Generic
	Th-230	2.32E-02	1,171	4.31E+03	2.09E+05	Generic
	U-232	3.21E-02	171	3.11E+03	1.51E+05	Generic
	U-233	7.97E-04	1,171	1.26E+05	6.09E+06	Generic
	U-234	4.99E-04	1,171	2.00E+05	9.72E+06	Generic
	U-236	3.45E-04	171	2.90E+05	1.41E+07	Generic
	U-233D	7.97E-04	1,171	1.26E+05	6.09E+06	Generic
	C-14N	8.03E-05	171	1.25E+06	6.04E+07	Generic
	Ag-108mH	6.32E-03	423	1.58E+04	1.01E+09	Special
	C-14H	8.03E-05	171	1.25E+06	6.04E+07	Generic
	Nb-94H	2.26E-02	423	4.43E+03	2.83E+08	Special
	Ni-59H	1.64E-06	171	6.10E+07	2.96E+09	Generic
	Ni-63H	1.71E-06	171	5.85E+07	2.84E+09	Generic
	Tc-99H	1.51E-02	171	6.61E+03	3.20E+05	Generic

Notes:

SWF radionuclides with future inventory are highlighted in green when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in red when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

The SWF model includes explicit gamma ray analyses (Verst, 2021a).

7.4.2.2. ST23

ST23 is a DU consisting of two parts: (1) an existing section containing several trench segments of a CIG SWF and (2) a future section intended to accept generic waste forms. The CIG trench segments were opened in calendar year 2000 and is a group of trench segments into which large, contaminated equipment and other materials were placed. Subsequently, the trench segments were encapsulated with grout that was poured around, between, and over the components, forming 192-inch-deep grout monoliths. No future waste is expected to be encapsulated in large grout formations such as the existing CIG SWFs; however, the use of grout as an engineering barrier is not being prohibited. ST23 is exceptional because the existing CIG-trench-segment portion contains more Cs-137 today (2,070 curies) than any other DU at the ELLWF.

The future section of ST23 that is scheduled to accept generic waste has the same geometry and physical properties as other trenches and the same applicable IHI scenarios and similar results as the other STs.

The CIG SWF behaves differently than generic waste. It has the same vertical geometry as other STs but does not have dynamic compaction. After the closure cap is installed, the regions of encapsulating grout remain 192 inches in vertical extent, with their top surfaces 8 feet below the erosion barrier (Figure 7-1, uncompacted ST). All CIG trench segments are covered by at least 12 inches of grout; therefore, the shallowest radiological waste is 9 feet below the erosion barrier and 12 feet bgs at the time of closure.

At the start of the IHI compliance period in Year 171, the grout is a barrier to excavation or penetration by drilling. As a result, only the acute discovery and chronic residential scenarios are applicable to CIG trench segments at that time. (The well drilling and post-drilling scenarios apply to the generic waste portion of ST23.) The grout degrades over time and loses its strength. It is assumed that the grout sufficiently deteriorates such that it no longer impedes penetration at 200 years after closure (Year 371). At this time, the well drilling and post-drilling scenarios will apply.

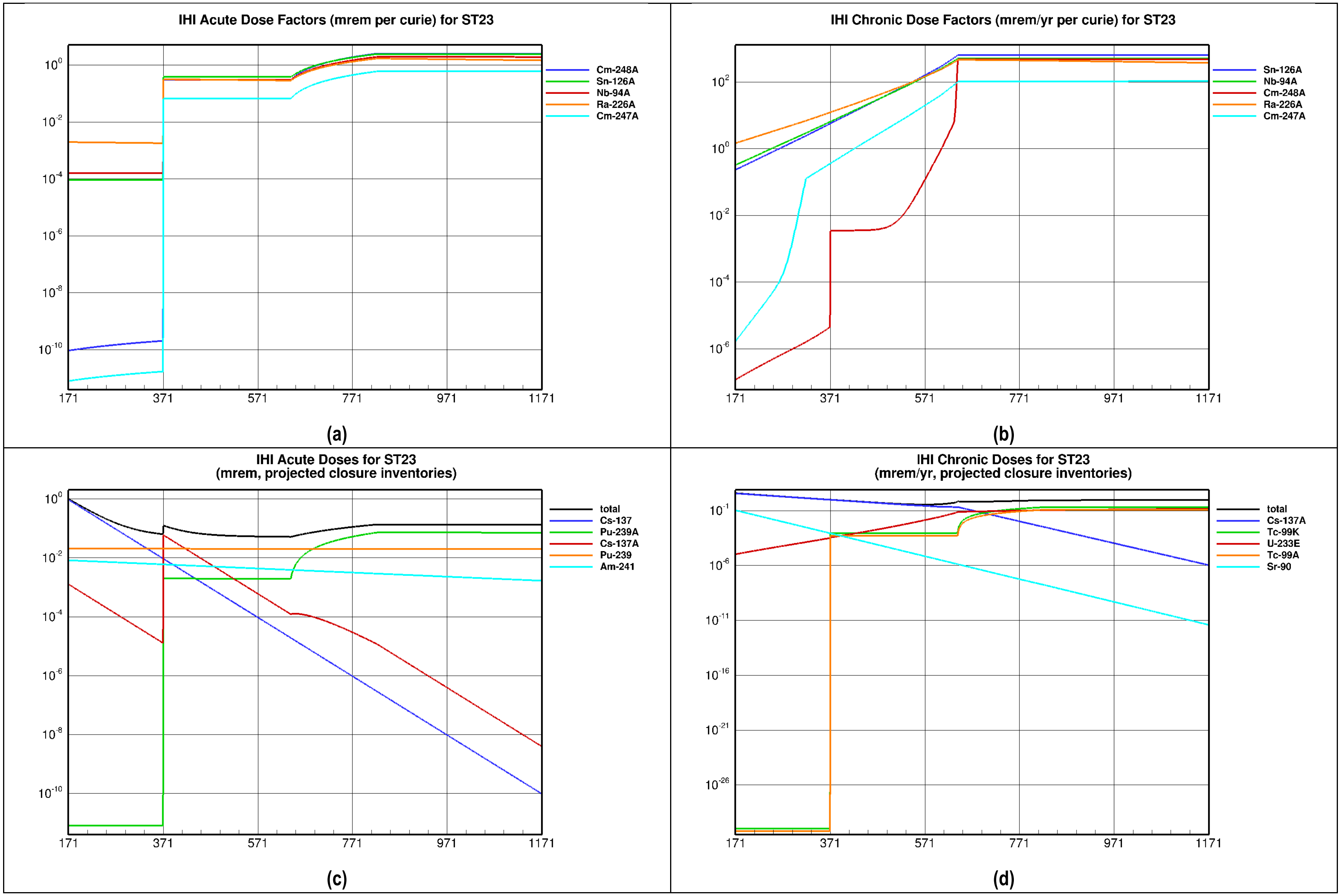
Erosion of the closure cap begins at Year 171 and proceeds at a rate of 1.4 mm yr^{-1}. At Year 641, SWFs are now 9.84 feet bgs and the basement construction and agricultural scenarios begin to apply (because the grout no longer is a barrier to penetration). The CIG trench segments in ST23 are the only part of the ELLWF where these two scenarios are relevant to IHI analysis.

The four graphs in Figure 7-5 show IHI acute and chronic doses for ST23. Calculations are for both ST23 generic waste and the CIG SWF. Only the five radionuclides with highest dose are shown in each graph; in every case, the top five radionuclides are CIG SWF radionuclides (note the suffix A). Figure 7-5(a) shows IHI acute doses on a per disposed curie basis. For the first 200 years, the grout prohibits penetration, and all acute dose is due to discovery. Beginning in Year 371, the grout can be penetrated by drilling, and the dominant risk driver becomes the well drilling scenario. At Year 641, erosion has proceeded sufficiently so that the ground surface (originally 12 feet above SWFs) is 9.84 feet above the top of the waste zone. At this point, the basement construction scenario begins to account for most of the dose. Erosion continues, exposing IHIs to increasing doses, until the erosion barrier is reached in Year 823. Subsequently, the basement ceases to get deeper with time, and the only change to dose is due to radioactive decay and ingrowth. All generic radionuclides in ST23 (not shown) have maximum doses below 1.0E-01 mrem per disposed curie.

Chronic doses per disposed curie are shown in Figure 7-5(b) for the five most impactful radionuclides. Because the CIG trench segments afford the least shielding to IHIs of any DU, gamma-emitting radionuclides in the residential scenario account for the most dose in the early years. Once the basement floor reaches the SWF in Year 641, the agricultural scenario is the risk driver.

Actual predicted doses to IHIs, computed using projected 2065 CWTS inventories, are shown in Figure 7-5(c) and Figure 7-5(d). Projected inventories for generic waste in other STs result in total IHI acute and chronic doses per ST of less than 1 mrem and 1 mrem yr^{-1}, respectively. Therefore, future IHI doses for ST23 (generic waste form + CIG SWF) are predicted to be well within the performance measures of 500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios.

IHI acute and chronic dose factors and inventory limits for ST23 are provided in Table 7-11 and Table 7-12, respectively. Many radionuclides in ST23 have the highest dose factors and lowest inventory limits of any DU at the ELLWF because the basement and agricultural scenarios are uniquely relevant to the ST23 CIG SWF. Nevertheless, IHI analysis indicates that doses to future IHIs meet U.S. DOE performance measures (U.S. DOE, 2017).



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 ST23 CIG inventories.

Figure 7-5. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for ST23

Table 7-11. Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for ST23

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (µCi m^{-3})	Waste Form Limit
Acute	Ag-108m	6.68E-02	171	7.49E+03	4.56E+05	Generic
	Am-241	1.46E-03	171	3.43E+05	2.09E+07	Generic
	Am-242m	1.74E-03	171	2.87E+05	1.75E+07	Generic
	Am-243	8.77E-03	171	5.70E+04	3.47E+06	Generic
	C-14	8.13E-07	171	6.15E+08	3.75E+10	Generic
	Cf-249	1.42E-02	171	3.53E+04	2.15E+06	Generic
	Cf-251	6.04E-03	171	8.28E+04	5.05E+06	Generic
	Cm-247	1.73E-02	1,171	2.89E+04	1.76E+06	Generic
	Cm-248	7.65E-02	171	6.54E+03	3.98E+05	Generic
	Cs-137	2.81E-03	171	1.78E+05	1.08E+07	Generic
	I-129	2.27E-04	171	2.21E+06	1.34E+08	Generic
	K-40	8.80E-03	171	5.68E+04	3.46E+06	Generic
	Nb-94	7.88E-02	171	6.34E+03	3.86E+05	Generic
	Ni-59	8.43E-07	171	5.93E+08	3.62E+10	Generic
	Ni-63	1.21E-07	171	4.14E+09	2.52E+11	Generic
	Np-237	1.03E-02	1,171	4.87E+04	2.97E+06	Generic
	Pu-239	1.66E-03	171	3.01E+05	1.84E+07	Generic
	Pu-240	1.64E-03	171	3.04E+05	1.85E+07	Generic
	Pu-241	4.98E-05	171	1.00E+07	6.12E+08	Generic
	Ra-226	9.04E-02	171	5.53E+03	3.37E+05	Generic
	Sn-126	9.67E-02	171	5.17E+03	3.15E+05	Generic
	Sr-90	3.72E-05	171	1.34E+07	8.18E+08	Generic
	Tc-99	2.12E-06	171	2.36E+08	1.44E+10	Generic
	Th-229	1.59E-02	171	3.14E+04	1.91E+06	Generic
	Th-230	3.79E-02	1,171	1.32E+04	8.04E+05	Generic
	U-232	3.18E-02	171	1.57E+04	9.59E+05	Generic
	U-233	1.85E-03	1,171	2.70E+05	1.65E+07	Generic
	U-234	3.93E-04	1,171	1.27E+06	7.75E+07	Generic
	U-236	1.56E-04	1,171	3.20E+06	1.95E+08	Generic
	U-233D	1.85E-03	1,171	2.70E+05	1.65E+07	Generic
	C-14K	2.00E-05	824	2.50E+07	4.72E+09	Special
	I-129K	6.36E-03	824	7.87E+04	1.48E+07	Special
	Tc-99K	7.21E-05	824	6.93E+06	1.31E+09	Special
	Am-241A	5.71E-02	823	8.76E+03	1.65E+06	Special
	Am-242mA	1.22E-02	823	4.09E+04	7.71E+06	Special
	Am-243A	3.62E-01	824	1.38E+03	2.60E+05	Special
	C-14A	2.00E-05	824	2.50E+07	4.72E+09	Special
	Cf-249A	1.57E-01	823	3.18E+03	6.00E+05	Special
	Cf-251A	2.44E-01	824	2.05E+03	3.86E+05	Special
	Cm-247A	6.02E-01	1,171	8.30E+02	1.56E+05	Special
	Cm-248A	2.49E+00	824	2.00E+02	3.78E+04	Special
	Cs-137A	2.89E-05	371	1.73E+07	3.26E+09	Special
	I-129A	6.36E-03	824	7.87E+04	1.48E+07	Special

Table 7-11 (cont'd). Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for ST23

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	K-40A	2.18E-01	824	2.29E+03	4.32E+05	Special
	Nb-94A	1.91E+00	824	2.61E+02	4.93E+04	Special
	Ni-59A	2.16E-05	824	2.31E+07	4.36E+09	Special
	Ni-63A	7.87E-08	371	6.35E+09	1.20E+12	Special
	Np-237A	3.47E-01	1,171	1.44E+03	2.72E+05	Special
	Pu-239A	2.36E-01	824	2.12E+03	4.00E+05	Special
	Pu-240A	2.21E-01	824	2.26E+03	4.25E+05	Special
	Pu-241A	1.96E-03	823	2.55E+05	4.81E+07	Special
	Ra-226A	1.67E+00	824	3.00E+02	5.65E+04	Special
	Sn-126A	2.40E+00	824	2.08E+02	3.93E+04	Special
	Sr-90A	6.29E-07	171	7.95E+08	1.50E+11	Special
	Tc-99A	7.21E-05	824	6.93E+06	1.31E+09	Special
	U-232A	9.14E-03	371	5.47E+04	1.03E+07	Special
	U-233A	9.93E-02	1,171	5.04E+03	9.49E+05	Special
	U-233E	9.93E-02	1,171	5.04E+03	9.49E+05	Special
	U-234A	2.56E-02	1,171	1.95E+04	3.68E+06	Special
	U-236A	1.78E-02	824	2.81E+04	5.29E+06	Special

Notes:

SWF radionuclides with future inventory are highlighted in green when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

Table 7-12. Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for ST23

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Ag-108m	1.56E-03	171	6.41E+04	3.91E+06	Generic
	Am-241	3.07E-05	171	3.26E+06	1.99E+08	Generic
	Am-242m	3.76E-05	171	2.66E+06	1.62E+08	Generic
	Am-243	1.25E-04	171	8.03E+05	4.89E+07	Generic
	C-14	1.01E-04	171	9.88E+05	6.02E+07	Generic
	Cf-249	1.82E-04	171	5.51E+05	3.36E+07	Generic
	Cf-251	9.42E-05	171	1.06E+06	6.47E+07	Generic
	Cm-247	2.28E-04	1,171	4.39E+05	2.67E+07	Generic
	Cm-248	8.93E-04	171	1.12E+05	6.82E+06	Generic
	Cs-137	8.19E-05	171	1.22E+06	7.44E+07	Generic
	I-129	1.89E-03	171	5.29E+04	3.23E+06	Generic
	K-40	7.51E-03	824	1.33E+04	8.12E+05	Generic
	Nb-94	6.35E-03	824	1.57E+04	9.59E+05	Generic
	Ni-59	2.06E-06	171	4.86E+07	2.96E+09	Generic
	Ni-63	2.55E-06	171	3.92E+07	2.39E+09	Generic
	Np-237	6.97E-04	1,171	1.43E+05	8.74E+06	Generic
	Pu-239	2.04E-05	171	4.91E+06	2.99E+08	Generic
	Pu-240	2.02E-05	171	4.95E+06	3.02E+08	Generic

Table 7-12 (cont'd). Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for ST23

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Pu-241	1.05E-06	171	9.56E+07	5.82E+09	Generic
	Ra-226	5.37E-02	824	1.86E+03	1.13E+05	Generic
	Sn-126	4.43E-03	824	2.25E+04	1.37E+06	Generic
	Sr-90	5.16E-04	171	1.94E+05	1.18E+07	Generic
	Tc-99	1.90E-02	171	5.26E+03	3.20E+05	Generic
	Th-229	4.75E-03	824	2.10E+04	1.28E+06	Generic
	Th-230	2.93E-02	1,171	3.41E+03	2.08E+05	Generic
	U-232	5.19E-02	171	1.93E+03	1.17E+05	Generic
	U-233	1.01E-03	1,171	9.95E+04	6.06E+06	Generic
	U-234	6.30E-04	1,171	1.59E+05	9.67E+06	Generic
	U-236	4.34E-04	171	2.31E+05	1.41E+07	Generic
	U-233D	1.01E-03	1,171	9.95E+04	6.06E+06	Generic
	C-14K	8.75E-02	824	1.14E+03	2.15E+05	Special
	I-129K	2.34E+00	824	4.27E+01	8.05E+03	Special
	Tc-99K	1.79E+01	824	5.59E+00	1.05E+03	Special
	Am-241A	7.91E-01	641	1.26E+02	2.38E+04	Special
	Am-242mA	1.62E-01	641	6.16E+02	1.16E+05	Special
	Am-243A	4.64E+01	641	2.15E+00	4.06E+02	Special
	C-14A	8.75E-02	824	1.14E+03	2.15E+05	Special
	Cf-249A	2.88E+01	641	3.48E+00	6.55E+02	Special
	Cf-251A	1.64E+01	641	6.09E+00	1.15E+03	Special
	Cm-247A	1.05E+02	1,171	9.54E-01	1.80E+02	Special
	Cm-248A	4.72E+02	824	2.12E-01	4.00E+01	Special
	Cs-137A	1.73E-03	171	5.77E+04	1.09E+07	Special
	I-129A	2.34E+00	824	4.27E+01	8.05E+03	Special
	K-40A	6.00E+01	824	1.67E+00	3.14E+02	Special
	Nb-94A	5.10E+02	641	1.96E-01	3.70E+01	Special
	Ni-59A	6.83E-03	824	1.46E+04	2.76E+06	Special
	Ni-63A	1.81E-05	784	5.53E+06	1.04E+09	Special
	Np-237A	6.33E+01	1,171	1.58E+00	2.98E+02	Special
	Pu-239A	9.65E-02	824	1.04E+03	1.95E+05	Special
	Pu-240A	8.20E-02	824	1.22E+03	2.30E+05	Special
	Pu-241A	2.72E-02	641	3.68E+03	6.94E+05	Special
	Ra-226A	4.59E+02	641	2.18E-01	4.11E+01	Special
	Sn-126A	6.37E+02	823	1.57E-01	2.96E+01	Special
	Sr-90A	3.42E-04	171	2.93E+05	5.52E+07	Special
	Tc-99A	1.79E+01	824	5.59E+00	1.05E+03	Special
	U-232A	9.71E-01	641	1.03E+02	1.94E+04	Special
	U-233A	9.53E+00	1,171	1.05E+01	1.98E+03	Special
	U-233E	9.53E+00	1,171	1.05E+01	1.98E+03	Special
	U-234A	1.87E+00	1,171	5.35E+01	1.01E+04	Special
	U-236A	4.24E-01	1,171	2.36E+02	4.45E+04	Special

Notes:

SWF radionuclides with future inventory are highlighted in green when a generic waste form model is employed to set disposal limits.

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

7.4.3. Low-Activity Waste Vault

Only four radionuclides (Cs-137, Nb-94, Ra-226, and Sr-90) remain after screening (Section 2.3.7) and are included in the IHI analysis for the LAWV. Despite its somewhat misleading name, the LAWV contains a higher activity of Sr-90, Nb-94, and Ra-226 than any trench and more Cs-137 than any trench except ST23. Nevertheless, the LAWV features a reinforced concrete roof that eliminates the acute basement construction and well drilling scenarios from consideration, as well as the chronic agriculture and post-drilling scenarios (Table 7-4).

IHI doses per disposed curie during the compliance period are calculated for the above four radionuclides (Figure 7-6). IHI acute dose rates are lower for the LAWV [Figure 7-6(a)] than the trenches because the well drilling scenario, a major contributor of dose for trenches, does not apply to the LAWV. IHI chronic dose rates for the LAWV [Figure 7-6(b)] are higher than for trenches because the 7.2-foot air gap in the LAWV allows for only 1.33 feet of solid shielding beneath the basement floor in the residential scenario (versus 3 to 6 feet in the STs). For acute and chronic exposure scenarios, Ra-226 and Nb-94 are the dominant radionuclides on a per disposed curie basis because of their gamma fields.

Acute and chronic dose factors (maximum dose rates during the compliance period), inventory limits, and volumetric concentration limits for LAWV radionuclides are provided in Table 7-13. Volumetric concentration limits represent the inventory limit divided by the actual or potential waste volume in the DU and are provided for information only. They are not intended for use as waste acceptance criteria.

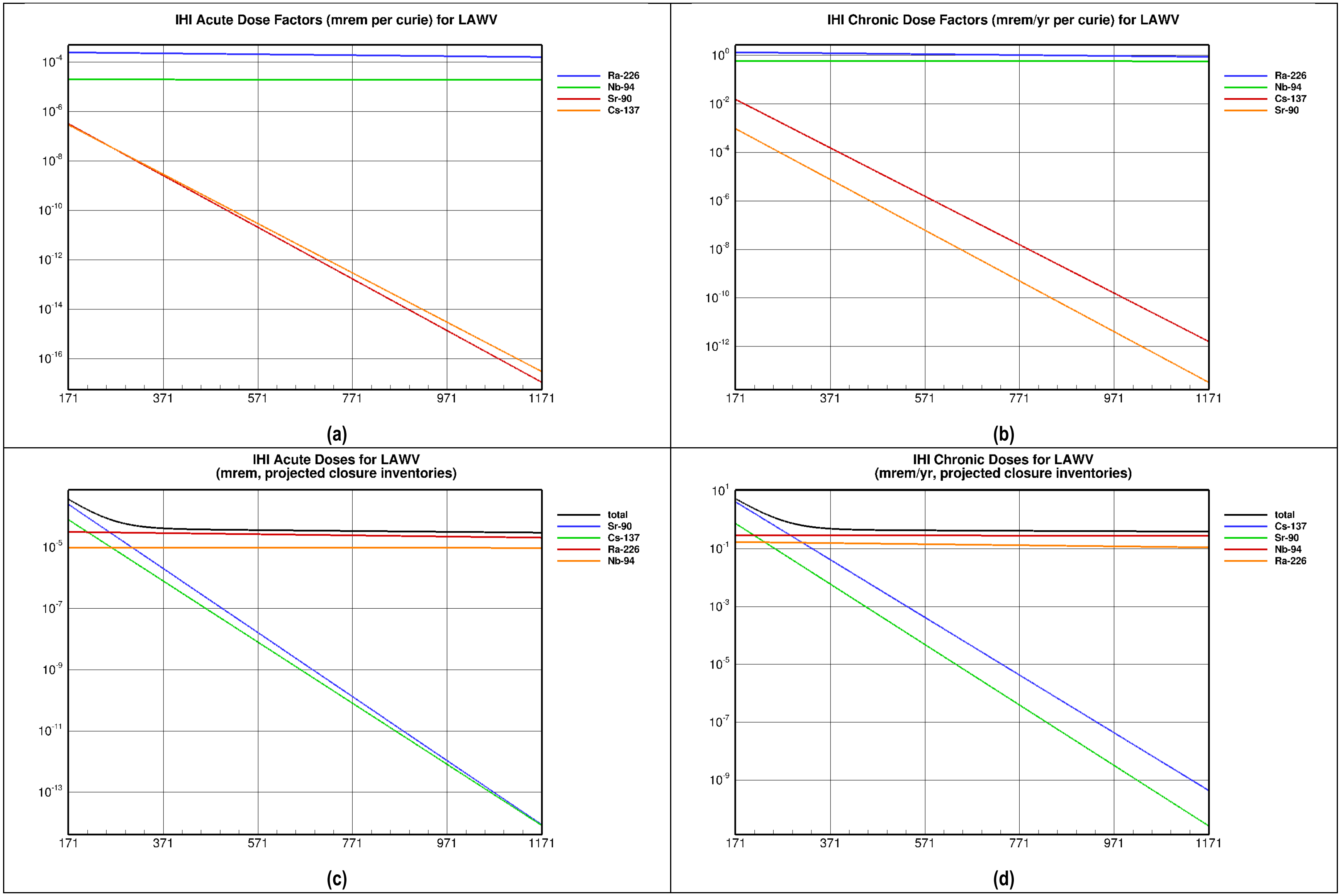
Using the projected 2065 radiological CWTS inventory for the LAWV (Section 2.3.3), estimated IHI acute doses are provided in Figure 7-6(c). For the IHI chronic dose, rates are shown in Figure 7-6(d). Expected doses to IHIs due to the projected inventory at closure are well below performance measures (500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios). For acute and chronic exposure scenarios, expected doses to IHIs are dominated by Sr-90 and Cs-137, respectively, in the early years, and by Ra-226 and Nb-94 after about Year 300.

Table 7-13. Inadvertent Human Intruder Acute and Chronic Dose Factors and Inventory Limits for Low-Activity Waste Vault

IHI Dose	Radionuclide	Dose Factor*	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	Cs-137	2.87E-07	171	1.74E+09	3.95E+10	Generic
	Nb-94	1.96E-05	171	2.55E+07	5.78E+08	Generic
	Ra-226	2.44E-04	171	2.05E+06	4.65E+07	Generic
	Sr-90	3.17E-07	171	1.58E+09	3.58E+10	Generic
Chronic	Cs-137	1.52E-02	171	6.59E+03	1.50E+05	Generic
	Nb-94	5.81E-01	171	1.72E+02	3.91E+03	Generic
	Ra-226	1.32E+00	171	7.58E+01	1.72E+03	Generic
	Sr-90	9.40E-04	171	1.06E+05	2.41E+06	Generic

Notes:

* mrem per Ci (Acute), mrem yr^{-1} per Ci (Chronic)



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 LAWV inventories.

Figure 7-6. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for Low-Activity Waste Vault

7.4.4. Intermediate-Level Vault

The ILV is a repository for activities associated with high levels of tritium, C-14, Cs-137, Ra-226, and Sr-90 in a relatively concentrated form. Waste in the ILV is secured beneath a 27-inch-thick reinforced concrete roof and 17 inches of grout, ensuring inadvertent human intrusion will not occur. The roof acts as a barrier to intrusion, which eliminates from consideration the acute basement construction and well drilling scenarios, as well as the chronic agriculture and post-drilling scenarios (Table 7-4).

After screening, only two radionuclides (Cs-137 and Ra-226) remain for IHI analysis (Section 2.3.7). Dose factors and inventory limits for both IHI acute and chronic exposure scenarios are presented in Table 7-14. Note that the acute and chronic dose factors and inventory limits for cesium-137 in the SWF (Cs-137T) are the same as those for generic waste (Cs-137).

Table 7-14. Inadvertent Human Intruder Acute and Chronic Dose Factors and Inventory Limits for Intermediate-Level Vault

IHI Dose	Radionuclide	Dose Factor*	Time of Maximum Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	Cs-137	9.09E-07	171	5.50E+08	7.18E+10	Generic
	Ra-226	1.36E-03	171	3.68E+05	4.80E+07	Generic
	Cs-137T	9.09E-07	171	5.50E+08	7.18E+10	Generic
Chronic	Cs-137	4.89E-05	171	2.04E+06	2.67E+08	Generic
	Ra-226	7.32E-02	171	1.37E+03	1.78E+05	Generic
	Cs-137T	4.89E-05	171	2.04E+06	2.67E+08	Generic

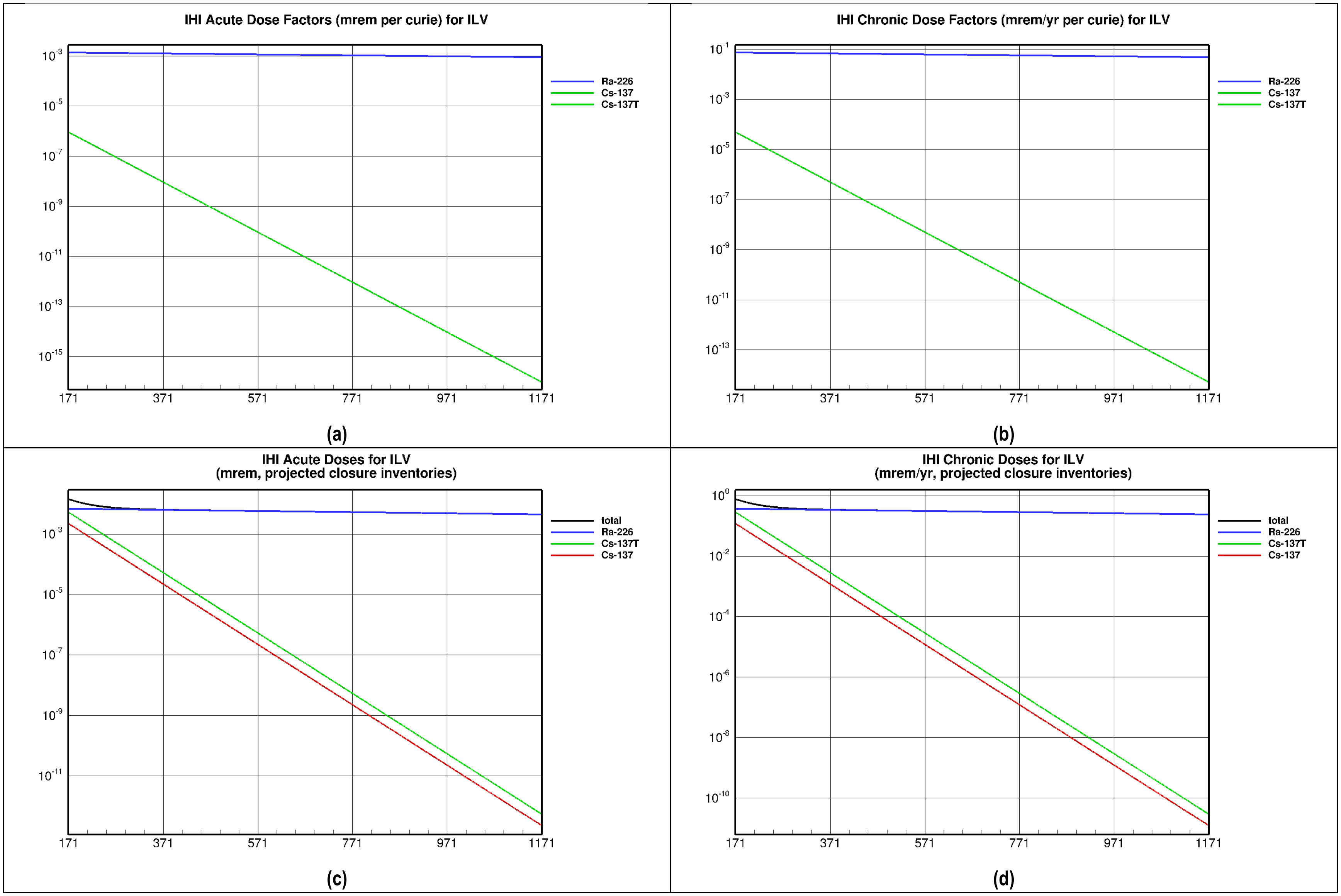
Notes:

* mrem per Ci (Acute), mrem yr^{-1} per Ci (Chronic)

SWF radionuclides with future inventory are highlighted in green when a generic waste form model is employed to set disposal limits.

Figure 7-7 shows IHI doses as a function of time. Figure 7-7(a) and Figure 7-7(b) represent the IHI acute dose (mrem per disposed curie) and chronic dose (mrem yr^{-1} per disposed curie), respectively. As shown in Figure 7-7(a), the acute dose factor for Ra-226 is about 1.36E-03 mrem per Ci compared with more than 4.89E-02 mrem per Ci at ET01 (Year 171), for example. IHI acute dose factors are lower at the ILV because the concrete roof prevents the well drilling scenario from contributing to dose. Chronic dose factors are shown in Figure 7-7(b) and are higher than acute dose factors because the chronic residential model provides for more IHI exposure time than the acute discovery model (6,136 hours per year versus 80 hours; Table 7-3).

Doses for an actual IHI are shown in Figure 7-7(c) and Figure 7-7(d), as computed using projected 2065 CWTS inventories provided in Section 8.7.1. Predicted IHI doses are below performance measures (500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios) during the compliance period.



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 ILV inventories. Note that the acute and chronic dose factors for cesium-137 in the SWF (Cs-137T) are the same as those for generic waste (Cs-137); therefore, only one curve is shown in (a) and (b).

Figure 7-7. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for Intermediate-Level Vault

7.4.5. Naval Reactor Component Disposal Areas

For IHI modeling, the two NRCDAs (NR07E and NR26E) are regarded as pads, occupied by numerous 18-foot-high non-crushable welded steel casks with walls and tops 15-inches thick. Waste comprising activated metal is contained within the casks, with one curie of each radionuclide distributed homogenously among them. All generic radionuclides were screened out in Section 2.3.7, so waste in both NRCDAs is treated as a SWF for IHI analysis (Figure 7-1). Although 13 radionuclides remain after NRCDAS screening (Table 2-27), only the acute discovery and chronic residential scenarios are applicable because the steel cask is an impenetrable barrier to excavation and drilling. Because the two NRCDAs have similar geometry and waste forms, NR07E is discussed here and considered representative of both. Dose factors, inventory limits, and dose vs time graphs for NR26E are included in Appendix G.

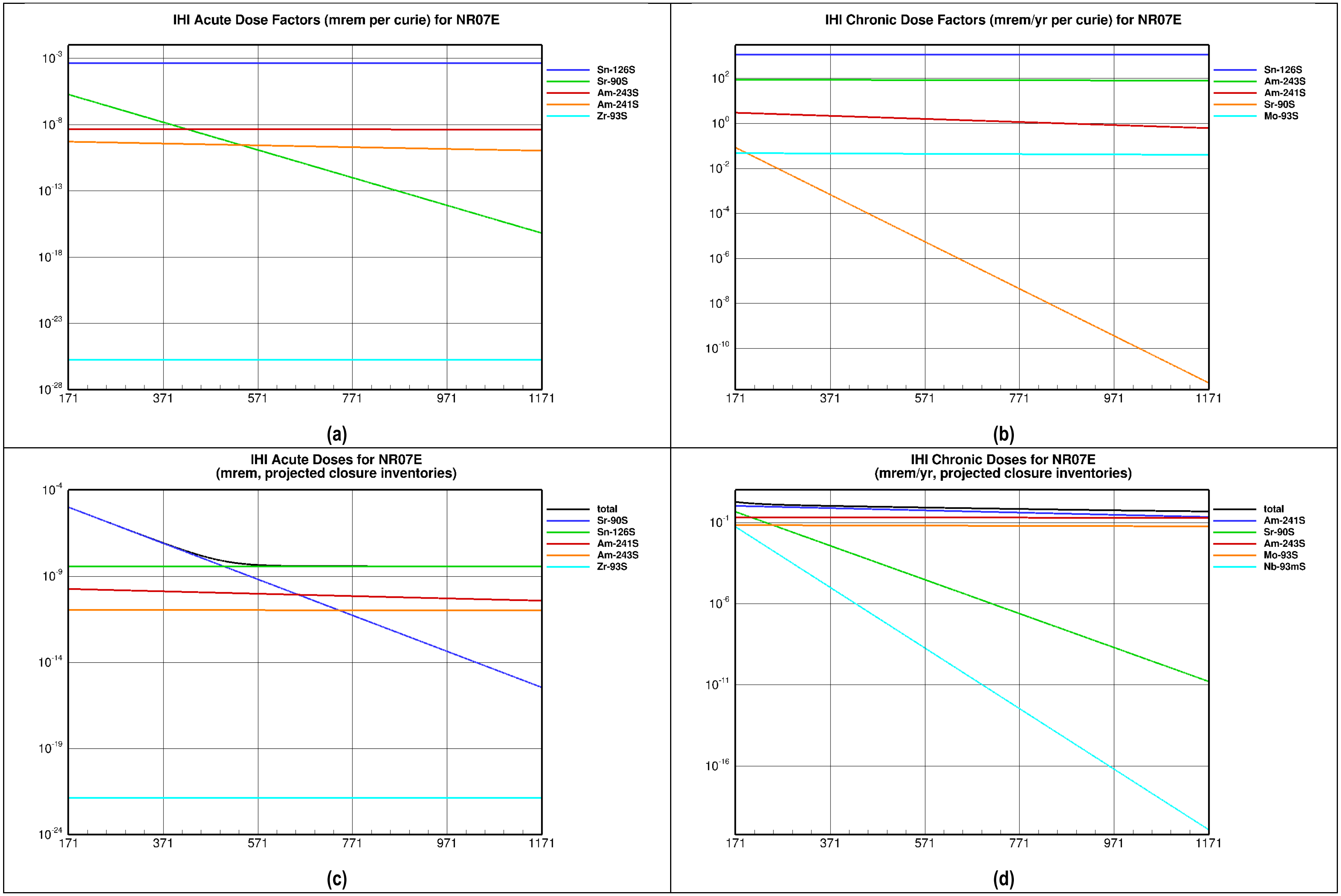
Initial scoping analyses for the 13 parent radionuclides were based on the geometric model employed in screening (i.e., the reference DU-type NRCDAS). This model assumed the cask material to behave like soil properties. Initial calculations indicated that six of the 13 parent radionuclides had unacceptable total SOF values because of their strong gamma-emitting aspects. External gamma-ray analyses were performed by Verst (2021a) for the following six parent radionuclides:

Co-60S, Cs-137S, Nb-94S, Ni-59S, Pu-241S, and Zr-93S

where explicit account of the cask materials and geometries was made. The resulting inventory limits result in acceptable SOF values. Inventory limits for the remaining seven parent radionuclides can be increased by incorporating gamma-ray analyses but this is not considered necessary.

IHI doses per disposed curie for NR07E during Years 171 to 1,171 are shown in Figure 7-8 for the highest-contributing radionuclides. Because excavation scenarios are not applied to NRCDAs, IHI acute doses per disposed curie [Figure 7-8(a)] are less than those in the trenches, with gamma-emitting Sn-126 showing the highest dose factor. However, IHI chronic dose factors in the NRCDAs [Figure 7-8(b)] are higher than all other DUs because NRCDAs provide the least external dose shielding for IHIs.

Dose factors and inventory limits for the acute and chronic exposure scenarios are provided in Table 7-15 and Table 7-16, respectively. Inventory limits are divided by waste volumes to generate concentration limits, which are provided in the table but have no programmatic role at the ELLWF.



Notes: (a) and (b) show mrem or mrem yr^{-1} per curie of disposed radionuclide versus model year; (c) and (d) show expected IHI doses in mrem or mrem yr^{-1} versus model year for projected 2065 NR07E inventories.

Figure 7-8. Inadvertent Human Intruder Acute and Chronic Dose Factors and Doses for NR07E

Table 7-15. Inadvertent Human Intruder Acute Dose Factors and Inventory Limits for NR07E

IHI Dose	Radionuclide	Dose Factor (mrem per curie)	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Acute	Am-241S	5.06E-10	171	9.88E+11	3.30E+14	Special
	Am-243S	4.53E-09	171	1.10E+11	3.68E+13	Special
	Co-60S	5.45E-36	171	---	---	Special
	Cs-137S	4.33E-28	171	---	---	Special
	Mo-93S	5.56E-30	171	---	---	Special
	Nb-93mS	2.94E-33	171	---	---	Special
	Nb-94S	9.05E-27	171	---	---	Special
	Ni-59S	9.09E-27	171	---	---	Special
	Pu-241S	2.45E-28	171	---	---	Special
	Sn-121mS	4.21E-31	171	---	---	Special
	Sn-126S	4.24E-04	171	1.18E+06	3.94E+08	Special
	Sr-90S	1.85E-06	171	2.71E+08	9.03E+10	Special
	Zr-93S	1.80E-26	243	---	---	Special

Notes:

--- = numerical values exceeding 1 x 10^{20}

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

SWF model that includes explicit gamma ray analyses (Verst, 2021a) is highlighted in green.

Table 7-16. Inadvertent Human Intruder Chronic Dose Factors and Inventory Limits for NR07E

IHI Dose	Radionuclide	Dose Factor (mrem yr^{-1} Ci^{-1})	Time of Max Dose (model year)	Inventory Limit (curies)	Concentration Limit (μCi m^{-3})	Waste Form Limit
Chronic	Am-241S	2.94E+00	171	3.40E+01	1.14E+04	Special
	Am-243S	8.59E+01	171	1.16E+00	3.88E+02	Special
	Co-60S	8.71E-13	171	1.15E+14	3.83E+16	Special
	Cs-137S	4.55E-07	171	2.20E+08	7.34E+10	Special
	Mo-93S	4.71E-02	171	2.12E+03	7.09E+05	Special
	Nb-93mS	7.23E-06	171	1.38E+07	4.62E+09	Special
	Nb-94S	9.09E-05	171	1.10E+06	3.67E+08	Special
	Ni-59S	1.07E-11	171	9.39E+12	3.13E+15	Special
	Pu-241S	1.32E-26	171	---	---	Special
	Sn-121mS	1.15E-02	171	8.66E+03	2.89E+06	Special
	Sn-126S	1.13E+03	171	8.86E-02	2.96E+01	Special
	Sr-90S	8.41E-02	171	1.19E+03	3.97E+05	Special
	Zr-93S	9.68E-25	243	---	---	Special

Notes:

--- = numerical values exceeding 1 x 10^{20}

SWF radionuclides with no future inventory are highlighted in yellow when a SWF model is employed to set disposal limits.

SWF model that includes explicit gamma ray analyses (Verst, 2021a) is highlighted in green.

Using the projected 2065 radiological inventory (Wohlwend and Butcher, 2018), estimated IHI acute and chronic doses for NR07E are shown in Figure 7-8(c) and Figure 7-8(d), respectively. Because Wohlwend and Butcher (2018) omitted an inventory for Sn-121m, NR07E is pessimistically assumed to contain 10 times (or 171 curies) as much Sn-121m as NR26E.

As a result, the maximum expected acute and chronic doses to an IHI at NR07E due to the projected 2065 CWTS inventory are 9.95E-06 mrem and 1.83 mrem yr^{-1}, respectively. These doses are well below performance measures (500 mrem EDE for acute exposure scenarios and 100 mrem yr^{-1} for chronic exposure scenarios). The IHI acute dose is initially due to Sr-90S and then gives way to Sn-126S after 500 years. The chronic dose is initially due to the combined effects of Am-241S and Sr-90S, giving way to Am-241S and Am-243S in later years.

7.5. TRIGGER VALUES

The inventory limits presented in this chapter provide an administrative control on future waste acceptance activities at ELLWF to protect MOPs. The limits described herein apply only to the 177 radionuclides currently tracked in CWTS. During the next 40 years of operations, additional radionuclides currently not tracked in CWTS may be identified for disposal.

The screening process described in Section 2.3.7 identifies 74 radionuclides which could pose a risk to IHIs in the future that are not tracked in CWTS or are not currently present in DUs. IHI trigger values (or preliminary IHI inventory limits) are calculated for these 74 radionuclides and are presented in Table 2-28 for the five types of DUs. Based on DU footprint size differences, these trigger values were adjusted and are provided in Appendix H, Section H.5.2. If future disposal of one or more of these radionuclides is proposed in an amount that exceeds a trigger value, an SA is required to obtain and document formal IHI CWTS inventory limit(s).

7.6. SENSITIVITY AND UNCERTAINTY ANALYSES

All predictions of future events involve uncertainty. For example, each parameter assignment shown in Table 7-3, along with many others not shown, are uncertain. To mitigate uncertainty, the IHI analysis is designed to be pessimistically leaning and overestimate radiological dose to IHIs. Pessimistically leaning assumptions include the following:

- **Activity in the Ground is Overestimated.** Although radionuclide inventories in CWTS are those that existed at the time of waste characterization before waste acceptance and burial, the Case 2 decay history is used for most radionuclides. In this case, decay is held to start at the time of DU closure; that is, decay between waste characterization and DU closure is not considered. For most DUs, the time between waste characterization and DU closure is 25 years or more, which is significant for the two greatest IHI risk drivers Cs-137 and Sr-90.
- **Dose Rates at the Point of Exposure are Overestimated.** Except for two radionuclides in ST14 and six radionuclides in the NRCDAs, no credit is taken for shielding of photons by the waste itself.

- **Doses to IHIs are Overestimated.** The IHI analysis stacks scenarios; that is, total IHI dose is the sum of doses from individual scenarios. For example, the IHI acute dose at the 29 trenches assumes that the IHI who discovers the erosion barrier while digging or drilling and then abandons the excavation is the same IHI who encounters the barrier while drilling a well and decides to continue. These two scenarios are mutually exclusive from a behavioral standpoint, yet the analysis assumes the same person does both.
- **Additional Behavioral Assumptions are Pessimistic.** For example, institutional memory is assumed to be lost the same year that dynamic compaction and site closure occurs which is unlikely. It is more likely that institutional memory will persist for 50 years or more, by which time Cs-137 and Sr-90 activity will have subsided significantly. In addition, waste encountered in the ground is assumed to be mistaken for soil and not recognized as something undesirable.
- **Leaching of Radionuclides by Groundwater is Ignored.** Although GW leaching may not be significant during the compliance period, Tc-99 is a leachable constituent and accounts for about 10% of IHI chronic dose in several trenches, considering their projected 2065 inventories. No credit is taken for potential Tc-99 leaching.

7.6.1. Effect of Alternative Start to 1,000-year Assessment Period

The U.S. DOE standard (U.S. DOE, 2017) for evaluating public health risks prescribes a 1,000-year assessment period following site closure. However, two distinct milestones are associated with the site closure of ELLWF: (1) the scheduled end of the operational period and installation of an interim cover, which will occur in 2065 (Year 71) and (2) dynamic compaction of STs and ETs and installation of a final closure cap in 2165 (Year 171). Although this PA begins the 1,000-year assessment period in Year 171 and continues to Year 1,171 (calendar years 2165 to 3165), this section evaluates the effect of commencing the 1,000 years at the end of operations in Year 71 and continuing to Year 1,071. Since institutional controls are in place from Years 71 to 171, the IHI analysis described in this section applies to Years 171 to 1,071 (calendar years 2165 to 3065) per Aleman et al. (2021).

A radionuclide's inventory limit is derived from the maximum dose or dose rate experienced by an IHI over the duration of the compliance period. The lower the maximum dose rate, the more lenient the inventory limit. Typically, radionuclides decay during the compliance period, with the maximum dose rate occurring at the beginning of the compliance period. For example, the IHI maximum acute dose from Sr-90 at ST01 for the projected 2065 inventory is 2.15E-05 mrem (Figure 7-9), occurring at Year 171. When the compliance period ends at Year 1,071 (versus Year 1,171), the maximum dose rate and inventory limit do not change.

A few radionuclide parents (parents of chains with moderately long-lived gamma-emitting daughters) show increasing dose through time and continue to increase at 1,171 years (see Th-230 in Figure 7-9). The inventory limit of Th-230 is derived from the Year 1,171 dose, which is 8.67E-06 mrem yr^{-1}. If the compliance period ends at Year 1,071, the dose is smaller (8.10E-06 mrem yr^{-1}) and the inventory limit is slightly higher.

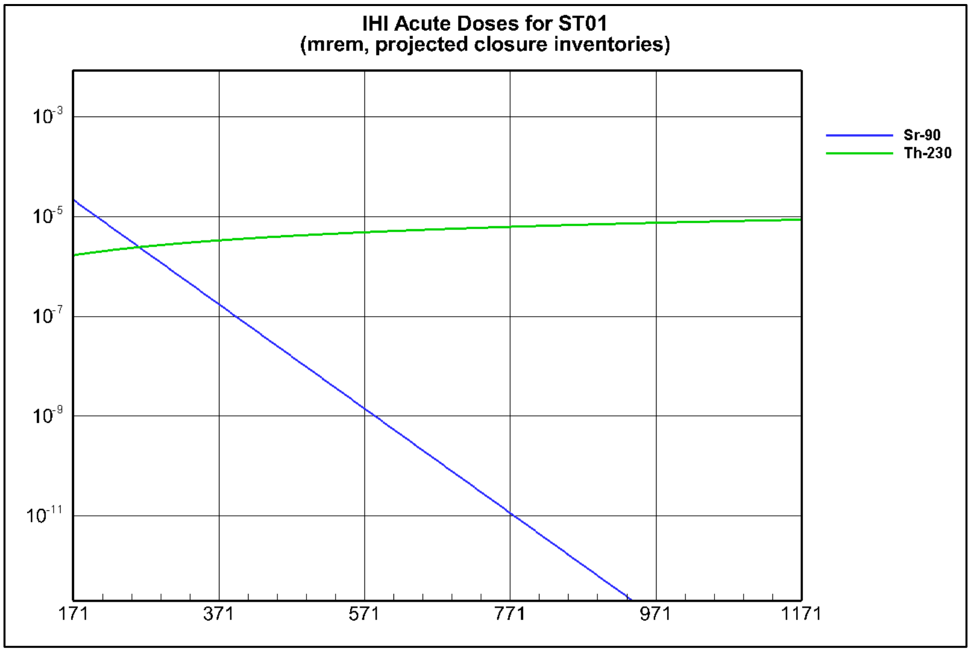


Figure 7-9. Inadvertent Human Intruder Acute Doses for ST01 Due to Sr-90 and Th-230 based on Projected 2065 ST01 Inventory

Among all 33 DUs, only six generic radionuclides subject to IHI analysis reach their dose maxima at Year 1,171: Cm-247, Np-237, Th-230, U-233, U-234, and U-236. As an example, Table 7-17 shows the changes in IHI inventory limits, as percentage increase, at ST01 when the IHI model compliance period is modified to terminate in model year 1,071. Modifying the compliance period has no effect on computed IHI inventory limits for most radionuclides, including Cs-137 and Sr-90. Although a slight increase in inventory limits occurs for six actinide metals (Cm-247, Np-237, Th-230, U-233, U-234, and U-236), the increase is less than 10% in every case.

Table 7-17. Inadvertent Human Intruder Acute and Chronic Inventory Limits for ST01 Generic Radionuclides with Assessment Period Ending at Year 1,071

Radionuclide	IHI Acute Inventory Limit (Ci)		Increase (%) Using Year 1,071	IHI Chronic Inventory Limit (Ci)		Increase (%) Using Year 1,071
	Year 171 to Year 1,071	Year 171 to Year 1,171		Year 171 to Year 1,071	Year 171 to Year 1,171	
Ag-108m	1.04E+04	1.04E+04	0	8.94E+04	8.94E+04	0
Am-241	4.77E+05	4.77E+05	0	4.53E+06	4.53E+06	0
Am-242m	4.38E+05	4.38E+05	0	4.25E+06	4.25E+06	0
Am-243	7.21E+04	7.21E+04	0	1.02E+06	1.02E+06	0
C-14	7.79E+08	7.79E+08	0	1.25E+06	1.25E+06	0
Cf-249	5.01E+04	5.01E+04	0	7.82E+05	7.82E+05	0
Cf-251	1.09E+05	1.09E+05	0	1.40E+06	1.40E+06	0
Cm-247	3.65E+04	3.63E+04	0.4	5.55E+05	5.52E+05	0.5
Cm-248	8.22E+03	8.22E+03	0	1.41E+05	1.41E+05	0
Cs-137	9.34E+05	9.34E+05	0	6.42E+06	6.42E+06	0
I-129	2.77E+06	2.77E+06	0	6.66E+04	6.66E+04	0
K-40	7.14E+04	7.14E+04	0	1.68E+04	1.68E+04	0
Nb-94	7.99E+03	7.99E+03	0	1.98E+04	1.98E+04	0
Ni-59	7.47E+08	7.47E+08	0	6.11E+07	6.11E+07	0
Ni-63	8.01E+09	8.01E+09	0	7.58E+07	7.58E+07	0
Np-237	6.13E+04	6.13E+04	0	1.80E+05	1.80E+05	0.1
Pu-239	3.80E+05	3.80E+05	0	6.19E+06	6.19E+06	0
Pu-240	3.85E+05	3.85E+05	0	6.27E+06	6.27E+06	0
Pu-241	1.39E+07	1.39E+07	0	1.32E+08	1.32E+08	0
Ra-226	7.14E+03	7.14E+03	0	2.40E+03	2.40E+03	0
Sn-126	6.50E+03	6.50E+03	0	2.84E+04	2.84E+04	0
Sr-90	7.56E+07	7.56E+07	0	1.09E+06	1.09E+06	0
Tc-99	2.97E+08	2.97E+08	0	6.61E+03	6.61E+03	0
Th-229	3.97E+04	3.97E+04	0	2.66E+04	2.66E+04	0
Th-230	1.77E+04	1.65E+04	7.0	4.58E+03	4.27E+03	7.1
U-232	3.70E+04	3.70E+04	0	4.53E+03	4.53E+03	0
U-233	3.65E+05	3.39E+05	7.9	1.30E+05	1.25E+05	4.5
U-234	1.74E+06	1.59E+06	9.3	2.08E+05	1.99E+05	4.3
U-236	4.02E+06	4.02E+06	0.0001	2.90E+05	2.90E+05	0

Notes:
Radionuclides highlighted in orange have larger inventory limits when ending the assessment period at Year 1,071.

7.6.2. Effect of Dynamic Compaction

Current closure plans call for dynamic compaction of all STs and ETs just before the beginning of the compliance period at model year 171. Dynamic compaction crushes metallic containers that may contain void space, creating a more dimensionally stable closure cap and compressing the waste zones and burying them deeper. This section evaluates the effect on IHI inventory limits if dynamic compaction does not occur (Aleman et al., 2021).

The IHI sensitivity analysis includes all trenches, assuming no compaction of waste. Without compaction, the tops of trench waste zones are only 8 feet beneath the erosion barrier (versus 12.9 feet with compaction). The shallower burial brings the acute basement and chronic agricultural scenarios into play, as well as increasing external dose in the acute discovery and chronic residential scenarios. A comparison of changes in inventory limits is presented in Table 7-18 for ST02.

Table 7-18. Comparison of Acute and Chronic Inadvertent Human Intruder Inventory Limits for ST02 With and Without Dynamic Compaction During Site Closure

Radionuclide	Acute IHI Inventory Limit (Ci)		Chronic IHI Inventory Limit (Ci)	
	No Compaction	ADC	No Compaction	ADC
Ag-108m	2.71E+03	1.04E+04	2.13E+00	8.89E+04
Am-241	2.27E+04	4.74E+05	5.02E+02	4.50E+06
Am-242m	8.27E+04	4.34E+05	1.19E+03	4.20E+06
Am-243	3.68E+03	7.20E+04	1.18E+01	1.01E+06
C-14	6.88E+07	7.78E+08	2.93E+03	1.25E+06
Cf-249	8.51E+03	4.98E+04	1.28E+01	7.77E+05
Cf-251	5.38E+03	1.09E+05	2.89E+01	1.40E+06
Cm-247	2.24E+03	3.63E+04	5.33E+00	5.52E+05
Cm-248	5.43E+02	8.21E+03	1.19E+00	1.41E+05
Cs-137	8.71E+05	8.71E+05	9.44E+03	5.98E+06
I-129	2.15E+05	2.77E+06	1.26E+02	6.65E+04
K-40	6.34E+03	7.14E+04	8.91E+00	1.67E+04
Nb-94	7.23E+02	7.99E+03	1.09E+00	1.98E+04
Ni-59	6.37E+07	7.46E+08	6.14E+04	6.10E+07
Ni-63	7.84E+09	7.84E+09	6.89E+06	7.42E+07
Np-237	3.90E+03	6.12E+04	8.74E+00	1.80E+05
Pu-239	5.49E+03	3.79E+05	2.91E+03	6.18E+06
Pu-240	5.84E+03	3.84E+05	3.25E+03	6.26E+06
Pu-241	6.62E+05	1.38E+07	1.46E+04	1.31E+08
Ra-226	8.27E+02	7.13E+03	1.11E+00	2.40E+03
Sn-126	5.76E+02	6.50E+03	8.78E-01	2.83E+04
Sr-90	7.08E+07	7.03E+07	1.78E+05	1.01E+06
Tc-99	1.87E+07	2.97E+08	1.43E+01	6.61E+03
Th-229	1.88E+03	3.96E+04	6.63E+00	2.66E+04
Th-230	1.36E+03	1.66E+04	2.25E+00	4.28E+03
U-232	3.62E+04	3.59E+04	6.49E+01	4.39E+03
U-233	1.33E+04	3.40E+05	5.33E+01	1.25E+05
U-234	5.14E+04	1.60E+06	2.31E+02	2.00E+05
U-236	7.29E+04	4.02E+06	6.13E+02	2.90E+05
U-233D	1.33E+04	3.40E+05	5.33E+01	1.25E+05
U-234G	5.14E+04	1.60E+06	2.31E+02	2.00E+05
U-236G	7.29E+04	4.02E+06	6.13E+02	2.90E+05
C-14N	6.88E+07	7.78E+08	2.93E+03	1.25E+06
I-129D	2.15E+05	2.77E+06	1.26E+02	6.65E+04
I-129G	2.15E+05	2.77E+06	1.26E+02	6.65E+04
I-129H	2.15E+05	2.77E+06	1.26E+02	6.65E+04
I-129I	2.15E+05	2.77E+06	1.26E+02	6.65E+04
I-129J	2.15E+05	2.77E+06	1.26E+02	6.65E+04

Notes:

SWF radionuclides are highlighted in red when a generic waste form model is employed to set disposal limits.

The scenario of no compaction generates acute inventory limits about an order of magnitude lower than in the nominal after-dynamic-compaction (ADC) scenario. The range of inventory limit reductions vary from no reduction at all for four short-lived nuclides (Cs-137, Ni-63, Sr-90, and U-232), up to nearly two orders of magnitude for Pu-239 and Pu-240.

Chronic IHI scenarios involve much lengthier periods of IHI exposure to radionuclides than acute scenarios; therefore, the effect of reduced shielding or greater volumes of excavated waste can significantly impact dose rates and, hence, inventory limits. In general, the no-compaction chronic inventory limits are much lower than their ADC counterparts. This phenomenon affects all ETs and STs. As with the acute scenarios, a few short-lived radionuclides show only moderate changes to inventory limits (e.g., a six-fold reduction in inventory limit for Sr-90), but strong gamma emitters (e.g., Ag-108m and Sn-126) and radionuclides with spontaneous fission decay modes (e.g., Cm-247 and Cm-248) have inventory limits reduced by four or even five orders of magnitude compared with ADC. Despite the low chronic inventory limits, the expected SOF remains less than 1% in terms of the projected 2065 inventory for ST02. However, specific ETs and STs with higher actinide inventories experience larger chronic SOF. For example, the expected 2065 SOF is 14% for ET02 and 11% for ST06.

7.6.3. Comparison with 2008 E-Area Low-Level Waste Facility Performance Assessment

For PA2022, IHI inventory limits are generally two orders of magnitude higher (i.e., lower doses) than those calculated in PA2008 (WSRC, 2008). In PA2008, a no-compaction scenario was used in the IHI analysis (versus the ADC approach in this PA). Furthermore, the ELLWF closure plan has been revised since 2008 and includes changes to the final closure cap design. The IHI analysis in this PA follows the revised closure plan (Phifer et al., 2009).

7.7. MAXIMUM DOSE AND DOSE RATES PER DISPOSAL UNIT

Dose history time profiles are provided for all 27 DUs in Appendix G, Section G.3. These dose and dose rate profiles were generated using the projected 2065 CWTS closure inventories discussed in Section 8.7.1 and provided in Appendix H, Section H.7.2. The projected 2065 CWTS inventories do not include biases or uncertainties and represent nominal values. The time history files contain results at one-year intervals where the maximum dose (acute) and dose rate (chronic) are listed in Table 7-19. Within CWTS, a small number of time windows are employed (as discussed in Appendix H, Section H.1.2) where the resulting maximum dose and dose rate values will typically be higher as shown in Table 7-19. As such, a slight built-in conservatism exists within CWTS, yielding on average, lower maximum total dose and dose rates of 2.6% and 8.6%, respectively. When the maximum dose or dose rate occurs at the end of the compliance period, both the time-window (Years 171 to1,171) and one-year window (1-yr) values are equal as seen for several DUs in Table 7-19 (e.g., LAWV, ILV, and NRCDAs).

Table 7-19. Comparison of Acute Dose and Chronic Dose Rate per Disposal Unit for Years 171-1,171 Time Window versus One-Year Window Results

DU	Years 171-1,171 Time Window		1-yr Window		Comparison	
	IHI Acute (mrem)	IHI Chronic (mrem yr^{-1})	IHI Acute (mrem)	IHI Chronic (mrem yr^{-1})	IHI Acute (%)	IHI Chronic (%)
ET01	3.21E-02	9.65E-03	3.03E-02	8.65E-03	5.8%	11.6%
ET02	8.88E-02	4.75E-02	8.27E-02	4.46E-02	7.3%	6.4%
ET03	2.48E-01	3.61E-02	2.47E-01	3.54E-02	0.4%	2.2%
ET04	2.54E-01	6.84E-02	2.48E-01	6.50E-02	2.7%	5.3%
ET05	3.89E-02	1.01E-02	3.83E-02	9.79E-03	1.6%	3.2%
ET07	1.44E-01	3.88E-02	1.40E-01	3.69E-02	2.7%	5.3%
ET08	1.91E-01	5.14E-02	1.86E-01	4.88E-02	2.7%	5.3%
ET09	2.08E-01	5.60E-02	2.03E-01	5.32E-02	2.7%	5.3%
ST01	4.30E-03	7.12E-04	4.27E-03	6.70E-04	0.6%	6.3%
ST02	1.47E-02	2.85E-03	1.41E-02	2.41E-03	4.1%	17.9%
ST03	1.52E-02	6.26E-03	1.48E-02	5.99E-03	2.9%	4.6%
ST04	2.76E-02	6.06E-03	2.63E-02	5.33E-03	4.7%	13.7%
ST05	2.52E-02	8.73E-03	2.26E-02	7.74E-03	11.6%	12.8%
ST06	2.90E-01	6.03E-02	2.85E-01	5.79E-02	1.7%	4.3%
ST07	8.70E-02	5.88E-03	8.68E-02	5.78E-03	0.3%	1.7%
ST08	1.31E-01	6.68E-03	1.31E-01	6.44E-03	0.5%	3.7%
ST09	2.04E-01	1.45E-02	2.04E-01	1.43E-02	0.3%	1.4%
ST10	5.85E-01	4.13E-02	5.83E-01	4.07E-02	0.3%	1.4%
ST11	3.71E-01	5.44E-02	3.67E-01	5.27E-02	1.1%	3.3%
ST14	1.84E-01	4.76E-02	1.84E-01	2.55E-02	0.1%	86.4%
ST18	1.11E-01	1.62E-02	1.10E-01	1.59E-02	0.7%	2.0%
ST23	1.16E+00	4.67E+00	1.00E+00	3.74E+00	15.3%	25.1%
ST24	4.44E-01	6.47E-02	4.42E-01	6.34E-02	0.7%	2.0%
LAWV	3.70E-04	5.35E+00	3.70E-04	5.35E+00	0.0%	0.0%
ILV	1.42E-02	7.67E-01	1.42E-02	7.67E-01	0.0%	0.0%
NR07E	9.95E-06	1.83E+00	9.95E-06	1.83E+00	0.0%	0.0%
NR26E	7.23E-04	6.83E+01	7.23E-04	6.83E+01	0.0%	0.0%
				avg =	**2.6%**	**8.6%**

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