571244

Sandia National Laboratories
Waste Isolation Pilot Plant

Radionuclide Inventory Screening Analysis for the 2019 Compliance Recertification Application Performance Assessment (CRA-2019 PA)

Revision 0

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ACRONYMS

ATWIR	Annual Transuranic Waste Inventory Report
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
CH	contact handled
CRA	Compliance Recertification Application
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FEP	feature, event, and process
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LANL	Los Alamos National Laboratory
PA	performance assessment
PABC	Performance Assessment Baseline Calculation
PAIR	Performance Assessment Inventory Report
PAVT	Performance Assessment Verification Test
RH	remote handled
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
TRU	transuranic
WIPP	Waste Isolation Pilot Plant
WUF	waste unit factor

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191. The DOE demonstrates compliance with the containment requirements according to the Certification Criteria in Title 40 CFR Part 194 by means of performance assessment (PA) calculations performed by Sandia National Laboratories (SNL). WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure. The models used in PA are maintained and updated with new information as part of a recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999.

PA calculations were included in the 1996 Compliance Certification Application (CCA) (U.S. DOE 1996), and in a subsequent Performance Assessment Verification Test (PAVT) (MacKinnon and Freeze 1997a, 1997b and 1997c). Based in part on the CCA and PAVT PA calculations, the EPA certified that the WIPP met the regulatory containment criteria. The facility was approved for disposal of TRU waste in May 1998 (U.S. EPA 1998).

The Land Withdrawal Act (U.S. Congress 1992) requires that the DOE apply for WIPP recertification every five years following the initial 1999 waste shipment. PA calculations were an integral part of the first WIPP recertification as documented in the 2004 Compliance Recertification Application (CRA-2004) (U.S. DOE 2004). During their review of the CRA-2004, the EPA requested an additional PA calculation, referred to as the CRA-2004 Performance Assessment Baseline Calculation (PABC) (Leigh et al. 2005), be conducted with modified assumptions and parameter values (Cotsworth 2005). Following review of the CRA-2004 and the CRA-2004 PABC, the EPA recertified the WIPP in March 2006 (U.S. EPA 2006).

PA calculations were completed for the second WIPP recertification and documented in the 2009 Compliance Recertification Application (CRA-2009). The CRA-2009 PA resulted from continued review of the CRA-2004 PABC, including a number of technical changes and corrections, as well as updates to parameters and improvements to the PA computer codes (Clayton et al. 2008). To incorporate additional information which was received after the CRA-2009 PA was completed, but before the submittal of the CRA-2009, the EPA has requested an additional PA calculation, referred to as the 2009 Compliance Recertification Application Performance Assessment Baseline Calculation (PABC-2009), be undertaken which included updated information (Cotsworth 2009). Following the completion and submission of the PABC-2009, the WIPP was recertified in 2010 (U.S. EPA 2010).

PA calculations were completed for the third WIPP recertification and documented in the 2014 Compliance Recertification Application (CRA-2014). Following review of the CRA-2014, the EPA recertified the WIPP in July 2017 (U.S. EPA 2017).

Los Alamos National Laboratory (LANL) has provided updated inventory data based on the Annual Transuranic Waste Inventory Report (ATWIR) – 2018 as documented in the Performance

Assessment Inventory Report (PAIR) – 2018 (Van Soest 2018), which contains updated estimates to the radionuclide content and waste material parameters using inventory information collected up to December 31, 2017. The 2018 LANL inventory update is the basis for the radionuclide inventory analysis presented in this document.

The purpose of this analysis is to document the basis for screening radionuclides that will be included in PA calculations. The radionuclide inventory in PAIR-2018 contains 195 radioisotopes. Many of these radioisotopes have low concentrations or are short lived and would not impact releases calculated by PA simulations. Additionally, PA calculations involve a suite of computationally intensive codes, and tracking all 195 radioisotopes is not practical. Therefore, the number of isotopes modeled in the PA codes is screened to reduce the number of isotopes while still capturing the dominant releases. This analysis provides a list of PA inventory-related parameters that will be used in PA calculations and it produces inventory input files for use in the PA code, EPAUNI. This analysis is governed by planning document AP-181 (Zeitler 2019), which discusses the methodology that will be used by Sandia National Laboratories to determine the WIPP repository radionuclide inventory information for use in PA calculations.

This calculation uses inventory input in curies from PAIR-2018 to determine the waste unit factor (Section 2), release limits and source term EPA units over a range of time periods (Section 3), and which radionuclides participate in radiolysis based on the relative amount of decay heats compared to the overall inventory heat production (Section 4). The computational methodology to combine radionuclide inventories into "lumped" inventories is provided in Section 5. The calculation of oxyanion moles (Section 6) and the identification of waste material parameters (Section 0) are also documented. Finally, this calculation documents the development of input files for the PA code EPAUNI based on radionuclide inventory data (Section 8).

Appendix A contains radionuclide inventories and potential releases (in EPA units) at six times. Appendix B contains radionuclide release limits and a calculation of the unit of waste. An inventory assessment that determines the percentage decay heat contribution for key radionuclides is provided in Appendix C. Appendix D presents the parameter values to be included in PA calculations based on PAIR-2018 (Van Soest 2018). Appendix E explains how the EPAUNI input files are generated from the inventory data contained in PAIR-2018.

2. CALCULATION OF WASTE UNIT FACTOR

2.1 PROBLEM DESCRIPTION

The waste unit factor (WUF), also referred to as the "unit of waste," is defined in the CCA as the number of millions of curies of alpha-emitting TRU radionuclides with half-lives longer than 20 years destined for disposal in the WIPP repository (U.S. DOE 1996). Computation of a new WUF based on the updated inventory information provided by Van Soest (2018), is required for PA calculations. This computation is performed using the following equation (Sanchez et al.1997):

$$f_w = \frac{\Sigma W_i}{10^6\, Ci} \tag{1}$$

where f_w is the WUF, and

W_i is the WIPP-scale activity in curies (Ci) for alpha-emitting TRU radionuclides having half-lives greater than 20 years.

This calculation uses the WIPP inventory provided by Van Soest (2018) decayed through 2033, which is the assumed closing date of WIPP.

2.2 ANALYSIS

To determine the radionuclides that are important with respect to WIPP PA, the release limits per 40 CFR 191 must be considered (see Appendix B, Table B-1). These release limits are normalized to a "unit of waste" (also called a "waste unit factor," f_w). For the TRU waste to be disposed of in the WIPP, the unit of waste is "an amount of TRU wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years" (40 CFR 191, Appendix A, Table 1). The unit of waste is determined in Table B-2 in Appendix B and summarized in Table 1. From these tables it can be seen that of the 195 radionuclides in the current inventory report (Van Soest 2018, Tables 5-3 and 5-4), there are reported data for the 17 TRU waste radionuclides that contribute to the unit of waste (i.e., that are alpha-emitting transuranic radionuclides with half-lives greater than 20 years). The overall quantity of TRU waste radionuclides from Table B-2 that apply to the unit of waste at 2033 is 3.30E+06 Ci, thus the value for the unit of waste, or WUF, is 3.30. The WUF parameter value is listed in Table D-1, which provides the specific parameter data entry information required for tracking parameters in PA. The WUF value is used as input to PA calculations in the codes EPAUNI, NUTS, PANEL, and PRECCDFGF. From Table 1 it is easily identified that the plutonium and americium radionuclides dominate the unit of waste, accounting for 99.98% of the total.

Table 1. Radionuclide Inventory Activities at 2033 that Contribute to Waste Unit Factor

Radionuclide	Activity (Ci)	Frequency
Am-241	1.14E+06	34.606%
Am-242m	9.23E+00	0.000%
Am-243	4.35E+02	0.013%
Cf-249	4.83E+01	0.001%
Cf-251	8.49E+00	0.000%
Cm-243	3.87E+01	0.001%
Cm-245	2.44E+01	0.001%
Cm-246	5.10E+02	0.015%
Cm-247	3.75E-01	0.000%
Cm-248	1.77E+00	0.000%
Cm-250	2.47E-06	0.000%
Np-237	3.44E+01	0.001%
Pu-238	9.64E+05	29.209%
Pu-239	8.74E+05	26.472%
Pu-240	3.19E+05	9.675%
Pu-242	1.64E+02	0.005%
Pu-244	3.40E-02	0.000%
Total	3.30E+06	100.000%
WUF	**3.30**	

For release to the accessible environment that involves a mix of radionuclides, the release limits in Table A-1 through Table A-6 are used to define maximum potential normalized releases (as discussed in Section 3) for comparison with the release limits. Now the unit of waste and the radionuclide-specific release limits are used to determine cumulative normalized release limits for the radionuclides specified in 40 CFR 191.13 (Table B-1). To help describe the 40 CFR 191 containment requirements, the following paragraphs were taken from *An Introduction to the Mechanics of Performance Assessment Using Examples of Calculations Done for the Waste Isolation Pilot Plant Between 1990 and 1992* (Rechard 1996, Section 6.1.2), which provides a very thorough introduction to the mechanics of the WIPP PA process:

> Containment Requirements in 40 CFR 191.13 specify general limits on the release of transuranic (TRU) waste, high-level waste, or spent nuclear fuel (SNF) from a geological repository. Environmental Protection Agency (EPA) release limits are defined as the normalizing factors for various radionuclides listed in Table 1 of Appendix A of EPA regulation 40 CFR 191 (see Table B-1). According to the Containment Requirements, there must be a reasonable expectation, based on a performance assessment that includes all significant processes and events, that the cumulative release of any one radionuclide over 10,000 years to the accessible environment shall have (these two points alone determine the EPA limits drawn on all WIPP Complimentary Cumulative Distribution Function codes):
>
> - less than 1 chance in 10 of exceeding the promulgated EPA radionuclides limits (L_i), and
> - less than 1 chance in 1000 of exceeding 10 times those quantities.
>
> For a mix of radionuclides, the sum of all releases, where each radionuclide is normalized with respect to its L_i, shall have:
>
> - Less than 1 chance in 10 of exceeding 1, and
> - Less than 1 chance in 1000 of exceeding 10.
>
> Where the sum of all releases is expressed by:

$$R_j = \frac{1}{f_w}\left\{\frac{Q_{1j}}{L_1} + \frac{Q_{2j}}{L_2} + \cdots + \frac{Q_{nRj}}{L_{nR}}\right\} = \sum_{i\text{-}1}^{nR} \frac{Q_{ij}}{f_w L_i} \leq 1 (or\ 10) \quad (2)$$

> where:
>
> f_w = WUF = $\frac{\Sigma W_i}{10^6\ Ci}$
> W_i = activity in Ci for α-emitting TRU repository wastes having half-lives ($T_{½}$) ≥ 20 years
> L_i = the EPA release limit for radionuclide i (see Table B-1 for examples and units)
> nR = number of radionuclides contributing to the release
> R_j = total normalized release (EPA unit) for the j^{th} scenario

Q_{ij} = cumulative release for radionuclide q_{ij} beyond a specified boundary, $\int_0^{10{,}000\,yr} q_{ij}dt$

q_{ij} = release rate into accessible environment at time t for radionuclide i and scenario j calculated from consequence model(s) (see Chapter 5.0 of Rechard 1996).

Figure 1 shows the variation of WUF with total activity, comparing the inventory based on PAIR-2018 (Van Soest 2018) to both CRA-2014 (Kicker and Zeitler 2013) and PABC-2009 (Fox et al. 2009) inventories. Figure 1 illustrates the following WUF relationships:

- If all radionuclides contribute to the WUF, then the WUF increases linearly with total activity (WUF = 10^{-6} · total activity).
- The EPA release limit for all radionuclides that contribute to the WUF is L = 100 Ci/unit of waste.
- The EPA release limit in curies = 100·WUF.
- The activity in EPA units = w_i / (WUF·L)
  where w_i = waste stream activity in curies and L = EPA release limit.
- If all radionuclides contribute to the WUF, then the total EPA units = 10,000.
- The total EPA units increases above 10,000 with the addition of radionuclides that do not contribute to the WUF.

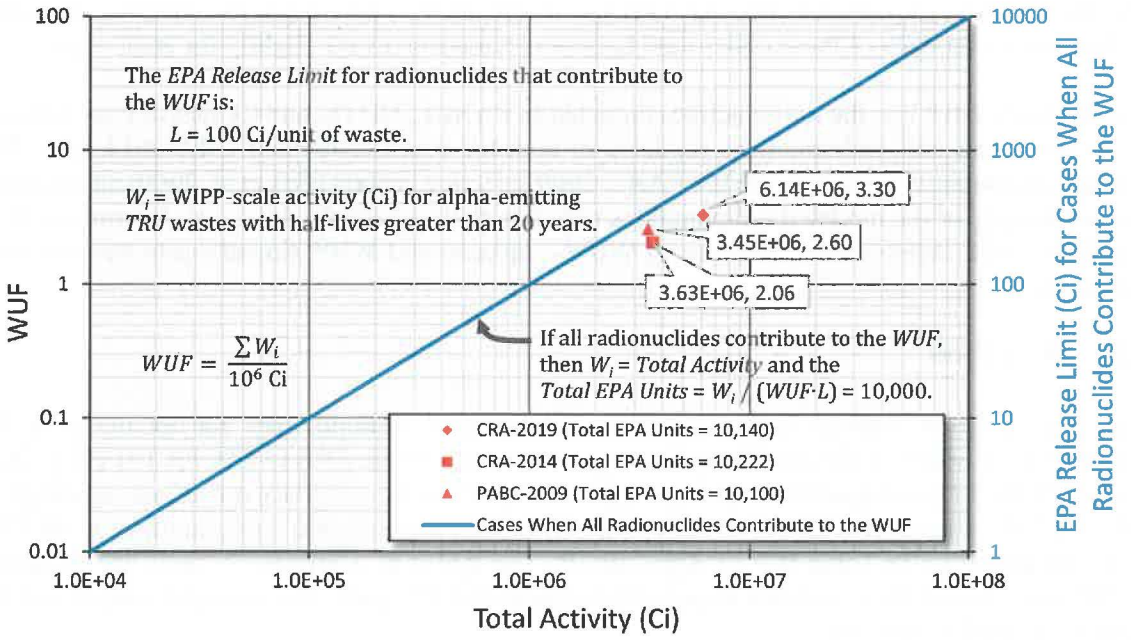

Figure 1. The Variation of WUF with Total Activity

3. RADIONUCLIDES EXPECTED TO DOMINATE POTENTIAL RELEASES

3.1 PROBLEM DESCRIPTION

Each potential radionuclide release mechanism modeled in PA has as its source an inventory of radionuclides that (1) the DOE expects will be disposed in WIPP and (2) analysts believe will be prevalent in a release via the individual release mechanism. For PA calculations, the DOE through its contractor, LANL, has documented a radionuclide inventory that it expected would be disposed in the WIPP (Van Soest 2018) decayed through the following years: 2033, 2133, 2383, 3033, 7033, and 12,033. These time periods are based on the assumption of a WIPP closing date of 2033. The radionuclide inventory contains 195 radioisotopes. However, not all of the 195 radioisotopes are important to track in a PA for the WIPP repository. Many of the isotopes have low concentrations or are short lived (short half-lives) and would not impact the releases calculated by PA simulations. In addition, tracking of all 195 radioisotopes is not practical since WIPP PA involves a suite of computationally intensive codes. Therefore, the number of isotopes tracked in the WIPP PA codes is reduced.

Three of the WIPP release-mechanism codes have radionuclide inventories as direct inputs: PANEL, NUTS, and CCDFGF. The three codes are used in calculations of releases via individual release mechanisms that are modeled in WIPP PA. PANEL provides the radionuclide source for direct brine release to the surface via a borehole (a potential short-term release mechanism), and it provides the radionuclide source for releases via a borehole to the Culebra member of the Rustler formation (a potential long-term release mechanism). NUTS calculates radionuclide releases via Salado formation to the accessible boundary (a potential long-term release mechanism). The inventory information is used in CCDFGF to calculate direct solid releases to the surface due to drilling activities (a potential short-term release mechanism). The criteria for selecting important radionuclides for each of these codes (and release mechanisms) vary slightly for each code.

For the CRA-2019 PA, the radionuclides modeled in PANEL, NUTS, and CCDFGF were selected to be consistent with radionuclides modeled in both the PABC-2009 and CRA-2014 PAs. This analysis documents variances with the PABC-2009 selection criteria (Fox et al. 2009) and assesses the sufficiency of the modeled radionuclides based on their potential releases as determined from the PAIR-2018 radionuclide inventory of WIPP-emplaced and WIPP-bound waste streams (Van Soest 2018).

3.2 ANALYSIS

The first criterion applied to the selection of important radionuclides for inclusion in PA calculations is based on the regulatory framework provided by the EPA in 40 CFR 191 (U.S. DOE 1996). Of the 195 radionuclides reported in PAIR-2018 (Van Soest 2018), not all are regulated by 40 CFR 191. The regulated radionuclides (i.e., those that are assigned a release limit in 40 CFR 191) are identified in Table B-1 of Appendix B. The tables in Appendix A show the projected WIPP inventory of these isotopes as potential releases in EPA units. The potential release in EPA units is defined as follows:

$$R_i = \frac{w_i}{f_w \cdot L_i} \tag{3}$$

where R_i is the radionuclide potential release expressed in EPA units for radionuclide i,
L_i is the release limit from 40 CFR 191 for radionuclide i (see Table B-1),
f_w is the WUF, and
w_i is the waste-stream-scale activity (contact handled [CH] + remote handled [RH]) in curies (Ci) for radionuclide i.

The repository is considered to comply with the EPA regulations if there is a less than 0.1 calculated probability (based on PA calculations) that the cumulative release to the accessible environment is greater than 1 EPA unit and a less than 0.001 probability that the cumulative release is greater than 10 EPA units.

Table 2 shows the radionuclide inventory in terms of EPA units at 0 years (2033), 100 years (2133), 350 years (2383), 1000 years (3033), 5000 years (7033), and 10,000 years (12033) for radionuclides that have an activity of at least 0.001 EPA units at some point from 2033 to 12033. Of the 195 isotopes given in PAIR-2018 (Van Soest 2018), only 38 have more than 0.001 EPA units of inventory at any time within the 10,000-year regulatory period. These are ^{227}Ac, ^{241}Am, ^{242m}Am, ^{243}Am, ^{14}C, ^{249}Cf, ^{251}Cf, ^{243}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm, ^{137}Cs, ^{129}I, ^{94}Nb, ^{59}Ni, ^{63}Ni, ^{237}Np, ^{231}Pa, ^{210}Pb, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{226}Ra, ^{151}Sm, ^{121m}Sn, ^{90}Sr, ^{99}Tc, ^{229}Th, ^{230}Th, ^{232}Th, ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U. Seven additional isotopes are included in Table 2 that were modeled in both the PABC-2009 and CRA-2014 PAs, but do not satisfy the 0.001 EPA unit criterion. According to Fox et al. (2009), these additional isotopes are included because (1) they have short half-lives and are not regulated by the EPA, but have significant activities and/or (2) they are the parents of regulated isotopes. The additional isotopes are: ^{252}Cf, ^{244}Cm, ^{147}Pm, ^{241}Pu, ^{244}Pu, ^{228}Ra, and ^{147}Sm. Table 2 includes 38 isotopes with the highest activity together with 7 other significant isotopes, reducing the total number of isotopes from 195 to 45, thus identifying the most significant isotopes for inclusion in PA calculations. The radionuclides used in PA codes PANEL, NUTS, and CCDFGF along with the list of inventory parameters in Appendix D (Table D-2) are all a subset of Table 2.

The contribution of each radionuclide to the overall potential release changes as the radionuclides decay or build-up over time. For example, the relatively short-lived isotope ^{238}Pu decays from a potential release of 2921 EPA units at closure to 1 EPA unit by 1000 years. An example of an isotope that increases in activity with time is ^{230}Th, which initially has less than 0.1 EPA unit of potential release that grows to over 2 EPA units after 10,000 years.

Table 2. Radionuclide Inventory Sorted by Maximum Potential Release During the Regulatory Period

Radionuclide	Half-Life[a] (y)	Potential Release[b] (EPA Units)						
		0 Years	100 Years	350 Years	1000 Years	5000 Years	10000 Years	Maximum
Am-241	4.32E+02	3.46E+03	3.11E+03	2.09E+03	7.36E+02	1.27E+00	3.60E-02	3.46E+03
Pu-238	8.77E+01	2.92E+03	1.33E+03	1.84E+02	1.08E+00	1.32E-12	2.75E-23	2.92E+03
Pu-239	2.41E+04	2.65E+03	2.64E+03	2.62E+03	2.57E+03	2.29E+03	1.99E+03	2.65E+03
Pu-240	6.56E+03	9.67E+02	9.58E+02	9.33E+02	8.71E+02	5.71E+02	3.37E+02	9.67E+02
Cs-137	3.02E+01	7.60E+01	7.54E+00	2.34E-02	7.01E-09	0.00E+00	0.00E+00	7.60E+01
Sr-90	2.88E+01	5.96E+01	5.08E+00	1.08E-02	1.20E-09	0.00E+00	0.00E+00	5.96E+01
U-234	2.46E+05	1.47E+00	2.04E+00	2.45E+00	2.51E+00	2.48E+00	2.45E+00	2.51E+00
Th-230	7.54E+04	8.04E-02	9.68E-02	1.50E-01	2.98E-01	1.19E+00	2.24E+00	2.24E+00
Cm-246	4.76E+03	1.54E+00	1.52E+00	1.47E+00	1.33E+00	7.42E-01	3.57E-01	1.54E+00
U-232	6.89E+01	1.35E+00	5.02E-01	4.19E-02	6.60E-05	3.71E-22	0.00E+00	1.35E+00
Am-243	7.37E+03	1.32E+00	1.30E+00	1.27E+00	1.20E+00	8.23E-01	5.15E-01	1.32E+00
Np-237	2.14E+06	1.04E-01	2.12E-01	4.20E-01	6.93E-01	8.40E-01	8.39E-01	8.40E-01
Pu-242	3.75E+05	4.96E-01	4.96E-01	4.96E-01	4.97E-01	5.01E-01	5.01E-01	5.01E-01
U-233	1.59E+05	3.85E-01	3.85E-01	3.85E-01	3.85E-01	3.93E-01	4.02E-01	4.02E-01
Ni-63	1.00E+02	2.64E-01	1.32E-01	2.34E-02	2.60E-04	2.42E-16	2.23E-31	2.64E-01
Th-229	7.34E+03	3.80E-03	7.13E-03	1.53E-02	3.59E-02	1.41E-01	2.32E-01	2.32E-01
U-236	2.34E+07	2.05E-03	4.90E-03	1.19E-02	2.92E-02	1.13E-01	1.79E-01	1.79E-01
Ra-226	1.60E+03	6.13E-02	5.91E-02	5.43E-02	4.65E-02	7.98E-02	1.77E-01	1.77E-01
Pb-210	2.22E+01	4.68E-02	5.91E-02	5.43E-02	4.65E-02	7.97E-02	1.77E-01	1.77E-01
C-14	5.70E+03	1.62E-01	1.60E-01	1.55E-01	1.43E-01	8.83E-02	4.82E-02	1.62E-01
Ni-59	1.01E+05	1.56E-01	1.56E-01	1.56E-01	1.55E-01	1.49E-01	1.42E-01	1.56E-01
Cf-249	3.51E+02	1.46E-01	1.20E-01	7.32E-02	2.02E-02	7.42E-06	3.76E-10	1.46E-01
U-238	4.47E+09	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01
Cm-243	2.91E+01	1.17E-01	1.03E-02	2.35E-05	3.20E-12	0.00E+00	0.00E+00	1.17E-01
Ac-227	2.18E+01	7.85E-02	4.93E-02	4.79E-02	4.75E-02	4.59E-02	4.50E-02	7.85E-02
Cm-245	8.50E+03	7.40E-02	7.45E-02	7.49E-02	7.32E-02	5.34E-02	3.55E-02	7.49E-02
Pa-231	3.28E+04	4.81E-02	4.80E-02	4.79E-02	4.75E-02	4.58E-02	4.50E-02	4.81E-02
Sm-151	9.00E+01	4.67E-02	2.16E-02	3.15E-03	2.11E-05	8.76E-19	1.65E-35	4.67E-02
U-235	7.04E+08	1.94E-02	1.97E-02	2.03E-02	2.20E-02	3.16E-02	4.21E-02	4.21E-02
Am-242m	1.41E+02	2.79E-02	1.71E-02	5.00E-03	2.05E-04	5.91E-13	1.25E-23	2.79E-02
Cf-251	9.00E+02	2.57E-02	2.38E-02	1.96E-02	1.19E-02	5.42E-04	1.14E-05	2.57E-02
Tc-99	2.11E+05	1.75E-02	1.75E-02	1.75E-02	1.75E-02	1.73E-02	1.70E-02	1.75E-02
Cm-248	3.48E+05	5.36E-03	5.36E-03	5.36E-03	5.35E-03	5.31E-03	5.25E-03	5.36E-03
Th-232	1.41E+10	3.59E-03	3.59E-03	3.59E-03	3.59E-03	3.59E-03	3.59E-03	3.59E-03
I-129	1.57E+07	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03
Sn-121m	4.39E+01	1.33E-03	3.78E-04	1.62E-05	4.49E-09	0.00E+00	0.00E+00	1.33E-03
Nb-94	2.03E+04	1.32E-03	1.31E-03	1.30E-03	1.27E-03	1.11E-03	9.36E-04	1.32E-03
Cm-247	1.56E+07	1.13E-03	1.13E-03	1.14E-03	1.14E-03	1.14E-03	1.14E-03	1.14E-03
Pu-244	8.00E+07	1.03E-04	1.03E-04	1.03E-04	1.03E-04	1.03E-04	1.04E-04	1.04E-04
Sm-147	1.06E+11	2.88E-10	2.90E-10	2.90E-10	2.90E-10	2.90E-10	2.90E-10	2.90E-10
Cf-252	2.65E+00	--	--	--	--	--	--	0.00E+00
Cm-244	1.81E+01	--	--	--	--	--	--	0.00E+00
Pm-147	2.62E+00	--	--	--	--	--	--	0.00E+00
Pu-241	1.44E+01	--	--	--	--	--	--	0.00E+00
Ra-228	5.75E+00	--	--	--	--	--	--	0.00E+00

(a) Half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1).

(b) Potential releases taken from Table A-1 through Table A-6 in Appendix A.

Consistent with PA calculations associated with the 2009 and 2014 CRAs (Fox et al. 2009; Kicker and Zeitler 2013), 30 radioisotopes are modeled in PANEL decay calculations. Those radioisotopes are: ^{241}Am, ^{243}Am, ^{252}Cf, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{248}Cm, ^{137}Cs, ^{237}Np, ^{231}Pa, ^{210}Pb, ^{147}Pm, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{244}Pu, ^{226}Ra, ^{228}Ra, ^{147}Sm, ^{90}Sr, ^{229}Th, ^{230}Th, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U and ^{238}U. These 30 radioisotopes are listed as parameter values in Table D-2, which provides the specific parameter data entry information required for tracking parameters in PA. Of these 30 radioisotopes, seven (^{252}Cf, ^{231}Pa, ^{210}Pb, ^{147}Pm, ^{226}Ra, ^{228}Ra and ^{147}Sm) are only included in the decay calculations, while the remaining 23 are used in both the decay calculations and the actinide mobilization calculations. The 23 radioisotopes modeled in PANEL actinide mobilization calculations were selected based on the greatest potential for dissolution and mobilization in a brine. For the CRA-2019 PA, these isotopes encompass 99.96% of the potential releases (in EPA units) at the time of repository closure based on the PAIR-2018 inventory (see Table 3). Therefore, there are sufficient radionuclides modeled in the PANEL calculations to capture the dominant releases.

Consistent with PA calculations associated with the 2009 and 2014 CRAs (Fox et al. 2009; Kicker and Zeitler 2013), the CRA-2019 NUTS calculation includes 10 isotopes: ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{229}Th, ^{230}Th, ^{233}U and ^{234}U. Because NUTS is more computationally intensive compared to PANEL, the number of isotopes modeled is reduced to increase efficiency. According to Fox et al. (2009), the criterion for selecting radionuclides for the NUTS calculation was historically based on those radionuclides that had a potential release greater than 1.0 EPA unit during the 10,000-year regulatory period. The following isotopes from the PAIR-2018 data satisfy this criterion: ^{241}Am, ^{243}Am, ^{246}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{230}Th, ^{232}U, and ^{234}U. Following the guidelines provided by Fox et al. (2009) to further reduce the number of isotopes modeled in NUTS, ^{137}Cs, ^{90}Sr, and ^{232}U can be excluded because they are short-lived (i.e., half-lives less than 100 years) radionuclides that will no longer be contributors to the release by the time radioactive material is transported via the Salado transport pathway to the accessible boundary. Although the isotopes ^{243}Am and ^{246}Cm fulfill the historical criterion of having a potential release greater than 1.0 EPA unit, their contribution to the overall potential release is less than 0.02%. Therefore not including these isotopes has a minor impact to overall releases.

The radionuclides modeled in NUTS (^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{229}Th, ^{230}Th, ^{233}U and ^{234}U) account for 98.61% of the potential releases (in EPA units) at the time of repository closure in the PAIR-2018 inventory (see Table 4). Therefore, there are sufficient radionuclides modeled in the NUTS calculations to capture the dominant releases.

Table 3. Contribution to Potential Release at 2033 for Isotopes Modeled in PANEL

Radionuclide	Total Inventory [a] (Ci)			Potential Release [b] (EPA Units)			
	CH	RH	Total	CH	RH	Total	Cum. %
Isotopes in Both the Decay and Actinide Mobilization Calculations							
Am-241	1.13E+06	1.30E+04	1.14E+06	3.42E+03	3.94E+01	3.46E+03	34.13%
Pu-238	9.42E+05	2.25E+04	9.64E+05	2.85E+03	6.83E+01	2.92E+03	62.93%
Pu-239	8.70E+05	4.22E+03	8.74E+05	2.63E+03	1.28E+01	2.65E+03	89.04%
Pu-240	3.16E+05	3.16E+03	3.19E+05	9.58E+02	9.58E+00	9.67E+02	98.58%
Cs-137	6.16E+02	2.50E+05	2.51E+05	1.87E-01	7.58E+01	7.60E+01	99.33%
Sr-90	8.18E+02	1.96E+05	1.97E+05	2.48E-01	5.93E+01	5.96E+01	99.92%
U-234	4.77E+02	9.70E+00	4.86E+02	1.44E+00	2.94E-02	1.47E+00	99.93%
Am-243	2.24E+01	4.12E+02	4.35E+02	6.78E-02	1.25E+00	1.32E+00	99.95%
Pu-242	1.48E+02	1.59E+01	1.64E+02	4.47E-01	4.82E-02	4.96E-01	99.95%
U-233	1.10E+02	1.72E+01	1.27E+02	3.33E-01	5.22E-02	3.85E-01	99.96%
U-238	3.92E+01	3.13E+00	4.23E+01	1.19E-01	9.49E-03	1.28E-01	99.96%
Cm-243	2.54E+00	3.61E+01	3.87E+01	7.69E-03	1.09E-01	1.17E-01	99.96%
Np-237	2.75E+01	6.96E+00	3.44E+01	8.32E-02	2.11E-02	1.04E-01	99.96%
Th-230	3.98E-01	2.26E+00	2.66E+00	1.21E-02	6.84E-02	8.04E-02	99.96%
Cm-245	2.97E+00	2.15E+01	2.44E+01	8.98E-03	6.51E-02	7.40E-02	99.96%
U-235	4.56E+00	1.85E+00	6.41E+00	1.38E-02	5.60E-03	1.94E-02	99.96%
Cm-248	4.63E-01	1.31E+00	1.77E+00	1.40E-03	3.96E-03	5.36E-03	99.96%
Th-229	3.80E-01	8.74E-01	1.25E+00	1.15E-03	2.65E-03	3.80E-03	99.96%
Th-232	9.60E-02	2.26E-02	1.19E-01	2.91E-03	6.84E-04	3.59E-03	99.96%
U-236	4.24E-01	2.53E-01	6.77E-01	1.28E-03	7.66E-04	2.05E-03	99.96%
Pu-244	5.80E-03	2.82E-02	3.40E-02	1.76E-05	8.55E-05	1.03E-04	99.96%
Pu-241	1.82E+06	4.53E+04	1.87E+06	N/A[c]	N/A[c]	N/A[c]	99.96%
Cm-244	6.19E+03	3.32E+04	3.94E+04	N/A[c]	N/A[c]	N/A[c]	99.96%
Isotopes in Decay Calculations Only							
Cf-252	5.07E-01	1.76E+00	2.26E+00	N/A[c]	N/A[c]	N/A[c]	0.00%
Pa-231	1.59E+01	1.04E-03	1.59E+01	4.81E-02	3.14E-06	4.81E-02	0.00%
Pb-210	9.79E-01	1.45E+01	1.55E+01	2.97E-03	4.39E-02	4.68E-02	0.00%
Pm-147	4.40E-01	2.54E+01	2.59E+01	N/A[c]	N/A[c]	N/A[c]	0.00%
Ra-226	1.78E+00	1.85E+01	2.03E+01	5.38E-03	5.60E-02	6.13E-02	0.00%
Ra-228	9.03E-02	4.55E-02	1.36E-01	N/A[c]	N/A[c]	N/A[c]	0.00%
Sm-147	1.23E-09	9.40E-08	9.52E-08	3.71E-12	2.85E-10	2.88E-10	0.00%

(a) Decayed radionuclide data taken from Van Soest 2018.
(b) CH potential release is defined as the total CH inventory in Ci divided by the release limit in Ci (see Table A-1). Similarly, RH potential release is defined as the total RH inventory in Ci divided by the release limit in Ci. Total potential releases taken from Table A-1 in Appendix A. The total potential release for all radionuclides is 10,140 EPA units at 2033.
(c) Cf-252, Cm-244, Pm-147, Pu-241, and Ra-228 are not regulated isotopes and have no release limits (See Appendix B, Table B-1). Therefore, potential release in EPA units cannot be calculated.

Table 4. Contribution to Potential Release at 2033 for Isotopes Modeled in NUTS

Radionuclide	Total Inventory [a] (Ci)			Potential Release [b] (EPA Units)			
	CH	RH	Total	CH	RH	Total	Cum. %
Am-241	1.13E+06	1.30E+04	1.14E+06	3.42E+03	3.94E+01	3.46E+03	34.13%
Pu-238	9.42E+05	2.25E+04	9.64E+05	2.85E+03	6.83E+01	2.92E+03	62.93%
Pu-239	8.70E+05	4.22E+03	8.74E+05	2.63E+03	1.28E+01	2.65E+03	89.04%
Pu-240	3.16E+05	3.16E+03	3.19E+05	9.58E+02	9.58E+00	9.67E+02	98.58%
U-234	4.77E+02	9.70E+00	4.86E+02	1.44E+00	2.94E-02	1.47E+00	98.60%
Pu-242	1.48E+02	1.59E+01	1.64E+02	4.47E-01	4.82E-02	4.96E-01	98.60%
U-233	1.10E+02	1.72E+01	1.27E+02	3.33E-01	5.22E-02	3.85E-01	98.61%
Th-230	3.98E-01	2.26E+00	2.66E+00	1.21E-02	6.84E-02	8.04E-02	98.61%
Th-229	3.80E-01	8.74E-01	1.25E+00	1.15E-03	2.65E-03	3.80E-03	98.61%
Pu-241	1.82E+06	4.53E+04	1.87E+06	N/A[c]	N/A[c]	N/A[c]	98.61%

(a) Decayed radionuclide data taken from Van Soest 2018.
(b) CH potential release is defined as the total CH inventory in Ci divided by the release limit in Ci (see Table A-1). Similarly, RH potential release is defined as the total RH inventory in Ci divided by the release limit in Ci. Total potential releases taken from Table A-1 in Appendix A. The total potential release for all radionuclides is 10,140 EPA units at 2033.
(c) Pu-241 is not a regulated isotope and has no release limit (See Appendix B, Table B-1). Therefore, potential release EPA units cannot be calculated.

Consistent with PA calculations associated with the 2009 and 2014 CRAs (Fox et al. 2009; Kicker and Zeitler 2013), the CRA-2019 CCDFGF calculation includes 10 isotopes: ^{241}Am, ^{244}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, ^{233}U, and ^{234}U. Fox et al. (2009) state that the radionuclides that are important for modeling the direct solid release pathway (included in CCDFGF) were historically based on those that have a potential release greater than 1.0 EPA unit during the 10,000 year regulatory period. Applying this criterion to the PAIR-2018 radionuclide inventory results in the following list: ^{241}Am, ^{243}Am, ^{246}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{230}Th, ^{232}U, and ^{234}U. Not including isotopes ^{243}Am, ^{246}Cm, ^{230}Th, and ^{232}U has a minor impact to PA calculations because they each have a low frequency of occurrence (approximately 0.04 % of the total activity). In contrast to the NUTS calculation, the isotopes ^{137}Cs and ^{90}Sr are maintained for this pathway even though they have relatively short half-lives, because a human intrusion event can occur as early as 100 years after repository closure. The 10 radionuclides used to model the direct solid release pathway in CRA-2019 CCDFGF calculations account for 99.94% of the EPA units at the time of repository closure in the PAIR-2018 inventory (see Table 5). Therefore, there are sufficient radionuclides modeled in the CCDFGF calculations to capture the dominant releases.

Table 5. Contribution to Potential Release at 2033 for Isotopes Modeled in CCDFGF

Radionuclide	Total Inventory [a] (Ci)			Potential Release [b] (EPA Units)			
	CH	RH	Total	CH	RH	Total	Cum. %
Am-241	1.13E+06	1.30E+04	1.14E+06	3.42E+03	3.94E+01	3.46E+03	34.13%
Pu-238	9.42E+05	2.25E+04	9.64E+05	2.85E+03	6.83E+01	2.92E+03	62.93%
Pu-239	8.70E+05	4.22E+03	8.74E+05	2.63E+03	1.28E+01	2.65E+03	89.04%
Pu-240	3.16E+05	3.16E+03	3.19E+05	9.58E+02	9.58E+00	9.67E+02	98.58%
Cs-137	6.16E+02	2.50E+05	2.51E+05	1.87E-01	7.58E+01	7.60E+01	99.33%
Sr-90	8.18E+02	1.96E+05	1.97E+05	2.48E-01	5.93E+01	5.96E+01	99.92%
U-234	4.77E+02	9.70E+00	4.86E+02	1.44E+00	2.94E-02	1.47E+00	99.93%
U-233	1.10E+02	1.72E+01	1.27E+02	3.33E-01	5.22E-02	3.85E-01	99.94%
Cm-244	6.19E+03	3.32E+04	3.94E+04	N/A[c]	N/A[c]	N/A[c]	99.94%
Pu-241	1.82E+06	4.53E+04	1.87E+06	N/A[c]	N/A[c]	N/A[c]	99.94%

(a) Decayed radionuclide data taken from Van Soest 2018.
(b) CH potential release is defined as the total CH inventory in Ci divided by the release limit in Ci (see Table A-1). Similarly, RH potential release is defined as the total RH inventory in Ci divided by the release limit in Ci. Total potential releases taken from Table A-1 in Appendix A. The total potential release for all radionuclides is 10,140 EPA units at 2033.
(c) Cm-244 and Pu-241 are not regulated isotopes and have no release limits (See Appendix B, Table B-1). Therefore, potential release in EPA units cannot be calculated.

4. RADIONUCLIDES WITH DECAY HEAT CONTRIBUTIONS TO RADIOLYSIS

Implementation of the radiolytic gas generation process model (Day 2019) requires parameterization of the decay heat associated with radionuclides in the repository. A screening analysis is performed to determine which radionuclides are the major contributors to the total decay heat and thus are necessary to include in the radiolysis calculations. The screening analysis consists of calculating the decay heat specific power generated by each of the 195 radionuclides in the inventory (as listed in the PAIR) and the fraction that each contributes to the total. Wattage is calculated based on the following equations:

$$W(t) = \sum_{i=1}^{n} W_i(t) \tag{4}$$

$$W_i(t) = I_i(t) \times DH_i / SA_i \tag{5}$$

where i = Index of radionuclides in the inventory
n = Total number of radionuclides in the inventory
$W(t)$ = Power ("wattage") in W for all radionuclides at time t
$W_i(t)$ = Power ("wattage") in W for radionuclide i at time t
$I_i(t)$ = Sum of CH and RH inventory in Ci for radionuclide i at time t
DH_i = Decay heat specific power in W/g for radionuclide i, and
SA_i = Specific activity in Ci/g for radionuclide i.

Specific activity (SA_i) is the activity per unit mass. The activity in one gram is given by

$$SA_i = \lambda N \quad (6)$$

where λ is the radionuclide radioactive decay constant (which is a function of the radionuclide half-life in seconds, $T_{½}$):

$$\lambda = \left(\frac{\ln(2)}{T_{1/2}}\right) \quad (7)$$

and N is the number of atoms of a radionuclide in one gram:

$$N = A_v/A_w \quad (8)$$

such that A_v is Avogadro's number, 6.022137 x 10^{23}/mol, and A_w is the atomic weight of the radionuclide in g/mol.

Knowing that one curie is defined as 3.7 x 10^{10} disintegrations per second (s^{-1}), then the specific activity (Ci/g) in Equation 5 is:

$$SA_i = \frac{\lambda A_v}{CiBq \cdot A_w} \quad (9)$$

where $CiBq$ = 3.7 x 10^{10} s^{-1}/Ci. Knowing that one MeV per second is equal to 1.602177 x 10^{-13} W, the decay heat specific power (W/g) in Equation 5 is given by:

$$DH_i = J \cdot E_{dis,i} \lambda A_v/A_w \quad (10)$$

where J = 1.602177 x 10^{-13} W/MeV per second and $E_{dis,i}$ is the total emitted disintegration energy of radionuclide i (MeV).

For the CRA-2019 inventory, five radionuclides which represent (at a minimum) greater than 96% of the total inventory decay heat are used. An inventory assessment that determines the percentage decay heat contribution for ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{242}Pu is provided in Appendix C. For those radionuclides, new DECAYNRG parameters given in are implemented to support the radiolysis and decay calculations (Day 2019).

Table 6. Radiolysis and Decay Parameters

Material	Property	Description	Value
AM241	DECAYNRG	Radionuclide disintegration energy (MeV)	5.6379
PU238	DECAYNRG	Radionuclide disintegration energy (MeV)	5.593
PU239	DECAYNRG	Radionuclide disintegration energy (MeV)	5.2442
PU240	DECAYNRG	Radionuclide disintegration energy (MeV)	5.2559
PU242	DECAYNRG	Radionuclide disintegration energy (MeV)	4.9855

NOTE: The source for DECAYNRG values is the International Commission on Radiological Protection (ICRP 2008, Table A.1). These parameter values are listed in Table D-6, which provides the specific parameter data entry information required for tracking parameters in PA.

5. CALCULATION OF RADIONUCLIDE INVENTORIES FOR USE IN NUTS

5.1 PROBLEM DESCRIPTION

Van Soest (2018, Tables 5-3 and 5-4) reports that the DOE waste generator sites are expected to dispose of TRU waste containing 195 different radionuclides in the WIPP. Not all of these radionuclides have significant inventories for disposal and not all of these radionuclides contribute to potential releases from the WIPP repository over the 10,000 year regulatory period. Section 3 identifies which radionuclides contribute to potential releases from the repository for the individual transport pathways modeled in performance assessment. For transport through the Salado to the accessible boundary and transport through the Salado to the Culebra which is modeled using the NUTS code in performance assessment, the important radionuclides are shown in Table 4 of Section 3.

The radionuclides in Table 4 are important contributors to potential releases and they have half-lives that are long enough to contribute to potential releases via the Salado. In addition, Section 3 identifies ^{241}Pu as being important because it is the parent isotope for ^{241}Am and it has a significant initial inventory. The inventory for ^{241}Pu at the time of repository closure (2033) is 1.82E+06 Ci in CH-TRU waste and 4.53E+04 Ci in RH-TRU waste (Table A-1 in Appendix A).

Because NUTS is a computationally intensive code, minimizing the number of radionuclides that NUTS must track in a calculation is beneficial. Therefore, inventories for the uranium, plutonium, americium and thorium isotopes can be combined into "lumped" inventories to facilitate the NUTS calculations for performance assessment. Technical justification for lumping is provided below (see Table 7 for lumped values).

5.2 COMPUTATIONAL METHODOLOGY

5.2.1 Theory

The theory behind combining radionuclide inventories into "lumped" inventories for transport calculations is that radionuclides of the same elemental form will transport at the same rate (Leigh and Trone 2005). Therefore, the inventories for isotopes of uranium can be combined. Additionally, inventories for isotopes of plutonium can be combined, and inventories for isotopes of thorium can be combined. Using the isotopes identified in Table 4 as important: (1) the activity of ^{234}U and ^{233}U will be combined to produce values for the material U234L (the lumped uranium inventory) for the NUTS calculation, (2) the activity of ^{239}Pu, ^{240}Pu and ^{242}Pu will be combined to produce values for the material PU239L for the NUTS calculation, and (3) the activity of ^{230}Th and ^{229}Th will be combined to produce values for the material TH230L in the NUTS calculation.

In Table 4, ^{238}Pu is also listed as an important radionuclide for the NUTS calculation. The inventory of ^{238}Pu is not combined with the other plutonium isotopes because of its relatively short half-life.

Finally, the inventory of ^{241}Pu is combined with the inventory of ^{241}Am because ^{241}Pu is a parent isotope to ^{241}Am and ^{241}Pu has a relatively short half-life when compared to ^{241}Am. Combining

the inventories for ^{241}Am and ^{241}Pu produces the inventory value for the material AM241L in the NUTS calculation.

The resulting decay chains for the NUTS calculations are:

$$^{238}\text{Pu} \rightarrow {}^{234}\text{U} \rightarrow {}^{230}\text{Th} \quad (11)$$

$$^{239}\text{Pu} \quad (12)$$

$$^{241}\text{Am} \quad (13)$$

5.2.2 Implementation

The computational methodology for combining radionuclide activities into lumped activity values (in curies) is shown in Equations 14 through 23 based on the approach by Leigh and Trone (2005, Section 3).

$$A_L(Pu238)_{CH} = A(Pu238)_{CH} \quad (14)$$

$$A_L(Pu238)_{RH} = A(Pu238)_{RH} \quad (15)$$

where:

$A_L(Pu238)_{CH}$ activity value for the property INVCHD (i.e., contact-handled inventory) for the material PU238L
$A(Pu238)_{CH}$ activity value for ^{238}Pu from Table 4 for CH-TRU
$A_L(Pu238)_{RH}$ activity value for the property INVRHD (i.e., remote-handled inventory) for the material PU238L
$A(Pu238)_{RH}$ activity value for ^{238}Pu from Table 4 for RH-TRU

$$A_L(Am241)_{CH} = A(Am241)_{CH} + A(Pu241)_{CH} * \tau_{1/2}(Pu241)/\tau_{1/2}(Am241) \quad (16)$$

$$A_L(Am241)_{RH} = A(Am241)_{RH} + A(Pu241)_{RH} * \tau_{1/2}(Pu241)/\tau_{1/2}(Am241) \quad (17)$$

where:

$A_L(Am241)_{CH}$ activity value for the property INVCHD for the material AM241L
$A(Am241)_{CH}$ activity value for ^{241}Am from Table 4 for CH-TRU
$A(Pu241)_{CH}$ activity value for ^{241}Pu from Table 4 for CH-TRU
$A_L(Am241)_{RH}$ activity value for the property INVRHD for the material AM241L
$A(Am241)_{RH}$ activity value for ^{241}Am from Table 4 for RH-TRU
$A(Pu241)_{RH}$ activity value for ^{241}Pu from Table 4 for RH-TRU
$\tau_{1/2}$ (Am241) half-life of ^{241}Am from Table 2
$\tau_{1/2}$ (Pu241) half-life of ^{241}Pu from Table 2

$$A_L(Pu239)_{CH} = A(Pu239)_{CH} + A(Pu240)_{CH} + A(Pu242)_{CH} * \tau_{1/2}(Pu242)/\tau_{1/2}(Pu239) \quad (18)$$

$$A_L(Pu239)_{RH} = A(Pu239)_{RH} + A(Pu240)_{RH} + A(Pu242)_{RH} * \tau_{1/2}(Pu242)/\tau_{1/2}(Pu239) \quad (19)$$

where:

$A_L(Pu239)_{CH}$ activity value for the property INVCHD for the material PU239L
$A(Pu239)_{CH}$ activity value for ^{239}Pu from Table 4 for CH-TRU
$A(Pu240)_{CH}$ activity value for ^{240}Pu from Table 4 for CH-TRU
$A(Pu242)_{CH}$ activity value for ^{242}Pu from Table 4 for CH-TRU
$A_L(Pu239)_{RH}$ activity value for the property INVRHD for the material PU239L
$A(Pu239)_{RH}$ activity value for ^{239}Pu from Table 4 for RH-TRU
$A(Pu240)_{RH}$ activity value for ^{240}Pu from Table 4 for RH-TRU
$A(Pu242)_{RH}$ activity value for ^{242}Pu from Table 4 for RH-TRU
$\tau_{1/2}(Pu239)$ half-life of ^{239}Pu from Table 2
$\tau_{1/2}(Pu242)$ half-life of ^{242}Pu from Table 2

$$A_L(U234)_{CH} = A(U234)_{CH} + A(U233)_{CH} \quad (20)$$

$$A_L(U234)_{RH} = A(U234)_{RH} + A(U233)_{RH} \quad (21)$$

where:
$A_L(U234)_{CH}$ activity value for the property INVCHD for the material U234L
$A(U234)_{CH}$ activity value for ^{234}U from Table 4 for CH-TRU
$A(U233)_{CH}$ activity value for ^{233}U from Table 4 for CH-TRU
$A_L(U234)_{RH}$ activity value for the property INVRHD for the material U234L
$A(U234)_{RH}$ activity value for ^{234}U from Table 4 for RH-TRU
$A(U233)_{RH}$ activity value for ^{233}U from Table 4 for RH-TRU

$$A_L(Th230)_{CH} = A(Th230)_{CH} + A(Th229)_{CH} \quad (22)$$

$$A_L(Th230)_{RH} = A(Th230)_{RH} + A(Th229)_{RH} \quad (23)$$

where:
$A_L(Th230)_{CH}$ activity value for the property INVCHD for the material TH230L
$A(Th230)_{CH}$ activity value for ^{230}Th from Table 4 for CH-TRU
$A(Th229)_{CH}$ activity value for ^{229}Th from Table 4 for CH-TRU
$A_L(Th230)_{RH}$ activity value for the property INVRHD for the material TH230L
$A(Th230)_{RH}$ activity value for ^{230}Th from Table 4 for RH-TRU
$A(Th229)_{RH}$ activity value for ^{229}Th from Table 4 for RH-TRU

5.3 RESULTS

Using the radionuclide activity values from Table A-1 and the equations from Section 5.2 gives the values in Table 7 for the lumped radionuclide inventories at the end of 2033.

Table 7. Lumped Radionuclide Inventory Values As of 12/31/2033

Material	INVCHD (Total Ci)	INVRHD (Total Ci)
AM241L	1.19E+06	1.45E+04
PU238L	9.42E+05	2.25E+04
PU239L	1.19E+06	7.63E+03
TH230L	7.78E-01	3.13E+00
U234L	5.86E+02	2.69E+01

NOTE: INVCHD is a parameter name that refers to contact-handled inventory in curies. INVRHD is a parameter name that refers to remote-handled inventory in curies. These parameter values are listed in Table D-3, which provides the specific parameter data entry information required for tracking parameters in PA.

6. OXYANION MOLES

Oxyanions (anions containing oxygen) that are important to PA because they may affect actinide solubility or gas generation rates include sulfates and nitrates. LANL provided masses of sulfate and nitrate in waste coming to the WIPP in PAIR-2018 (Van Soest 2018, Table 5-8). The values are 1.69E+06 kg of nitrate and 4.54E+05 kg of sulfate. A conversion to moles is needed for input to PA calculations in the code BRAGFLO, as provided by oxyanion parameters NITRATE:QINIT and SULFATE:QINIT (Appendix D, Table D-5). The molecular weights for nitrate and sulfate are given in Tierney (1996). The molecular weight of nitrate used in Tierney (1996) is 6.20E-02 kg/mol. The molecular weight of sulfate used in Tierney (1996) is 9.606E-02 kg/mol. The conversion is as follows:

$$M_{waste}^{NO_3^-} = \left[\frac{1.69\text{E+06 kg}}{6.20\text{E-02 kg/mol}}\right] = 2.72\text{E+07 moles } NO_3^- \quad (24)$$

$$M_{waste}^{SO_4^{-2}} = \left[\frac{4.54\text{E+05 kg}}{9.606\text{E-02 kg/mol}}\right] = 4.73\text{E+06 moles } SO_4^{-2} \quad (25)$$

7. WASTE MATERIAL PARAMETERS

To support PA calculations in the code BRAGFLO, the total inventory of all nonradiological waste material parameters is required for both CH- and RH-TRU waste. Nonradiological waste material parameters include cellulosic, plastic, and rubber materials; iron-based metal/alloys; aluminum-based metal/alloys; other metals; solidified inorganic materials; solidified organic materials; vitrified materials; cements; soils; and other inorganic materials. These components may affect actinide solubility or gas generation rates. The waste material parameters are listed in Table D-4, which provides the specific parameter data entry information required for tracking parameters in PA.

8. EPAUNI INPUT FILES

The radionuclides that are important for modeling the direct solid release pathway (via the CCDFGF code) are: ^{241}Am, ^{244}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, ^{233}U, and ^{234}U. These 10 radionuclides account for 99.94% of the EPA units at the time of repository closure in the PAIR-2018 inventory as documented in Section 3.2 (see Table 5). These ten radionuclides are modeled

in EPAUNI, which is the computational code that calculates the activities as function of time, determines the EPA units associated with the radionuclides, and generates the normalized distribution associated with the volumetric EPA units.

EPAUNI input files provide data for both CH- and RH-TRU waste and include the following files:

- *epu_CRA19_ch.inp*
- *epu_CRA19_ch_misc.inp*
- *epu_CRA19_rh.inp*
- *epu_CRA19_rh_misc.inp*

The input files *epu_CRA19_ch.inp* and *epu_CRA19_rh.inp* provide data for CH and RH waste, respectively, and include WIPP inventory data taken directly from PAIR-2018 (Van Soest 2018). These files include the scaled volume (m^3) and activity (Ci) for the 10 select radionuclides from each waste stream in the inventory. The EPAUNI input files *epu_CRA19_ch_misc.inp* and *epu_CRA19_rh_misc.inp* provide flags for directing code settings for reading input and producing output. The WUF value (as documented in Section 2.2) is manually entered into these two files.

Additional details for generating EPAUNI input files are provided in Appendix E.

9. REFERENCES

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APPENDIX A – Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste

Table A-1. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2033)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	3.80E-01	8.74E-01	--	--	--
Ac-227	B-A	21.772 y	2.47E+01	1.19E+00	100	330	7.85E-02
Ac-228	B-	6.15 h	9.03E-02	4.56E-02	--	--	--
Ag-108	B-ECB+	2.37 m	1.45E-04	5.15E-03	--	--	--
Ag-108m	ECIT	418 y	1.67E-03	5.92E-02	1000	3302	1.84E-05
Ag-109m	IT	39.6 s	4.49E-08	1.10E-03	--	--	--
Ag-110	B-EC	24.6 s	1.02E-09	7.94E-09	--	--	--
Ag-110m	B-IT	249.76 d	7.50E-08	5.84E-07	--	--	--
Am-241	A	432.2 y	1.13E+06	1.30E+04	100	330	3.46E+03
Am-242	B-EC	16.02 h	4.46E+00	4.72E+00	--	--	--
Am-242m	ITA	141 y	4.48E+00	4.74E+00	100	330	2.79E-02
Am-243	A	7.37E+3 y	2.24E+01	4.12E+02	100	330	1.32E+00
Am-245	B-	2.05 h	1.88E-09	5.99E-08	--	--	--
Am-246	B-	39 m	2.91E-08	5.88E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	4.78E-02	1000	3302	1.45E-05
Ar-42	B-	32.9 y	0.00E+00	8.75E-02	1000	3302	2.65E-05
At-217	A	3.23E-2 s	3.80E-01	8.74E-01	--	--	--
Ba-133	EC	10.52 y	2.31E-03	3.88E+00	--	--	--
Ba-137m	IT	2.552 m	5.82E+02	2.36E+05	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.03E-05	1000	3302	3.11E-09
Bi-210	B-A	5.013 d	9.79E-01	1.45E+01	--	--	--
Bi-211	A B-	2.14 m	2.48E+01	1.19E+00	--	--	--
Bi-212	B-A	60.55 m	4.49E+02	9.23E+00	--	--	--
Bi-213	B-A	45.59 m	3.80E-01	8.74E-01	--	--	--
Bi-214	B-A	19.9 m	1.78E+00	1.85E+01	--	--	--
Bk-249	B-A	330 d	1.30E-04	4.13E-03	--	--	--
Bk-250	B-	3.212 h	1.63E-08	3.30E-07	--	--	--
C-14	B-	5.70E+3 y	2.27E-02	5.34E+01	100	330	1.62E-01
Ca-45	B-	162.67 d	2.42E-21	1.05E-11	--	--	--
Cd-109	EC	461.4 d	4.49E-08	1.10E-03	--	--	--
Cd-113	B-	7.7E+15 y	2.35E-22	1.16E-17	1000	3302	3.51E-21
Cd-113m	B-IT	14.1 y	8.45E-05	3.33E+00	--	--	--
Ce-139	EC	137.641 d	1.82E-17	1.02E-12	--	--	--
Ce-144	B-	284.91 d	6.62E-07	6.76E-03	--	--	--
Cf-249	ASF	351 y	1.10E+01	3.73E+01	100	330	1.46E-01
Cf-250	ASF	13.08 y	3.26E+00	1.26E+02	--	--	--
Cf-251	A	900 y	1.01E-01	8.39E+00	100	330	2.57E-02
Cf-252	ASF	2.645 y	5.07E-01	1.76E+00	--	--	--
Cl-36	B-ECB+	3.01E+5 y	2.02E-07	0.00E+00	1000	3302	6.13E-11
Cm-242	ASF	162.8 d	3.69E+00	3.91E+00	--	--	--

Table A-1. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-243	AEC	29.1 y	2.54E+00	3.61E+01	100	330	1.17E-01
Cm-244	ASF	18.10 y	6.19E+03	3.32E+04	--	--	--
Cm-245	ASF	8.5E+3 y	2.97E+00	2.15E+01	100	330	7.40E-02
Cm-246	ASF	4.76E+3 y	5.44E+01	4.55E+02	100	330	1.54E+00
Cm-247	A	1.56E+7 y	3.34E-01	4.08E-02	100	330	1.13E-03
Cm-248	ASF	3.48E+5 y	4.63E-01	1.31E+00	100	330	5.36E-03
Cm-250	AB-SF	8300 y	1.17E-07	2.35E-06	100	330	7.48E-09
Co-60	B-	5.2713 y	3.10E-01	3.79E+02	--	--	--
Cs-134	B-EC	2.0648 y	2.80E-03	1.08E+01	--	--	--
Cs-135	B-	2.3E+6 y	1.67E-04	6.47E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	6.16E+02	2.50E+05	1000	3302	7.60E+01
Dy-159	EC	144.4 d	0.00E+00	4.60E-13	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	4.19E-10	--	--	--
Eu-149	EC	93.1 d	0.00E+00	6.03E-20	--	--	--
Eu-152	ECB+B-	13.537 y	1.29E+01	7.38E+01	--	--	--
Eu-154	B-EC	8.593 y	6.85E+00	2.30E+03	--	--	--
Eu-155	B-	4.7611 y	1.33E+00	1.83E+02	--	--	--
Fe-55	EC	2.737 y	1.03E-03	6.46E+01	--	--	--
Fr-221	A	4.9 m	3.80E-01	8.74E-01	--	--	--
Fr-223	B-A	22.00 m	3.41E-01	1.64E-02	--	--	--
Gd-152	A	1.08E+14 y	5.91E-13	4.54E-12	100	330	1.55E-14
Gd-153	EC	240.4 d	5.08E-09	7.77E-08	--	--	--
H-3	B-	12.32 y	2.87E+04	7.18E+03	--	--	--
Ho-166m	B-	1.20E+3 y	1.06E-03	2.94E-05	1000	3302	3.31E-07
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	2.14E-28	1.01E-14	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	1.02E-02	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	8.75E-02	--	--	--
Kr-85	B-	10.756 y	2.41E-01	5.35E+02	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	8.71E-07	1000	3302	2.64E-10
Lu-177	B-	6.647 d	0.00E+00	2.66E-14	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	1.21E-13	--	--	--
Mn-54	ECB+B-	312.12 d	4.62E-08	4.19E-03	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	5.47E-01	1000	3302	1.66E-04
Na-22	ECB+	2.6019 y	3.13E-02	2.56E-03	--	--	--
Nb-91	ECB+	680 y	0.00E+00	7.12E-02	1000	3302	2.16E-05
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.38E-03	3.65E+00	--	--	--
Nb-94	B-	2.03E+4 y	1.97E-03	4.34E+00	1000	3302	1.32E-03
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14

Table A-1. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ni-59	ECB+	1.01E+5 y	2.53E-02	5.16E+02	1000	3302	1.56E-01
Ni-63	B-	100.1 y	5.25E+00	8.67E+02	1000	3302	2.64E-01
Np-235	ECA	396.1 d	0.00E+00	2.57E-04	--	--	--
Np-237	A	2.144E+6 y	2.75E+01	6.96E+00	100	330	1.04E-01
Np-238	B-	2.117 d	2.02E-02	2.14E-02	--	--	--
Np-239	B-	2.3565 d	2.24E+01	4.12E+02	--	--	--
Np-240	B-	61.9 m	6.95E-06	3.38E-05	--	--	--
Np-240m	B-IT	7.22 m	5.79E-03	2.82E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	1.77E-21	--	--	--
Os-194	B-	6.0 y	0.00E+00	1.02E-02	--	--	--
Pa-231	A	3.276E+4 y	1.59E+01	1.04E-03	100	330	4.81E-02
Pa-233	B-	26.967 d	2.75E+01	6.96E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	3.80E-01	8.74E-01	--	--	--
Pb-210	B-A	22.20 y	9.79E-01	1.45E+01	100	330	4.68E-02
Pb-211	B-	36.1 m	2.48E+01	1.19E+00	--	--	--
Pb-212	B-	10.64 h	4.49E+02	9.23E+00	--	--	--
Pb-214	B-	26.8 m	1.78E+00	1.85E+01	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	1.61E+00	--	--	--
Pm-146	ECB-	5.53 y	6.32E-07	5.26E-01	--	--	--
Pm-147	B-	2.6234 y	4.40E-01	2.54E+01	--	--	--
Po-210	A	138.376 d	9.79E-01	1.45E+01	--	--	--
Po-211	A	0.516 s	6.81E-02	3.27E-03	--	--	--
Po-212	A	2.99E-7 s	2.88E+02	5.91E+00	--	--	--
Po-213	A	4.2E-6 s	3.72E-01	8.55E-01	--	--	--
Po-214	A	1.643E-4 s	1.78E+00	1.85E+01	--	--	--
Po-215	A	1.781E-3 s	2.48E+01	1.19E+00	--	--	--
Po-216	A	0.145 s	4.49E+02	9.23E+00	--	--	--
Po-218	A B-	3.10 m	1.78E+00	1.85E+01	--	--	--
Pr-144	B-	17.28 m	6.62E-07	6.76E-03	--	--	--
Pr-144m	ITB-	7.2 m	9.27E-09	9.46E-05	--	--	--
Pu-236	ASF	2.858 y	8.69E-12	6.65E-02	--	--	--
Pu-238	ASF	87.7 y	9.42E+05	2.25E+04	100	330	2.92E+03
Pu-239	A	2.411E+4 y	8.70E+05	4.22E+03	100	330	2.65E+03
Pu-240	ASF	6564 y	3.16E+05	3.16E+03	100	330	9.67E+02
Pu-241	B-A	14.35 y	1.82E+06	4.53E+04	--	--	--
Pu-242	ASF	3.75E+5 y	1.48E+02	1.59E+01	100	330	4.96E-01
Pu-243	B-	4.956 h	3.34E-01	4.08E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.80E-03	2.82E-02	100	330	1.03E-04
Pu-246	B-	10.84 d	2.91E-08	5.88E-07	--	--	--

Table A-1. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-223	A	11.43 d	2.48E+01	1.19E+00	--	--	--
Ra-224	A	3.66 d	4.49E+02	9.23E+00	--	--	--
Ra-225	B-	14.9 d	3.80E-01	8.74E-01	--	--	--
Ra-226	A	1600 y	1.78E+00	1.85E+01	100	330	6.13E-02
Ra-228	B-	5.75 y	9.03E-02	4.55E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	1.30E-08	--	--	--
Rh-106	B-	29.80 s	9.91E-05	2.11E-02	--	--	--
Rn-219	A	3.96 s	2.48E+01	1.19E+00	--	--	--
Rn-220	A	55.6 s	4.49E+02	9.23E+00	--	--	--
Rn-222	A	3.8235 d	1.78E+00	1.85E+01	--	--	--
Ru-106	B-	373.59 d	9.91E-05	2.11E-02	--	--	--
S-35	B-	87.51 d	1.50E-30	6.34E-22	--	--	--
Sb-125	B-	2.75856 y	5.70E-03	1.52E+01	--	--	--
Sb-126	B-	12.35 d	1.18E-06	8.05E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.71E-05	1.22E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	6.10E-22	--	--	--
Se-75	EC	119.779 d	1.19E-32	1.05E-15	--	--	--
Se-79	B-	2.95E+5 y	6.91E-05	1.80E-01	1000	3302	5.46E-05
Sm-145	EC	340 d	0.00E+00	1.08E-05	--	--	--
Sm-146	A	1.03E+8 y	1.70E-13	6.18E-08	100	330	1.87E-10
Sm-147	A	1.060E11 y	1.23E-09	9.40E-08	100	330	2.88E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	1.27E+01	1.41E+02	1000	3302	4.67E-02
Sn-113	EC	115.09 d	2.14E-28	1.01E-14	--	--	--
Sn-119m	IT	293.1 d	3.38E-24	5.50E-06	--	--	--
Sn-121	B-	27.03 h	7.50E-05	3.42E+00	--	--	--
Sn-121m	ITB-	43.9 y	9.66E-05	4.40E+00	1000	3302	1.33E-03
Sn-123	B-	129.2 d	0.00E+00	1.37E-13	--	--	--
Sn-126	B-	2.30E+5 y	1.71E-05	1.22E-01	1000	3302	3.69E-05
Sr-90	B-	28.79 y	8.18E+02	1.96E+05	1000	3302	5.96E+01
Ta-182	B-	114.43 d	3.50E-25	9.08E-13	--	--	--
Tb-157	EC	71 y	0.00E+00	1.84E-01	1000	3302	5.59E-05
Tc-97	EC	2.6E+6 y	0.00E+00	1.69E-06	1000	3302	5.11E-10
Tc-97m	IT	90.1 d	0.00E+00	2.46E-20	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.39E-07	1000	3302	1.03E-10
Tc-99	B-	2.111E+5 y	4.56E+01	5.33E+02	10000	33017	1.75E-02
Te-121	EC	19.16 d	0.00E+00	4.02E-12	--	--	--
Te-121m	ITEC	154 d	0.00E+00	4.04E-12	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	1.61E-28	2.57E-15	--	--	--
Te-125m	IT	57.40 d	1.39E-03	3.70E+00	--	--	--

Table A-1. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Te-127	B-	9.35 h	0.00E+00	9.30E-16	--	--	--
Te-127m	ITB-	109 d	0.00E+00	9.49E-16	--	--	--
Th-227	A	18.68 d	2.44E+01	1.17E+00	--	--	--
Th-228	A	1.9116 y	4.49E+02	9.23E+00	--	--	--
Th-229	A	7.34E+3 y	3.80E-01	8.74E-01	100	330	3.80E-03
Th-230	A	7.538E+4 y	3.98E-01	2.26E+00	10	33	8.04E-02
Th-231	B-	25.52 h	4.56E+00	1.85E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	1.32E-08	0.00E+00	--	--	--
Tl-206	B-	4.200 m	1.29E-06	1.91E-05	--	--	--
Tl-207	B-	4.77 m	2.47E+01	1.19E+00	--	--	--
Tl-208	B-	3.053 m	1.61E+02	3.32E+00	--	--	--
Tl-209	B-	2.161 m	7.98E-03	1.83E-02	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	3.99E-15	--	--	--
Tm-171	B-	1.92 y	0.00E+00	7.37E-03	--	--	--
U-232	A	68.9 y	4.38E+02	8.87E+00	100	330	1.35E+00
U-233	A	1.592E+5 y	1.10E+02	1.72E+01	100	330	3.85E-01
U-234	A	2.455E+5 y	4.77E+02	9.70E+00	100	330	1.47E+00
U-235	A	7.04E+8 y	4.56E+00	1.85E+00	100	330	1.94E-02
U-236	A	2.342E+7 y	4.24E-01	2.53E-01	100	330	2.05E-03
U-237	B-	6.75 d	4.36E+01	1.08E+00	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.79E-03	2.82E-02	--	--	--
V-49	EC	330 d	0.00E+00	1.26E-04	--	--	--
W-181	EC	121.2 d	0.00E+00	1.77E-16	--	--	--
Y-90	B-	64.10 h	8.19E+02	1.96E+05	--	--	--
Zn-65	ECB+	244.06 d	2.40E-10	6.10E-08	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.44E-01	1000	3302	7.44E-05
Total:	--	--	5.12E+06	1.01E+06	--	--	10140

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.

(b) Decayed radionuclide inventory information taken from Van Soest (2018).

(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.

(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

Table A-2. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2133)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	1.34E+00	1.02E+00	--	--	--
Ac-227	B-A	21.772 y	1.62E+01	5.29E-02	100	330	4.93E-02
Ac-228	B-	6.15 h	9.60E-02	2.26E-02	--	--	--
Ag-108	B-ECB+	2.37 m	8.41E-05	2.98E-03	--	--	--
Ag-108m	ECIT	418 y	9.66E-04	3.43E-02	1000	3302	1.07E-05
Ag-109m	IT	39.6 s	7.54E-32	1.88E-27	--	--	--
Ag-110	B-EC	24.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110m	B-IT	249.76 d	0.00E+00	0.00E+00	--	--	--
Am-241	A	432.2 y	1.02E+06	1.24E+04	100	330	3.11E+03
Am-242	B-EC	16.02 h	2.73E+00	2.89E+00	--	--	--
Am-242m	ITA	141 y	2.74E+00	2.90E+00	100	330	1.71E-02
Am-243	A	7.37E+3 y	2.22E+01	4.09E+02	100	330	1.30E+00
Am-245	B-	2.05 h	0.00E+00	0.00E+00	--	--	--
Am-246	B-	39 m	2.90E-08	5.86E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	3.69E-02	1000	3302	1.12E-05
Ar-42	B-	32.9 y	0.00E+00	1.06E-02	1000	3302	3.22E-06
At-217	A	3.23E-2 s	1.34E+00	1.02E+00	--	--	--
Ba-133	EC	10.52 y	3.18E-06	5.33E-03	--	--	--
Ba-137m	IT	2.552 m	5.77E+01	2.35E+04	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.03E-05	1000	3302	3.11E-09
Bi-210	B-A	5.013 d	1.71E+00	1.78E+01	--	--	--
Bi-211	A B-	2.14 m	1.62E+01	5.30E-02	--	--	--
Bi-212	B-A	60.55 m	1.67E+02	3.40E+00	--	--	--
Bi-213	B-A	45.59 m	1.34E+00	1.02E+00	--	--	--
Bi-214	B-A	19.9 m	1.73E+00	1.78E+01	--	--	--
Bk-249	B-A	330 d	0.00E+00	0.00E+00	--	--	--
Bk-250	B-	3.212 h	1.63E-08	3.28E-07	--	--	--
C-14	B-	5.70E+3 y	2.24E-02	5.27E+01	100	330	1.60E-01
Ca-45	B-	162.67 d	0.00E+00	0.00E+00	--	--	--
Cd-109	EC	461.4 d	7.63E-32	1.88E-27	--	--	--
Cd-113	B-	7.7E+15 y	4.13E-22	1.86E-17	1000	3302	5.63E-21
Cd-113m	B-IT	14.1 y	6.19E-07	2.44E-02	--	--	--
Ce-139	EC	137.641 d	0.00E+00	0.00E+00	--	--	--
Ce-144	B-	284.91 d	0.00E+00	0.00E+00	--	--	--
Cf-249	ASF	351 y	9.00E+00	3.06E+01	100	330	1.20E-01
Cf-250	ASF	13.08 y	1.63E-02	6.27E-01	--	--	--
Cf-251	A	900 y	9.31E-02	7.77E+00	100	330	2.38E-02
Cf-252	ASF	2.645 y	2.10E-12	7.30E-12	--	--	--
Cl-36	B-ECB+	3.01E+5 y	2.02E-07	0.00E+00	1000	3302	6.12E-11
Cm-242	ASF	162.8 d	2.26E+00	2.39E+00	--	--	--
Cm-243	AEC	29.1 y	2.23E-01	3.17E+00	100	330	1.03E-02
Cm-244	ASF	18.10 y	1.35E+02	7.21E+02	--	--	--

Table A-2. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2133) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-245	ASF	8.5E+3 y	3.02E+00	2.16E+01	100	330	7.45E-02
Cm-246	ASF	4.76E+3 y	5.36E+01	4.49E+02	100	330	1.52E+00
Cm-247	A	1.56E+7 y	3.34E-01	4.09E-02	100	330	1.13E-03
Cm-248	ASF	3.48E+5 y	4.62E-01	1.31E+00	100	330	5.36E-03
Cm-250	AB-SF	8300 y	1.16E-07	2.34E-06	100	330	7.45E-09
Co-60	B-	5.2713 y	6.01E-07	7.35E-04	--	--	--
Cs-134	B-EC	2.0648 y	7.03E-18	2.72E-14	--	--	--
Cs-135	B-	2.3E+6 y	1.67E-04	6.47E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	6.11E+01	2.48E+04	1000	3302	7.54E+00
Dy-159	EC	144.4 d	0.00E+00	0.00E+00	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	0.00E+00	--	--	--
Eu-149	EC	93.1 d	0.00E+00	0.00E+00	--	--	--
Eu-152	ECB+B-	13.537 y	7.12E-02	4.07E-01	--	--	--
Eu-154	B-EC	8.593 y	2.14E-03	7.20E-01	--	--	--
Eu-155	B-	4.7611 y	4.92E-07	6.76E-05	--	--	--
Fe-55	EC	2.737 y	9.70E-15	6.05E-10	--	--	--
Fr-221	A	4.9 m	1.34E+00	1.02E+00	--	--	--
Fr-223	B-A	22.00 m	2.24E-01	7.30E-04	--	--	--
Gd-152	A	1.08E+14 y	1.03E-12	7.07E-12	100	330	2.45E-14
Gd-153	EC	240.4 d	0.00E+00	0.00E+00	--	--	--
H-3	B-	12.32 y	1.04E+02	2.60E+01	--	--	--
Ho-166m	B-	1.20E+3 y	1.00E-03	2.77E-05	1000	3302	3.13E-07
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	0.00E+00	0.00E+00	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	9.74E-08	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	1.06E-02	--	--	--
Kr-85	B-	10.756 y	3.74E-04	8.32E-01	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	8.70E-07	1000	3302	2.64E-10
Lu-177	B-	6.647 d	0.00E+00	0.00E+00	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	0.00E+00	--	--	--
Mn-54	ECB+B-	312.12 d	0.00E+00	0.00E+00	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	5.37E-01	1000	3302	1.63E-04
Na-22	ECB+	2.6019 y	8.42E-14	6.89E-15	--	--	--
Nb-91	ECB+	680 y	0.00E+00	6.43E-02	1000	3302	1.95E-05
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.37E-03	7.26E-01	--	--	--
Nb-94	B-	2.03E+4 y	1.97E-03	4.33E+00	1000	3302	1.31E-03
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14
Ni-59	ECB+	1.01E+5 y	2.53E-02	5.15E+02	1000	3302	1.56E-01
Ni-63	B-	100.1 y	2.62E+00	4.34E+02	1000	3302	1.32E-01

Table A-2. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2133) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Np-235	ECA	396.1 d	0.00E+00	0.00E+00	--	--	--
Np-237	A	2.144E+6 y	6.27E+01	7.39E+00	100	330	2.12E-01
Np-238	B-	2.117 d	1.23E-02	1.31E-02	--	--	--
Np-239	B-	2.3565 d	2.22E+01	4.09E+02	--	--	--
Np-240	B-	61.9 m	6.95E-06	3.38E-05	--	--	--
Np-240m	B-IT	7.22 m	5.79E-03	2.82E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	0.00E+00	--	--	--
Os-194	B-	6.0 y	0.00E+00	9.74E-08	--	--	--
Pa-231	A	3.276E+4 y	1.59E+01	4.94E-03	100	330	4.80E-02
Pa-233	B-	26.967 d	6.27E+01	7.39E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	1.34E+00	1.02E+00	--	--	--
Pb-210	B-A	22.20 y	1.71E+00	1.78E+01	100	330	5.91E-02
Pb-211	B-	36.1 m	1.62E+01	5.30E-02	--	--	--
Pb-212	B-	10.64 h	1.67E+02	3.40E+00	--	--	--
Pb-214	B-	26.8 m	1.73E+00	1.78E+01	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	3.21E-02	--	--	--
Pm-146	ECB-	5.53 y	2.27E-12	1.89E-06	--	--	--
Pm-147	B-	2.6234 y	1.47E-12	8.51E-11	--	--	--
Po-210	A	138.376 d	1.71E+00	1.78E+01	--	--	--
Po-211	A	0.516 s	4.46E-02	1.46E-04	--	--	--
Po-212	A	2.99E-7 s	1.07E+02	2.18E+00	--	--	--
Po-213	A	4.2E-6 s	1.31E+00	9.96E-01	--	--	--
Po-214	A	1.643E-4 s	1.73E+00	1.78E+01	--	--	--
Po-215	A	1.781E-3 s	1.62E+01	5.30E-02	--	--	--
Po-216	A	0.145 s	1.67E+02	3.40E+00	--	--	--
Po-218	A B-	3.10 m	1.73E+00	1.78E+01	--	--	--
Pr-144	B-	17.28 m	0.00E+00	0.00E+00	--	--	--
Pr-144m	ITB-	7.2 m	0.00E+00	0.00E+00	--	--	--
Pu-236	ASF	2.858 y	3.62E-22	2.77E-12	--	--	--
Pu-238	ASF	87.7 y	4.27E+05	1.02E+04	100	330	1.33E+03
Pu-239	A	2.411E+4 y	8.67E+05	4.21E+03	100	330	2.64E+03
Pu-240	ASF	6564 y	3.13E+05	3.22E+03	100	330	9.58E+02
Pu-241	B-A	14.35 y	1.45E+04	3.83E+02	--	--	--
Pu-242	ASF	3.75E+5 y	1.48E+02	1.60E+01	100	330	4.96E-01
Pu-243	B-	4.956 h	3.34E-01	4.09E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.80E-03	2.82E-02	100	330	1.03E-04
Pu-246	B-	10.84 d	2.90E-08	5.86E-07	--	--	--
Ra-223	A	11.43 d	1.62E+01	5.30E-02	--	--	--
Ra-224	A	3.66 d	1.67E+02	3.40E+00	--	--	--

Table A-2. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2133) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-225	B-	14.9 d	1.34E+00	1.02E+00	--	--	--
Ra-226	A	1600 y	1.73E+00	1.78E+01	100	330	5.91E-02
Ra-228	B-	5.75 y	9.60E-02	2.26E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	0.00E+00	--	--	--
Rh-106	B-	29.80 s	0.00E+00	0.00E+00	--	--	--
Rn-219	A	3.96 s	1.62E+01	5.30E-02	--	--	--
Rn-220	A	55.6 s	1.67E+02	3.40E+00	--	--	--
Rn-222	A	3.8235 d	1.73E+00	1.78E+01	--	--	--
Ru-106	B-	373.59 d	0.00E+00	0.00E+00	--	--	--
S-35	B-	87.51 d	0.00E+00	0.00E+00			
Sb-125	B-	2.75856 y	5.34E-14	1.42E-10	--	--	--
Sb-126	B-	12.35 d	1.18E-06	8.05E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.70E-05	1.22E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	0.00E+00	--	--	--
Se-75	EC	119.779 d	0.00E+00	0.00E+00	--	--	--
Se-79	B-	2.95E+5 y	6.91E-05	1.80E-01	1000	3302	5.46E-05
Sm-145	EC	340 d	0.00E+00	0.00E+00	--	--	--
Sm-146	A	1.03E+8 y	1.81E-13	7.13E-08	100	330	2.16E-10
Sm-147	A	1.060E11 y	1.24E-09	9.46E-08	100	330	2.90E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	5.88E+00	6.54E+01	1000	3302	2.16E-02
Sn-113	EC	115.09 d	0.00E+00	0.00E+00	--	--	--
Sn-119m	IT	293.1 d	0.00E+00	0.00E+00	--	--	--
Sn-121	B-	27.03 h	2.13E-05	9.69E-01	--	--	--
Sn-121m	ITB-	43.9 y	2.74E-05	1.25E+00	1000	3302	3.78E-04
Sn-123	B-	129.2 d	0.00E+00	0.00E+00	--	--	--
Sn-126	B-	2.30E+5 y	1.70E-05	1.22E-01	1000	3302	3.68E-05
Sr-90	B-	28.79 y	6.97E+01	1.67E+04	1000	3302	5.08E+00
Ta-182	B-	114.43 d	0.00E+00	0.00E+00	--	--	--
Tb-157	EC	71 y	0.00E+00	1.16E-01	1000	3302	3.52E-05
Tc-97	EC	2.6E+6 y	0.00E+00	1.69E-06	1000	3302	5.11E-10
Tc-97m	IT	90.1 d	0.00E+00	0.00E+00	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.39E-07	1000	3302	1.03E-10
Tc-99	B-	2.111E+5 y	4.56E+01	5.33E+02	10000	33017	1.75E-02
Te-121	EC	19.16 d	0.00E+00	0.00E+00	--	--	--
Te-121m	ITEC	154 d	0.00E+00	0.00E+00	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	0.00E+00	0.00E+00	--	--	--
Te-125m	IT	57.40 d	1.30E-14	3.47E-11	--	--	--
Te-127	B-	9.35 h	0.00E+00	0.00E+00	--	--	--
Te-127m	ITB-	109 d	0.00E+00	0.00E+00	--	--	--

Table A-2. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2133) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Th-227	A	18.68 d	1.60E+01	5.23E-02	--	--	--
Th-228	A	1.9116 y	1.67E+02	3.40E+00	--	--	--
Th-229	A	7.34E+3 y	1.34E+00	1.02E+00	100	330	7.13E-03
Th-230	A	7.538E+4 y	9.31E-01	2.27E+00	10	33	9.68E-02
Th-231	B-	25.52 h	4.65E+00	1.85E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	1.43E-16	0.00E+00	--	--	--
Tl-206	B-	4.200 m	2.25E-06	2.35E-05	--	--	--
Tl-207	B-	4.77 m	1.62E+01	5.29E-02	--	--	--
Tl-208	B-	3.053 m	6.01E+01	1.22E+00	--	--	--
Tl-209	B-	2.161 m	2.81E-02	2.14E-02	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	0.00E+00	--	--	--
Tm-171	B-	1.92 y	0.00E+00	1.55E-18	--	--	--
U-232	A	68.9 y	1.62E+02	3.29E+00	100	330	5.02E-01
U-233	A	1.592E+5 y	1.10E+02	1.72E+01	100	330	3.85E-01
U-234	A	2.455E+5 y	6.60E+02	1.41E+01	100	330	2.04E+00
U-235	A	7.04E+8 y	4.65E+00	1.85E+00	100	330	1.97E-02
U-236	A	2.342E+7 y	1.36E+00	2.62E-01	100	330	4.90E-03
U-237	B-	6.75 d	3.48E-01	9.16E-03	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.79E-03	2.82E-02	--	--	--
V-49	EC	330 d	0.00E+00	0.00E+00	--	--	--
W-181	EC	121.2 d	0.00E+00	0.00E+00	--	--	--
Y-90	B-	64.10 h	6.97E+01	1.67E+04	--	--	--
Zn-65	ECB+	244.06 d	0.00E+00	0.00E+00	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.44E-01	1000	3302	7.43E-05
Total:	--	--	2.64E+06	1.16E+05	--	--	8055

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.

(b) Decayed radionuclide inventory information taken from Van Soest (2018).

(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.

(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

Table A-3. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2383)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	3.70E+00	1.37E+00	--	--	--
Ac-227	B-A	21.772 y	1.58E+01	1.47E-02	100	330	4.79E-02
Ac-228	B-	6.15 h	9.60E-02	2.26E-02	--	--	--
Ag-108	B-ECB+	2.37 m	2.15E-05	7.62E-04	--	--	--
Ag-108m	ECIT	418 y	2.47E-04	8.76E-03	1000	3302	2.73E-06
Ag-109m	IT	39.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110	B-EC	24.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110m	B-IT	249.76 d	0.00E+00	0.00E+00	--	--	--
Am-241	A	432.2 y	6.80E+05	8.32E+03	100	330	2.09E+03
Am-242	B-EC	16.02 h	7.98E-01	8.45E-01	--	--	--
Am-242m	ITA	141 y	8.02E-01	8.49E-01	100	330	5.00E-03
Am-243	A	7.37E+3 y	2.17E+01	3.99E+02	100	330	1.27E+00
Am-245	B-	2.05 h	0.00E+00	0.00E+00	--	--	--
Am-246	B-	39 m	2.87E-08	5.80E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	1.94E-02	1000	3302	5.87E-06
Ar-42	B-	32.9 y	0.00E+00	5.48E-05	1000	3302	1.66E-08
At-217	A	3.23E-2 s	3.70E+00	1.37E+00	--	--	--
Ba-133	EC	10.52 y	2.23E-13	3.74E-10	--	--	--
Ba-137m	IT	2.552 m	1.79E-01	7.27E+01	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.03E-05	1000	3302	3.11E-09
Bi-210	B-A	5.013 d	1.73E+00	1.62E+01	--	--	--
Bi-211	A B-	2.14 m	1.58E+01	1.47E-02	--	--	--
Bi-212	B-A	60.55 m	1.40E+01	3.05E-01	--	--	--
Bi-213	B-A	45.59 m	3.70E+00	1.37E+00	--	--	--
Bi-214	B-A	19.9 m	1.73E+00	1.62E+01	--	--	--
Bk-249	B-A	330 d	0.00E+00	0.00E+00	--	--	--
Bk-250	B-	3.212 h	1.61E-08	3.25E-07	--	--	--
C-14	B-	5.70E+3 y	2.17E-02	5.12E+01	100	330	1.55E-01
Ca-45	B-	162.67 d	0.00E+00	0.00E+00	--	--	--
Cd-109	EC	461.4 d	0.00E+00	0.00E+00	--	--	--
Cd-113	B-	7.7E+15 y	4.14E-22	1.86E-17	1000	3302	5.65E-21
Cd-113m	B-IT	14.1 y	2.84E-12	1.12E-07	--	--	--
Ce-139	EC	137.641 d	0.00E+00	0.00E+00	--	--	--
Ce-144	B-	284.91 d	0.00E+00	0.00E+00	--	--	--
Cf-249	ASF	351 y	5.49E+00	1.87E+01	100	330	7.32E-02
Cf-250	ASF	13.08 y	4.48E-08	1.43E-06	--	--	--
Cf-251	A	900 y	7.67E-02	6.41E+00	100	330	1.96E-02
Cf-252	ASF	2.645 y	0.00E+00	0.00E+00	--	--	--
Cl-36	B-ECB+	3.01E+5 y	2.02E-07	0.00E+00	1000	3302	6.12E-11
Cm-242	ASF	162.8 d	6.60E-01	6.99E-01	--	--	--
Cm-243	AEC	29.1 y	5.10E-04	7.26E-03	100	330	2.35E-05
Cm-244	ASF	18.10 y	9.35E-03	5.01E-02	--	--	--

Table A-3. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2383) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-245	ASF	8.5E+3 y	3.10E+00	2.16E+01	100	330	7.49E-02
Cm-246	ASF	4.76E+3 y	5.17E+01	4.33E+02	100	330	1.47E+00
Cm-247	A	1.56E+7 y	3.34E-01	4.10E-02	100	330	1.14E-03
Cm-248	ASF	3.48E+5 y	4.62E-01	1.31E+00	100	330	5.36E-03
Cm-250	AB-SF	8300 y	1.15E-07	2.32E-06	100	330	7.38E-09
Co-60	B-	5.2713 y	3.14E-21	3.84E-18	--	--	--
Cs-134	B-EC	2.0648 y	0.00E+00	0.00E+00	--	--	--
Cs-135	B-	2.3E+6 y	1.67E-04	6.47E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	1.89E-01	7.70E+01	1000	3302	2.34E-02
Dy-159	EC	144.4 d	0.00E+00	0.00E+00	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	0.00E+00	--	--	--
Eu-149	EC	93.1 d	0.00E+00	0.00E+00	--	--	--
Eu-152	ECB+B-	13.537 y	1.60E-07	9.17E-07	--	--	--
Eu-154	B-EC	8.593 y	3.72E-12	1.25E-09	--	--	--
Eu-155	B-	4.7611 y	4.08E-23	5.61E-21	--	--	--
Fe-55	EC	2.737 y	0.00E+00	0.00E+00	--	--	--
Fr-221	A	4.9 m	3.70E+00	1.37E+00	--	--	--
Fr-223	B-A	22.00 m	2.18E-01	2.03E-04	--	--	--
Gd-152	A	1.08E+14 y	1.04E-12	7.08E-12	100	330	2.46E-14
Gd-153	EC	240.4 d	0.00E+00	0.00E+00	--	--	--
H-3	B-	12.32 y	8.17E-05	2.04E-05	--	--	--
Ho-166m	B-	1.20E+3 y	8.69E-04	2.40E-05	1000	3302	2.70E-07
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	0.00E+00	0.00E+00	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	2.77E-20	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	5.48E-05	--	--	--
Kr-85	B-	10.756 y	3.57E-11	7.93E-08	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	8.68E-07	1000	3302	2.63E-10
Lu-177	B-	6.647 d	0.00E+00	0.00E+00	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	0.00E+00	--	--	--
Mn-54	ECB+B-	312.12 d	0.00E+00	0.00E+00	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	5.11E-01	1000	3302	1.55E-04
Na-22	ECB+	2.6019 y	0.00E+00	0.00E+00	--	--	--
Nb-91	ECB+	680 y	0.00E+00	4.99E-02	1000	3302	1.51E-05
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.37E-03	6.65E-01	--	--	--
Nb-94	B-	2.03E+4 y	1.95E-03	4.29E+00	1000	3302	1.30E-03
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14
Ni-59	ECB+	1.01E+5 y	2.52E-02	5.14E+02	1000	3302	1.56E-01
Ni-63	B-	100.1 y	4.65E-01	7.68E+01	1000	3302	2.34E-02

Table A-3. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2383) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Np-235	ECA	396.1 d	0.00E+00	0.00E+00	--	--	--
Np-237	A	2.144E+6 y	1.30E+02	8.22E+00	100	330	4.20E-01
Np-238	B-	2.117 d	3.61E-03	3.82E-03	--	--	--
Np-239	B-	2.3565 d	2.17E+01	3.99E+02	--	--	--
Np-240	B-	61.9 m	6.95E-06	3.39E-05	--	--	--
Np-240m	B-IT	7.22 m	5.79E-03	2.82E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	0.00E+00	--	--	--
Os-194	B-	6.0 y	0.00E+00	2.76E-20	--	--	--
Pa-231	A	3.276E+4 y	1.58E+01	1.47E-02	100	330	4.79E-02
Pa-233	B-	26.967 d	1.30E+02	8.22E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	3.70E+00	1.37E+00	--	--	--
Pb-210	B-A	22.20 y	1.73E+00	1.62E+01	100	330	5.43E-02
Pb-211	B-	36.1 m	1.58E+01	1.47E-02	--	--	--
Pb-212	B-	10.64 h	1.40E+01	3.05E-01	--	--	--
Pb-214	B-	26.8 m	1.73E+00	1.62E+01	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	1.80E-06	--	--	--
Pm-146	ECB-	5.53 y	5.58E-26	4.64E-20	--	--	--
Pm-147	B-	2.6234 y	0.00E+00	0.00E+00	--	--	--
Po-210	A	138.376 d	1.73E+00	1.62E+01	--	--	--
Po-211	A	0.516 s	4.35E-02	4.04E-05	--	--	--
Po-212	A	2.99E-7 s	9.00E+00	1.95E-01	--	--	--
Po-213	A	4.2E-6 s	3.62E+00	1.34E+00	--	--	--
Po-214	A	1.643E-4 s	1.73E+00	1.62E+01	--	--	--
Po-215	A	1.781E-3 s	1.58E+01	1.47E-02	--	--	--
Po-216	A	0.145 s	1.40E+01	3.05E-01	--	--	--
Po-218	A B-	3.10 m	1.73E+00	1.62E+01	--	--	--
Pr-144	B-	17.28 m	0.00E+00	0.00E+00	--	--	--
Pr-144m	ITB-	7.2 m	0.00E+00	0.00E+00	--	--	--
Pu-236	ASF	2.858 y	0.00E+00	0.00E+00	--	--	--
Pu-238	ASF	87.7 y	5.93E+04	1.42E+03	100	330	1.84E+02
Pu-239	A	2.411E+4 y	8.61E+05	4.18E+03	100	330	2.62E+03
Pu-240	ASF	6564 y	3.05E+05	3.14E+03	100	330	9.33E+02
Pu-241	B-A	14.35 y	3.19E+00	2.17E+01	--	--	--
Pu-242	ASF	3.75E+5 y	1.48E+02	1.62E+01	100	330	4.96E-01
Pu-243	B-	4.956 h	3.34E-01	4.10E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.80E-03	2.82E-02	100	330	1.03E-04
Pu-246	B-	10.84 d	2.87E-08	5.80E-07	--	--	--
Ra-223	A	11.43 d	1.58E+01	1.47E-02	--	--	--
Ra-224	A	3.66 d	1.40E+01	3.05E-01	--	--	--

Table A-3. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2383) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-225	B-	14.9 d	3.70E+00	1.37E+00	--	--	--
Ra-226	A	1600 y	1.73E+00	1.62E+01	100	330	5.43E-02
Ra-228	B-	5.75 y	9.60E-02	2.26E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	0.00E+00	--	--	--
Rh-106	B-	29.80 s	0.00E+00	0.00E+00	--	--	--
Rn-219	A	3.96 s	1.58E+01	1.47E-02	--	--	--
Rn-220	A	55.6 s	1.40E+01	3.05E-01	--	--	--
Rn-222	A	3.8235 d	1.73E+00	1.62E+01	--	--	--
Ru-106	B-	373.59 d	0.00E+00	0.00E+00	--	--	--
S-35	B-	87.51 d	0.00E+00	0.00E+00	--	--	--
Sb-125	B-	2.75856 y	0.00E+00	0.00E+00	--	--	--
Sb-126	B-	12.35 d	1.18E-06	8.03E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.70E-05	1.21E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	0.00E+00	--	--	--
Se-75	EC	119.779 d	0.00E+00	0.00E+00	--	--	--
Se-79	B-	2.95E+5 y	6.90E-05	1.80E-01	1000	3302	5.46E-05
Sm-145	EC	340 d	0.00E+00	0.00E+00	--	--	--
Sm-146	A	1.03E+8 y	1.81E-13	7.13E-08	100	330	2.16E-10
Sm-147	A	1.060E11 y	1.24E-09	9.46E-08	100	330	2.90E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	8.57E-01	9.54E+00	1000	3302	3.15E-03
Sn-113	EC	115.09 d	0.00E+00	0.00E+00	--	--	--
Sn-119m	IT	293.1 d	0.00E+00	0.00E+00	--	--	--
Sn-121	B-	27.03 h	9.11E-07	4.15E-02	--	--	--
Sn-121m	ITB-	43.9 y	1.17E-06	5.35E-02	1000	3302	1.62E-05
Sn-123	B-	129.2 d	0.00E+00	0.00E+00	--	--	--
Sn-126	B-	2.30E+5 y	1.70E-05	1.21E-01	1000	3302	3.68E-05
Sr-90	B-	28.79 y	1.48E-01	3.54E+01	1000	3302	1.08E-02
Ta-182	B-	114.43 d	0.00E+00	0.00E+00	--	--	--
Tb-157	EC	71 y	0.00E+00	3.66E-02	1000	3302	1.11E-05
Tc-97	EC	2.6E+6 y	0.00E+00	1.69E-06	1000	3302	5.11E-10
Tc-97m	IT	90.1 d	0.00E+00	0.00E+00	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.39E-07	1000	3302	1.03E-10
Tc-99	B-	2.111E+5 y	4.55E+01	5.33E+02	10000	33017	1.75E-02
Te-121	EC	19.16 d	0.00E+00	0.00E+00	--	--	--
Te-121m	ITEC	154 d	0.00E+00	0.00E+00	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	0.00E+00	0.00E+00	--	--	--
Te-125m	IT	57.40 d	0.00E+00	0.00E+00	--	--	--
Te-127	B-	9.35 h	0.00E+00	0.00E+00	--	--	--
Te-127m	ITB-	109 d	0.00E+00	0.00E+00	--	--	--

Table A-3. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 2383) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Th-227	A	18.68 d	1.56E+01	1.45E-02	--	--	--
Th-228	A	1.9116 y	1.40E+01	3.05E-01	--	--	--
Th-229	A	7.34E+3 y	3.70E+00	1.37E+00	100	330	1.53E-02
Th-230	A	7.538E+4 y	2.64E+00	2.30E+00	10	33	1.50E-01
Th-231	B-	25.52 h	4.86E+00	1.85E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	1.77E-36	0.00E+00	--	--	--
Tl-206	B-	4.200 m	2.29E-06	2.14E-05	--	--	--
Tl-207	B-	4.77 m	1.58E+01	1.47E-02	--	--	--
Tl-208	B-	3.053 m	5.05E+00	1.10E-01	--	--	--
Tl-209	B-	2.161 m	7.76E-02	2.88E-02	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	0.00E+00	--	--	--
Tm-171	B-	1.92 y	0.00E+00	0.00E+00	--	--	--
U-232	A	68.9 y	1.36E+01	2.75E-01	100	330	4.19E-02
U-233	A	1.592E+5 y	1.10E+02	1.72E+01	100	330	3.85E-01
U-234	A	2.455E+5 y	7.91E+02	1.72E+01	100	330	2.45E+00
U-235	A	7.04E+8 y	4.86E+00	1.85E+00	100	330	2.03E-02
U-236	A	2.342E+7 y	3.64E+00	2.86E-01	100	330	1.19E-02
U-237	B-	6.75 d	7.63E-05	5.18E-04	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.79E-03	2.82E-02	--	--	--
V-49	EC	330 d	0.00E+00	0.00E+00	--	--	--
W-181	EC	121.2 d	0.00E+00	0.00E+00	--	--	--
Y-90	B-	64.10 h	1.48E-01	3.54E+01	--	--	--
Zn-65	ECB+	244.06 d	0.00E+00	0.00E+00	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.44E-01	1000	3302	7.43E-05
Total:	--	--	1.91E+06	2.00E+04	--	--	5831

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.
(b) Decayed radionuclide inventory information taken from Van Soest (2018).
(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.
(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

Table A-4. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 3033)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	9.59E+00	2.25E+00	--	--	--
Ac-227	B-A	21.772 y	1.57E+01	3.98E-02	100	330	4.75E-02
Ac-228	B-	6.15 h	9.60E-02	2.26E-02	--	--	--
Ag-108	B-ECB+	2.37 m	6.18E-07	2.19E-05	--	--	--
Ag-108m	ECIT	418 y	7.11E-06	2.52E-04	1000	3302	7.85E-08
Ag-109m	IT	39.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110	B-EC	24.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110m	B-IT	249.76 d	0.00E+00	0.00E+00	--	--	--
Am-241	A	432.2 y	2.40E+05	2.95E+03	100	330	7.36E+02
Am-242	B-EC	16.02 h	3.27E-02	3.46E-02	--	--	--
Am-242m	ITA	141 y	3.28E-02	3.48E-02	100	330	2.05E-04
Am-243	A	7.37E+3 y	2.04E+01	3.75E+02	100	330	1.20E+00
Am-245	B-	2.05 h	0.00E+00	0.00E+00	--	--	--
Am-246	B-	39 m	2.80E-08	5.65E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	3.63E-03	1000	3302	1.10E-06
Ar-42	B-	32.9 y	0.00E+00	6.16E-11	1000	3302	1.86E-14
At-217	A	3.23E-2 s	9.59E+00	2.25E+00	--	--	--
Ba-133	EC	10.52 y	5.60E-32	9.38E-29	--	--	--
Ba-137m	IT	2.552 m	5.36E-08	2.18E-05	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.03E-05	1000	3302	3.11E-09
Bi-210	B-A	5.013 d	2.57E+00	1.28E+01	--	--	--
Bi-211	A B-	2.14 m	1.57E+01	3.98E-02	--	--	--
Bi-212	B-A	60.55 m	1.18E-01	2.30E-02	--	--	--
Bi-213	B-A	45.59 m	9.59E+00	2.25E+00	--	--	--
Bi-214	B-A	19.9 m	2.57E+00	1.28E+01	--	--	--
Bk-249	B-A	330 d	0.00E+00	0.00E+00	--	--	--
Bk-250	B-	3.212 h	1.57E-08	3.17E-07	--	--	--
C-14	B-	5.70E+3 y	2.01E-02	4.73E+01	100	330	1.43E-01
Ca-45	B-	162.67 d	0.00E+00	0.00E+00	--	--	--
Cd-109	EC	461.4 d	0.00E+00	0.00E+00	--	--	--
Cd-113	B-	7.7E+15 y	4.14E-22	1.86E-17	1000	3302	5.65E-21
Cd-113m	B-IT	14.1 y	3.76E-26	1.48E-21	--	--	--
Ce-139	EC	137.641 d	0.00E+00	0.00E+00	--	--	--
Ce-144	B-	284.91 d	0.00E+00	0.00E+00	--	--	--
Cf-249	ASF	351 y	1.52E+00	5.16E+00	100	330	2.02E-02
Cf-250	ASF	13.08 y	1.57E-08	3.17E-07	--	--	--
Cf-251	A	900 y	4.65E-02	3.88E+00	100	330	1.19E-02
Cf-252	ASF	2.645 y	0.00E+00	0.00E+00	--	--	--
Cl-36	B-ECB+	3.01E+5 y	2.02E-07	0.00E+00	1000	3302	6.11E-11
Cm-242	ASF	162.8 d	2.70E-02	2.86E-02	--	--	--
Cm-243	AEC	29.1 y	6.94E-11	9.88E-10	100	330	3.20E-12
Cm-244	ASF	18.10 y	1.44E-13	7.74E-13	--	--	--

Table A-4. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 3033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-245	ASF	8.5E+3 y	3.10E+00	2.11E+01	100	330	7.32E-02
Cm-246	ASF	4.76E+3 y	4.70E+01	3.93E+02	100	330	1.33E+00
Cm-247	A	1.56E+7 y	3.34E-01	4.11E-02	100	330	1.14E-03
Cm-248	ASF	3.48E+5 y	4.62E-01	1.30E+00	100	330	5.35E-03
Cm-250	AB-SF	8300 y	1.12E-07	2.26E-06	100	330	7.19E-09
Co-60	B-	5.2713 y	0.00E+00	0.00E+00	--	--	--
Cs-134	B-EC	2.0648 y	0.00E+00	0.00E+00	--	--	--
Cs-135	B-	2.3E+6 y	1.67E-04	6.47E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	5.68E-08	2.31E-05	1000	3302	7.01E-09
Dy-159	EC	144.4 d	0.00E+00	0.00E+00	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	0.00E+00	--	--	--
Eu-149	EC	93.1 d	0.00E+00	0.00E+00	--	--	--
Eu-152	ECB+B-	13.537 y	3.33E-22	1.91E-21	--	--	--
Eu-154	B-EC	8.593 y	0.00E+00	0.00E+00	--	--	--
Eu-155	B-	4.7611 y	0.00E+00	0.00E+00	--	--	--
Fe-55	EC	2.737 y	0.00E+00	0.00E+00	--	--	--
Fr-221	A	4.9 m	9.59E+00	2.25E+00	--	--	--
Fr-223	B-A	22.00 m	2.16E-01	5.49E-04	--	--	--
Gd-152	A	1.08E+14 y	1.04E-12	7.08E-12	100	330	2.46E-14
Gd-153	EC	240.4 d	0.00E+00	0.00E+00	--	--	--
H-3	B-	12.32 y	1.10E-20	2.75E-21	--	--	--
Ho-166m	B-	1.20E+3 y	5.97E-04	1.65E-05	1000	3302	1.86E-07
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	0.00E+00	0.00E+00	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	0.00E+00	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	6.16E-11	--	--	--
Kr-85	B-	10.756 y	1.99E-29	4.42E-26	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	8.61E-07	1000	3302	2.61E-10
Lu-177	B-	6.647 d	0.00E+00	0.00E+00	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	0.00E+00	--	--	--
Mn-54	ECB+B-	312.12 d	0.00E+00	0.00E+00	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	4.49E-01	1000	3302	1.36E-04
Na-22	ECB+	2.6019 y	0.00E+00	0.00E+00	--	--	--
Nb-91	ECB+	680 y	0.00E+00	2.57E-02	1000	3302	7.79E-06
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.37E-03	6.14E-01	--	--	--
Nb-94	B-	2.03E+4 y	1.91E-03	4.20E+00	1000	3302	1.27E-03
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14
Ni-59	ECB+	1.01E+5 y	2.51E-02	5.11E+02	1000	3302	1.55E-01
Ni-63	B-	100.1 y	5.16E-03	8.52E-01	1000	3302	2.60E-04

Table A-4. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 3033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Np-235	ECA	396.1 d	0.00E+00	0.00E+00	--	--	--
Np-237	A	2.144E+6 y	2.19E+02	9.30E+00	100	330	6.93E-01
Np-238	B-	2.117 d	1.48E-04	1.56E-04	--	--	--
Np-239	B-	2.3565 d	2.04E+01	3.75E+02	--	--	--
Np-240	B-	61.9 m	6.96E-06	3.39E-05	--	--	--
Np-240m	B-IT	7.22 m	5.80E-03	2.82E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	0.00E+00	--	--	--
Os-194	B-	6.0 y	0.00E+00	0.00E+00	--	--	--
Pa-231	A	3.276E+4 y	1.56E+01	3.98E-02	100	330	4.75E-02
Pa-233	B-	26.967 d	2.19E+02	9.30E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	9.59E+00	2.25E+00	--	--	--
Pb-210	B-A	22.20 y	2.57E+00	1.28E+01	100	330	4.65E-02
Pb-211	B-	36.1 m	1.57E+01	3.98E-02	--	--	--
Pb-212	B-	10.64 h	1.18E-01	2.30E-02	--	--	--
Pb-214	B-	26.8 m	2.57E+00	1.28E+01	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	1.58E-17	--	--	--
Pm-146	ECB-	5.53 y	0.00E+00	0.00E+00	--	--	--
Pm-147	B-	2.6234 y	0.00E+00	0.00E+00	--	--	--
Po-210	A	138.376 d	2.57E+00	1.28E+01	--	--	--
Po-211	A	0.516 s	4.31E-02	1.09E-04	--	--	--
Po-212	A	2.99E-7 s	7.56E-02	1.48E-02	--	--	--
Po-213	A	4.2E-6 s	9.39E+00	2.20E+00	--	--	--
Po-214	A	1.643E-4 s	2.57E+00	1.28E+01	--	--	--
Po-215	A	1.781E-3 s	1.57E+01	3.98E-02	--	--	--
Po-216	A	0.145 s	1.18E-01	2.30E-02	--	--	--
Po-218	A B-	3.10 m	2.57E+00	1.28E+01	--	--	--
Pr-144	B-	17.28 m	0.00E+00	0.00E+00	--	--	--
Pr-144m	ITB-	7.2 m	0.00E+00	0.00E+00	--	--	--
Pu-236	ASF	2.858 y	0.00E+00	0.00E+00	--	--	--
Pu-238	ASF	87.7 y	3.48E+02	8.40E+00	100	330	1.08E+00
Pu-239	A	2.411E+4 y	8.45E+05	4.11E+03	100	330	2.57E+03
Pu-240	ASF	6564 y	2.85E+05	2.93E+03	100	330	8.71E+02
Pu-241	B-A	14.35 y	3.11E+00	2.11E+01	--	--	--
Pu-242	ASF	3.75E+5 y	1.48E+02	1.67E+01	100	330	4.97E-01
Pu-243	B-	4.956 h	3.34E-01	4.11E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.80E-03	2.83E-02	100	330	1.03E-04
Pu-246	B-	10.84 d	2.80E-08	5.65E-07	--	--	--
Ra-223	A	11.43 d	1.57E+01	3.98E-02	--	--	--
Ra-224	A	3.66 d	1.18E-01	2.30E-02	--	--	--

Table A-4. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 3033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-225	B-	14.9 d	9.59E+00	2.25E+00	--	--	--
Ra-226	A	1600 y	2.57E+00	1.28E+01	100	330	4.65E-02
Ra-228	B-	5.75 y	9.60E-02	2.26E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	0.00E+00	--	--	--
Rh-106	B-	29.80 s	0.00E+00	0.00E+00	--	--	--
Rn-219	A	3.96 s	1.57E+01	3.98E-02	--	--	--
Rn-220	A	55.6 s	1.18E-01	2.30E-02	--	--	--
Rn-222	A	3.8235 d	2.57E+00	1.28E+01	--	--	--
Ru-106	B-	373.59 d	0.00E+00	0.00E+00	--	--	--
S-35	B-	87.51 d	0.00E+00	0.00E+00	--	--	--
Sb-125	B-	2.75856 y	0.00E+00	0.00E+00	--	--	--
Sb-126	B-	12.35 d	1.17E-06	8.00E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.69E-05	1.21E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	0.00E+00	--	--	--
Se-75	EC	119.779 d	0.00E+00	0.00E+00	--	--	--
Se-79	B-	2.95E+5 y	6.89E-05	1.80E-01	1000	3302	5.45E-05
Sm-145	EC	340 d	0.00E+00	0.00E+00	--	--	--
Sm-146	A	1.03E+8 y	1.81E-13	7.13E-08	100	330	2.16E-10
Sm-147	A	1.060E11 y	1.24E-09	9.46E-08	100	330	2.90E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	5.73E-03	6.38E-02	1000	3302	2.11E-05
Sn-113	EC	115.09 d	0.00E+00	0.00E+00	--	--	--
Sn-119m	IT	293.1 d	0.00E+00	0.00E+00	--	--	--
Sn-121	B-	27.03 h	2.53E-10	1.15E-05	--	--	--
Sn-121m	ITB-	43.9 y	3.25E-10	1.48E-05	1000	3302	4.49E-09
Sn-123	B-	129.2 d	0.00E+00	0.00E+00	--	--	--
Sn-126	B-	2.30E+5 y	1.69E-05	1.21E-01	1000	3302	3.66E-05
Sr-90	B-	28.79 y	1.65E-08	3.95E-06	1000	3302	1.20E-09
Ta-182	B-	114.43 d	0.00E+00	0.00E+00	--	--	--
Tb-157	EC	71 y	0.00E+00	1.82E-03	1000	3302	5.50E-07
Tc-97	EC	2.6E+6 y	0.00E+00	1.69E-06	1000	3302	5.11E-10
Tc-97m	IT	90.1 d	0.00E+00	0.00E+00	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.39E-07	1000	3302	1.03E-10
Tc-99	B-	2.111E+5 y	4.54E+01	5.32E+02	10000	33017	1.75E-02
Te-121	EC	19.16 d	0.00E+00	0.00E+00	--	--	--
Te-121m	ITEC	154 d	0.00E+00	0.00E+00	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	0.00E+00	0.00E+00	--	--	--
Te-125m	IT	57.40 d	0.00E+00	0.00E+00	--	--	--
Te-127	B-	9.35 h	0.00E+00	0.00E+00	--	--	--
Te-127m	ITB-	109 d	0.00E+00	0.00E+00	--	--	--

Table A-4. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 3033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Th-227	A	18.68 d	1.54E+01	3.92E-02	--	--	--
Th-228	A	1.9116 y	1.18E-01	2.30E-02	--	--	--
Th-229	A	7.34E+3 y	9.59E+00	2.25E+00	100	330	3.59E-02
Th-230	A	7.538E+4 y	7.44E+00	2.39E+00	10	33	2.98E-01
Th-231	B-	25.52 h	5.41E+00	1.85E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	0.00E+00	0.00E+00	--	--	--
Tl-206	B-	4.200 m	3.39E-06	1.69E-05	--	--	--
Tl-207	B-	4.77 m	1.56E+01	3.97E-02	--	--	--
Tl-208	B-	3.053 m	4.24E-02	8.28E-03	--	--	--
Tl-209	B-	2.161 m	2.01E-01	4.73E-02	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	0.00E+00	--	--	--
Tm-171	B-	1.92 y	0.00E+00	0.00E+00	--	--	--
U-232	A	68.9 y	2.13E-02	4.32E-04	100	330	6.60E-05
U-233	A	1.592E+5 y	1.10E+02	1.72E+01	100	330	3.85E-01
U-234	A	2.455E+5 y	8.11E+02	1.77E+01	100	330	2.51E+00
U-235	A	7.04E+8 y	5.41E+00	1.85E+00	100	330	2.20E-02
U-236	A	2.342E+7 y	9.31E+00	3.44E-01	100	330	2.92E-02
U-237	B-	6.75 d	7.43E-05	5.04E-04	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.80E-03	2.82E-02	--	--	--
V-49	EC	330 d	0.00E+00	0.00E+00	--	--	--
W-181	EC	121.2 d	0.00E+00	0.00E+00	--	--	--
Y-90	B-	64.10 h	1.65E-08	3.95E-06	--	--	--
Zn-65	ECB+	244.06 d	0.00E+00	0.00E+00	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.44E-01	1000	3302	7.43E-05
Total:	--	--	1.37E+06	1.25E+04	--	--	4188

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.
(b) Decayed radionuclide inventory information taken from Van Soest (2018).
(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.
(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

Table A-5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 7033)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	3.98E+01	6.67E+00	--	--	--
Ac-227	B-A	21.772 y	1.50E+01	1.88E-01	100	330	4.59E-02
Ac-228	B-	6.15 h	9.60E-02	2.26E-02	--	--	--
Ag-108	B-ECB+	2.37 m	2.04E-16	7.24E-15	--	--	--
Ag-108m	ECIT	418 y	2.35E-15	8.32E-14	1000	3302	2.59E-17
Ag-109m	IT	39.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110	B-EC	24.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110m	B-IT	249.76 d	0.00E+00	0.00E+00	--	--	--
Am-241	A	432.2 y	3.97E+02	2.09E+01	100	330	1.27E+00
Am-242	B-EC	16.02 h	9.43E-11	9.99E-11	--	--	--
Am-242m	ITA	141 y	9.48E-11	1.00E-10	100	330	5.91E-13
Am-243	A	7.37E+3 y	1.41E+01	2.58E+02	100	330	8.23E-01
Am-245	B-	2.05 h	0.00E+00	0.00E+00	--	--	--
Am-246	B-	39 m	2.39E-08	4.82E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	1.21E-07	1000	3302	3.67E-11
Ar-42	B-	32.9 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
At-217	A	3.23E-2 s	3.98E+01	6.67E+00	--	--	--
Ba-133	EC	10.52 y	0.00E+00	0.00E+00	--	--	--
Ba-137m	IT	2.552 m	0.00E+00	0.00E+00	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.03E-05	1000	3302	3.11E-09
Bi-210	B-A	5.013 d	2.18E+01	4.52E+00	--	--	--
Bi-211	A B-	2.14 m	1.50E+01	1.88E-01	--	--	--
Bi-212	B-A	60.55 m	9.60E-02	2.26E-02	--	--	--
Bi-213	B-A	45.59 m	3.98E+01	6.67E+00	--	--	--
Bi-214	B-A	19.9 m	2.18E+01	4.52E+00	--	--	--
Bk-249	B-A	330 d	0.00E+00	0.00E+00	--	--	--
Bk-250	B-	3.212 h	1.34E-08	2.70E-07	--	--	--
C-14	B-	5.70E+3 y	1.24E-02	2.92E+01	100	330	8.83E-02
Ca-45	B-	162.67 d	0.00E+00	0.00E+00	--	--	--
Cd-109	EC	461.4 d	0.00E+00	0.00E+00	--	--	--
Cd-113	B-	7.7E+15 y	4.14E-22	1.86E-17	1000	3302	5.65E-21
Cd-113m	B-IT	14.1 y	0.00E+00	0.00E+00	--	--	--
Ce-139	EC	137.641 d	0.00E+00	0.00E+00	--	--	--
Ce-144	B-	284.91 d	0.00E+00	0.00E+00	--	--	--
Cf-249	ASF	351 y	5.56E-04	1.89E-03	100	330	7.42E-06
Cf-250	ASF	13.08 y	1.34E-08	2.70E-07	--	--	--
Cf-251	A	900 y	2.12E-03	1.77E-01	100	330	5.42E-04
Cf-252	ASF	2.645 y	0.00E+00	0.00E+00	--	--	--
Cl-36	B-ECB+	3.01E+5 y	2.00E-07	0.00E+00	1000	3302	6.06E-11
Cm-242	ASF	162.8 d	7.83E-11	8.29E-11	--	--	--
Cm-243	AEC	29.1 y	0.00E+00	0.00E+00	100	330	0.00E+00
Cm-244	ASF	18.10 y	0.00E+00	0.00E+00	--	--	--

Table A-5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 7033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-245	ASF	8.5E+3 y	2.29E+00	1.54E+01	100	330	5.34E-02
Cm-246	ASF	4.76E+3 y	2.61E+01	2.19E+02	100	330	7.42E-01
Cm-247	A	1.56E+7 y	3.34E-01	4.13E-02	100	330	1.14E-03
Cm-248	ASF	3.48E+5 y	4.58E-01	1.29E+00	100	330	5.31E-03
Cm-250	AB-SF	8300 y	9.55E-08	1.93E-06	100	330	6.13E-09
Co-60	B-	5.2713 y	0.00E+00	0.00E+00	--	--	--
Cs-134	B-EC	2.0648 y	0.00E+00	0.00E+00	--	--	--
Cs-135	B-	2.3E+6 y	1.66E-04	6.46E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Dy-159	EC	144.4 d	0.00E+00	0.00E+00	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	0.00E+00	--	--	--
Eu-149	EC	93.1 d	0.00E+00	0.00E+00	--	--	--
Eu-152	ECB+B-	13.537 y	0.00E+00	0.00E+00	--	--	--
Eu-154	B-EC	8.593 y	0.00E+00	0.00E+00	--	--	--
Eu-155	B-	4.7611 y	0.00E+00	0.00E+00	--	--	--
Fe-55	EC	2.737 y	0.00E+00	0.00E+00	--	--	--
Fr-221	A	4.9 m	3.98E+01	6.67E+00	--	--	--
Fr-223	B-A	22.00 m	2.06E-01	2.59E-03	--	--	--
Gd-152	A	1.08E+14 y	1.04E-12	7.08E-12	100	330	2.46E-14
Gd-153	EC	240.4 d	0.00E+00	0.00E+00	--	--	--
H-3	B-	12.32 y	0.00E+00	0.00E+00	--	--	--
Ho-166m	B-	1.20E+3 y	5.92E-05	1.63E-06	1000	3302	1.84E-08
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	0.00E+00	0.00E+00	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	0.00E+00	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	0.00E+00	--	--	--
Kr-85	B-	10.756 y	0.00E+00	0.00E+00	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	8.22E-07	1000	3302	2.49E-10
Lu-177	B-	6.647 d	0.00E+00	0.00E+00	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	0.00E+00	--	--	--
Mn-54	ECB+B-	312.12 d	0.00E+00	0.00E+00	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	2.03E-01	1000	3302	6.16E-05
Na-22	ECB+	2.6019 y	0.00E+00	0.00E+00	--	--	--
Nb-91	ECB+	680 y	0.00E+00	4.36E-04	1000	3302	1.32E-07
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.37E-03	4.11E-01	--	--	--
Nb-94	B-	2.03E+4 y	1.66E-03	3.66E+00	1000	3302	1.11E-03
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14
Ni-59	ECB+	1.01E+5 y	2.42E-02	4.93E+02	1000	3302	1.49E-01
Ni-63	B-	100.1 y	4.81E-15	7.96E-13	1000	3302	2.42E-16

Table A-5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 7033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Np-235	ECA	396.1 d	0.00E+00	0.00E+00	--	--	--
Np-237	A	2.144E+6 y	2.68E+02	9.91E+00	100	330	8.40E-01
Np-238	B-	2.117 d	4.27E-13	4.51E-13	--	--	--
Np-239	B-	2.3565 d	1.41E+01	2.58E+02	--	--	--
Np-240	B-	61.9 m	6.97E-06	3.39E-05	--	--	--
Np-240m	B-IT	7.22 m	5.81E-03	2.83E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	0.00E+00	--	--	--
Os-194	B-	6.0 y	0.00E+00	0.00E+00	--	--	--
Pa-231	A	3.276E+4 y	1.49E+01	1.88E-01	100	330	4.58E-02
Pa-233	B-	26.967 d	2.68E+02	9.91E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	3.98E+01	6.67E+00	--	--	--
Pb-210	B-A	22.20 y	2.18E+01	4.52E+00	100	330	7.97E-02
Pb-211	B-	36.1 m	1.50E+01	1.88E-01	--	--	--
Pb-212	B-	10.64 h	9.60E-02	2.26E-02	--	--	--
Pb-214	B-	26.8 m	2.18E+01	4.52E+00	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	0.00E+00	--	--	--
Pm-146	ECB-	5.53 y	0.00E+00	0.00E+00	--	--	--
Pm-147	B-	2.6234 y	0.00E+00	0.00E+00	--	--	--
Po-210	A	138.376 d	2.18E+01	4.52E+00	--	--	--
Po-211	A	0.516 s	4.11E-02	5.16E-04	--	--	--
Po-212	A	2.99E-7 s	6.15E-02	1.45E-02	--	--	--
Po-213	A	4.2E-6 s	3.89E+01	6.53E+00	--	--	--
Po-214	A	1.643E-4 s	2.18E+01	4.52E+00	--	--	--
Po-215	A	1.781E-3 s	1.50E+01	1.88E-01	--	--	--
Po-216	A	0.145 s	9.60E-02	2.26E-02	--	--	--
Po-218	A B-	3.10 m	2.18E+01	4.52E+00	--	--	--
Pr-144	B-	17.28 m	0.00E+00	0.00E+00	--	--	--
Pr-144m	ITB-	7.2 m	0.00E+00	0.00E+00	--	--	--
Pu-236	ASF	2.858 y	0.00E+00	0.00E+00	--	--	--
Pu-238	ASF	87.7 y	2.15E-10	2.21E-10	100	330	1.32E-12
Pu-239	A	2.411E+4 y	7.53E+05	3.70E+03	100	330	2.29E+03
Pu-240	ASF	6564 y	1.87E+05	1.92E+03	100	330	5.71E+02
Pu-241	B-A	14.35 y	2.29E+00	1.54E+01	--	--	--
Pu-242	ASF	3.75E+5 y	1.47E+02	1.88E+01	100	330	5.01E-01
Pu-243	B-	4.956 h	3.34E-01	4.13E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.82E-03	2.83E-02	100	330	1.03E-04
Pu-246	B-	10.84 d	2.39E-08	4.82E-07	--	--	--
Ra-223	A	11.43 d	1.50E+01	1.88E-01	--	--	--
Ra-224	A	3.66 d	9.60E-02	2.26E-02	--	--	--

Table A-5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 7033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-225	B-	14.9 d	3.98E+01	6.67E+00	--	--	--
Ra-226	A	1600 y	2.18E+01	4.52E+00	100	330	7.98E-02
Ra-228	B-	5.75 y	9.60E-02	2.26E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	0.00E+00	--	--	--
Rh-106	B-	29.80 s	0.00E+00	0.00E+00	--	--	--
Rn-219	A	3.96 s	1.50E+01	1.88E-01	--	--	--
Rn-220	A	55.6 s	9.60E-02	2.26E-02	--	--	--
Rn-222	A	3.8235 d	2.18E+01	4.52E+00	--	--	--
Ru-106	B-	373.59 d	0.00E+00	0.00E+00	--	--	--
S-35	B-	87.51 d	0.00E+00	0.00E+00	--	--	--
Sb-125	B-	2.75856 y	0.00E+00	0.00E+00	--	--	--
Sb-126	B-	12.35 d	1.14E-06	7.78E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.65E-05	1.18E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	0.00E+00	--	--	--
Se-75	EC	119.779 d	0.00E+00	0.00E+00	--	--	--
Se-79	B-	2.95E+5 y	6.83E-05	1.78E-01	1000	3302	5.40E-05
Sm-145	EC	340 d	0.00E+00	0.00E+00	--	--	--
Sm-146	A	1.03E+8 y	1.81E-13	7.13E-08	100	330	2.16E-10
Sm-147	A	1.060E11 y	1.24E-09	9.46E-08	100	330	2.90E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	2.38E-16	2.66E-15	1000	3302	8.76E-19
Sn-113	EC	115.09 d	0.00E+00	0.00E+00	--	--	--
Sn-119m	IT	293.1 d	0.00E+00	0.00E+00	--	--	--
Sn-121	B-	27.03 h	0.00E+00	0.00E+00	--	--	--
Sn-121m	ITB-	43.9 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Sn-123	B-	129.2 d	0.00E+00	0.00E+00	--	--	--
Sn-126	B-	2.30E+5 y	1.65E-05	1.18E-01	1000	3302	3.56E-05
Sr-90	B-	28.79 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Ta-182	B-	114.43 d	0.00E+00	0.00E+00	--	--	--
Tb-157	EC	71 y	0.00E+00	1.70E-11	1000	3302	5.16E-15
Tc-97	EC	2.6E+6 y	0.00E+00	1.69E-06	1000	3302	5.10E-10
Tc-97m	IT	90.1 d	0.00E+00	0.00E+00	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.39E-07	1000	3302	1.03E-10
Tc-99	B-	2.111E+5 y	4.48E+01	5.25E+02	10000	33017	1.73E-02
Te-121	EC	19.16 d	0.00E+00	0.00E+00	--	--	--
Te-121m	ITEC	154 d	0.00E+00	0.00E+00	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	0.00E+00	0.00E+00	--	--	--
Te-125m	IT	57.40 d	0.00E+00	0.00E+00	--	--	--
Te-127	B-	9.35 h	0.00E+00	0.00E+00	--	--	--
Te-127m	ITB-	109 d	0.00E+00	0.00E+00	--	--	--

Table A-5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 7033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Th-227	A	18.68 d	1.48E+01	1.85E-01	--	--	--
Th-228	A	1.9116 y	9.60E-02	2.26E-02	--	--	--
Th-229	A	7.34E+3 y	3.98E+01	6.67E+00	100	330	1.41E-01
Th-230	A	7.538E+4 y	3.63E+01	2.94E+00	10	33	1.19E+00
Th-231	B-	25.52 h	8.55E+00	1.87E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	0.00E+00	0.00E+00	--	--	--
Tl-206	B-	4.200 m	2.88E-05	5.96E-06	--	--	--
Tl-207	B-	4.77 m	1.49E+01	1.87E-01	--	--	--
Tl-208	B-	3.053 m	3.45E-02	8.12E-03	--	--	--
Tl-209	B-	2.161 m	8.35E-01	1.40E-01	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	0.00E+00	--	--	--
Tm-171	B-	1.92 y	0.00E+00	0.00E+00	--	--	--
U-232	A	68.9 y	1.20E-19	2.43E-21	100	330	3.71E-22
U-233	A	1.592E+5 y	1.13E+02	1.71E+01	100	330	3.93E-01
U-234	A	2.455E+5 y	8.02E+02	1.75E+01	100	330	2.48E+00
U-235	A	7.04E+8 y	8.55E+00	1.87E+00	100	330	3.16E-02
U-236	A	2.342E+7 y	3.68E+01	6.27E-01	100	330	1.13E-01
U-237	B-	6.75 d	5.47E-05	3.68E-04	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.81E-03	2.83E-02	--	--	--
V-49	EC	330 d	0.00E+00	0.00E+00	--	--	--
W-181	EC	121.2 d	0.00E+00	0.00E+00	--	--	--
Y-90	B-	64.10 h	0.00E+00	0.00E+00	--	--	--
Zn-65	ECB+	244.06 d	0.00E+00	0.00E+00	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.44E-01	1000	3302	7.42E-05
Total:	--	--	9.43E+05	7.64E+03	--	--	2873

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.
(b) Decayed radionuclide inventory information taken from Van Soest (2018).
(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.
(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

Table A-6. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 12,033)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ac-225	A	10.0 d	6.63E+01	1.03E+01	--	--	--
Ac-227	B-A	21.772 y	1.45E+01	3.57E-01	100	330	4.50E-02
Ac-228	B-	6.15 h	9.60E-02	2.26E-02	--	--	--
Ag-108	B-ECB+	2.37 m	2.87E-28	1.02E-26	--	--	--
Ag-108m	ECIT	418 y	3.30E-27	1.17E-25	1000	3302	3.64E-29
Ag-109m	IT	39.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110	B-EC	24.6 s	0.00E+00	0.00E+00	--	--	--
Ag-110m	B-IT	249.76 d	0.00E+00	0.00E+00	--	--	--
Am-241	A	432.2 y	1.65E+00	1.02E+01	100	330	3.60E-02
Am-242	B-EC	16.02 h	2.00E-21	2.11E-21	--	--	--
Am-242m	ITA	141 y	2.00E-21	2.12E-21	100	330	1.25E-23
Am-243	A	7.37E+3 y	8.94E+00	1.61E+02	100	330	5.15E-01
Am-245	B-	2.05 h	0.00E+00	0.00E+00	--	--	--
Am-246	B-	39 m	1.96E-08	3.95E-07	--	--	--
Ar-39	B-	269 y	0.00E+00	3.07E-13	1000	3302	9.31E-17
Ar-42	B-	32.9 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
At-217	A	3.23E-2 s	6.63E+01	1.03E+01	--	--	--
Ba-133	EC	10.52 y	0.00E+00	0.00E+00	--	--	--
Ba-137m	IT	2.552 m	0.00E+00	0.00E+00	--	--	--
Be-10	B-	1.51E+6 y	0.00E+00	1.02E-05	1000	3302	3.10E-09
Bi-210	B-A	5.013 d	5.50E+01	3.51E+00	--	--	--
Bi-211	A B-	2.14 m	1.45E+01	3.57E-01	--	--	--
Bi-212	B-A	60.55 m	9.60E-02	2.26E-02	--	--	--
Bi-213	B-A	45.59 m	6.63E+01	1.03E+01	--	--	--
Bi-214	B-A	19.9 m	5.50E+01	3.51E+00	--	--	--
Bk-249	B-A	330 d	0.00E+00	0.00E+00	--	--	--
Bk-250	B-	3.212 h	1.10E-08	2.21E-07	--	--	--
C-14	B-	5.70E+3 y	6.77E-03	1.59E+01	100	330	4.82E-02
Ca-45	B-	162.67 d	0.00E+00	0.00E+00	--	--	--
Cd-109	EC	461.4 d	0.00E+00	0.00E+00	--	--	--
Cd-113	B-	7.7E+15 y	4.14E-22	1.86E-17	1000	3302	5.65E-21
Cd-113m	B-IT	14.1 y	0.00E+00	0.00E+00	--	--	--
Ce-139	EC	137.641 d	0.00E+00	0.00E+00	--	--	--
Ce-144	B-	284.91 d	0.00E+00	0.00E+00	--	--	--
Cf-249	ASF	351 y	2.82E-08	9.59E-08	100	330	3.76E-10
Cf-250	ASF	13.08 y	1.10E-08	2.21E-07	--	--	--
Cf-251	A	900 y	4.47E-05	3.73E-03	100	330	1.14E-05
Cf-252	ASF	2.645 y	0.00E+00	0.00E+00	--	--	--
Cl-36	B-ECB+	3.01E+5 y	1.98E-07	0.00E+00	1000	3302	5.99E-11
Cm-242	ASF	162.8 d	1.66E-21	1.75E-21	--	--	--
Cm-243	AEC	29.1 y	0.00E+00	0.00E+00	100	330	0.00E+00
Cm-244	ASF	18.10 y	0.00E+00	0.00E+00	--	--	--

Table A-6. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 12033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Cm-245	ASF	8.5E+3 y	1.52E+00	1.02E+01	100	330	3.55E-02
Cm-246	ASF	4.76E+3 y	1.26E+01	1.05E+02	100	330	3.57E-01
Cm-247	A	1.56E+7 y	3.34E-01	4.13E-02	100	330	1.14E-03
Cm-248	ASF	3.48E+5 y	4.53E-01	1.28E+00	100	330	5.25E-03
Cm-250	AB-SF	8300 y	7.83E-08	1.58E-06	100	330	5.02E-09
Co-60	B-	5.2713 y	0.00E+00	0.00E+00	--	--	--
Cs-134	B-EC	2.0648 y	0.00E+00	0.00E+00	--	--	--
Cs-135	B-	2.3E+6 y	1.66E-04	6.45E-02	1000	3302	1.96E-05
Cs-137	B-	30.1671 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Dy-159	EC	144.4 d	0.00E+00	0.00E+00	--	--	--
Es-254	A B-SF	275.7 d	0.00E+00	0.00E+00	--	--	--
Eu-149	EC	93.1 d	0.00E+00	0.00E+00	--	--	--
Eu-152	ECB+B-	13.537 y	0.00E+00	0.00E+00	--	--	--
Eu-154	B-EC	8.593 y	0.00E+00	0.00E+00	--	--	--
Eu-155	B-	4.7611 y	0.00E+00	0.00E+00	--	--	--
Fe-55	EC	2.737 y	0.00E+00	0.00E+00	--	--	--
Fr-221	A	4.9 m	6.63E+01	1.03E+01	--	--	--
Fr-223	B-A	22.00 m	2.00E-01	4.93E-03	--	--	--
Gd-152	A	1.08E+14 y	1.04E-12	7.08E-12	100	330	2.46E-14
Gd-153	EC	240.4 d	0.00E+00	0.00E+00	--	--	--
H-3	B-	12.32 y	0.00E+00	0.00E+00	--	--	--
Ho-166m	B-	1.20E+3 y	3.30E-06	9.10E-08	1000	3302	1.03E-09
I-129	B-	1.57E+7 y	5.02E-03	8.30E-01	100	330	2.53E-03
In-113m	IT	1.6579 h	0.00E+00	0.00E+00	--	--	--
In-115	B-	4.41E+14 y	0.00E+00	1.33E-16	1000	3302	4.03E-20
Ir-194	B-	19.28 h	0.00E+00	0.00E+00	--	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	0.00E+00	1000	3302	1.21E-05
K-42	B-	12.360 h	0.00E+00	0.00E+00	--	--	--
Kr-85	B-	10.756 y	0.00E+00	0.00E+00	--	--	--
La-137	EC	6.0E+4 y	0.00E+00	7.76E-07	1000	3302	2.35E-10
Lu-177	B-	6.647 d	0.00E+00	0.00E+00	--	--	--
Lu-177m	B-IT	160.4 d	0.00E+00	0.00E+00	--	--	--
Mn-54	ECB+B-	312.12 d	0.00E+00	0.00E+00	--	--	--
Mo-93	EC	4.0E+3 y	0.00E+00	7.55E-02	1000	3302	2.29E-05
Na-22	ECB+	2.6019 y	0.00E+00	0.00E+00	--	--	--
Nb-91	ECB+	680 y	0.00E+00	2.66E-06	1000	3302	8.07E-10
Nb-92	EC	3.47E+7 y	0.00E+00	6.52E-08	1000	3302	1.98E-11
Nb-93m	IT	16.13 y	1.37E-03	3.05E-01	--	--	--
Nb-94	B-	2.03E+4 y	1.40E-03	3.09E+00	1000	3302	9.36E-04
Nd-144	A	2.29E+15 y	1.54E-13	8.52E-12	100	330	2.63E-14
Ni-59	ECB+	1.01E+5 y	2.31E-02	4.70E+02	1000	3302	1.42E-01
Ni-63	B-	100.1 y	4.42E-30	7.30E-28	1000	3302	2.23E-31

Table A-6. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 12033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)		Release Limit[c]		Potential Release[d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Np-235	ECA	396.1 d	0.00E+00	0.00E+00	--	--	--
Np-237	A	2.144E+6 y	2.67E+02	9.91E+00	100	330	8.39E-01
Np-238	B-	2.117 d	9.02E-24	9.55E-24	--	--	--
Np-239	B-	2.3565 d	8.94E+00	1.61E+02	--	--	--
Np-240	B-	61.9 m	6.99E-06	3.40E-05	--	--	--
Np-240m	B-IT	7.22 m	5.83E-03	2.83E-02	--	--	--
Os-185	EC	93.6 d	0.00E+00	0.00E+00	--	--	--
Os-194	B-	6.0 y	0.00E+00	0.00E+00	--	--	--
Pa-231	A	3.276E+4 y	1.45E+01	3.57E-01	100	330	4.50E-02
Pa-233	B-	26.967 d	2.67E+02	9.91E+00	--	--	--
Pa-234	B-	6.70 h	5.09E-02	4.07E-03	--	--	--
Pa-234m	B-IT	1.17 m	3.92E+01	3.13E+00	--	--	--
Pb-209	B-	3.253 h	6.63E+01	1.03E+01	--	--	--
Pb-210	B-A	22.20 y	5.50E+01	3.51E+00	100	330	1.77E-01
Pb-211	B-	36.1 m	1.45E+01	3.57E-01	--	--	--
Pb-212	B-	10.64 h	9.60E-02	2.26E-02	--	--	--
Pb-214	B-	26.8 m	5.50E+01	3.51E+00	--	--	--
Pd-107	B-	6.5E+6 y	3.30E-06	1.70E-02	1000	3302	5.16E-06
Pm-145	ECA	17.7 y	0.00E+00	0.00E+00	--	--	--
Pm-146	ECB-	5.53 y	0.00E+00	0.00E+00	--	--	--
Pm-147	B-	2.6234 y	0.00E+00	0.00E+00	--	--	--
Po-210	A	138.376 d	5.50E+01	3.51E+00	--	--	--
Po-211	A	0.516 s	3.99E-02	9.82E-04	--	--	--
Po-212	A	2.99E-7 s	6.15E-02	1.45E-02	--	--	--
Po-213	A	4.2E-6 s	6.49E+01	1.01E+01	--	--	--
Po-214	A	1.643E-4 s	5.50E+01	3.51E+00	--	--	--
Po-215	A	1.781E-3 s	1.45E+01	3.57E-01	--	--	--
Po-216	A	0.145 s	9.60E-02	2.26E-02	--	--	--
Po-218	A B-	3.10 m	5.50E+01	3.51E+00	--	--	--
Pr-144	B-	17.28 m	0.00E+00	0.00E+00	--	--	--
Pr-144m	ITB-	7.2 m	0.00E+00	0.00E+00	--	--	--
Pu-236	ASF	2.858 y	0.00E+00	0.00E+00	--	--	--
Pu-238	ASF	87.7 y	4.40E-21	4.66E-21	100	330	2.75E-23
Pu-239	A	2.411E+4 y	6.52E+05	3.23E+03	100	330	1.99E+03
Pu-240	ASF	6564 y	1.10E+05	1.13E+03	100	330	3.37E+02
Pu-241	B-A	14.35 y	1.52E+00	1.02E+01	--	--	--
Pu-242	ASF	3.75E+5 y	1.45E+02	2.00E+01	100	330	5.01E-01
Pu-243	B-	4.956 h	3.34E-01	4.13E-02	--	--	--
Pu-244	ASF	8.00E+7 y	5.84E-03	2.83E-02	100	330	1.04E-04
Pu-246	B-	10.84 d	1.96E-08	3.95E-07	--	--	--
Ra-223	A	11.43 d	1.45E+01	3.57E-01	--	--	--
Ra-224	A	3.66 d	9.60E-02	2.26E-02	--	--	--

Table A-6. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 12033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Ra-225	B-	14.9 d	6.63E+01	1.03E+01	--	--	--
Ra-226	A	1600 y	5.50E+01	3.51E+00	100	330	1.77E-01
Ra-228	B-	5.75 y	9.60E-02	2.26E-02	--	--	--
Rb-87	B-	4.923E10 y	1.80E-10	1.29E-06	1000	3302	3.91E-10
Rh-102	ECB+B-	207 d	0.00E+00	0.00E+00	--	--	--
Rh-106	B-	29.80 s	0.00E+00	0.00E+00	--	--	--
Rn-219	A	3.96 s	1.45E+01	3.57E-01	--	--	--
Rn-220	A	55.6 s	9.60E-02	2.26E-02	--	--	--
Rn-222	A	3.8235 d	5.50E+01	3.51E+00	--	--	--
Ru-106	B-	373.59 d	0.00E+00	0.00E+00	--	--	--
S-35	B-	87.51 d	0.00E+00	0.00E+00	--	--	--
Sb-125	B-	2.75856 y	0.00E+00	0.00E+00	--	--	--
Sb-126	B-	12.35 d	1.10E-06	7.51E-03	--	--	--
Sb-126m	B-IT	19.15 m	1.59E-05	1.14E-01	--	--	--
Sc-46	B-	83.79 d	0.00E+00	0.00E+00	--	--	--
Se-75	EC	119.779 d	0.00E+00	0.00E+00	--	--	--
Se-79	B-	2.95E+5 y	6.75E-05	1.76E-01	1000	3302	5.33E-05
Sm-145	EC	340 d	0.00E+00	0.00E+00	--	--	--
Sm-146	A	1.03E+8 y	1.81E-13	7.13E-08	100	330	2.16E-10
Sm-147	A	1.060E11 y	1.24E-09	9.46E-08	100	330	2.90E-10
Sm-148	A	7E+15 y	1.75E-16	9.12E-17	100	330	8.06E-19
Sm-151	B-	90 y	4.48E-33	4.99E-32	1000	3302	1.65E-35
Sn-113	EC	115.09 d	0.00E+00	0.00E+00	--	--	--
Sn-119m	IT	293.1 d	0.00E+00	0.00E+00	--	--	--
Sn-121	B-	27.03 h	0.00E+00	0.00E+00	--	--	--
Sn-121m	ITB-	43.9 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Sn-123	B-	129.2 d	0.00E+00	0.00E+00	--	--	--
Sn-126	B-	2.30E+5 y	1.59E-05	1.14E-01	1000	3302	3.44E-05
Sr-90	B-	28.79 y	0.00E+00	0.00E+00	1000	3302	0.00E+00
Ta-182	B-	114.43 d	0.00E+00	0.00E+00	--	--	--
Tb-157	EC	71 y	0.00E+00	1.57E-21	1000	3302	4.77E-25
Tc-97	EC	2.6E+6 y	0.00E+00	1.68E-06	1000	3302	5.10E-10
Tc-97m	IT	90.1 d	0.00E+00	0.00E+00	--	--	--
Tc-98	B-	4.2E+6 y	0.00E+00	3.38E-07	1000	3302	1.02E-10
Tc-99	B-	2.111E+5 y	4.41E+01	5.16E+02	10000	33017	1.70E-02
Te-121	EC	19.16 d	0.00E+00	0.00E+00	--	--	--
Te-121m	ITEC	154 d	0.00E+00	0.00E+00	--	--	--
Te-123	EC	6.00E+14 y	6.98E-22	3.41E-14	1000	3302	1.03E-17
Te-123m	IT	119.25 d	0.00E+00	0.00E+00	--	--	--
Te-125m	IT	57.40 d	0.00E+00	0.00E+00	--	--	--
Te-127	B-	9.35 h	0.00E+00	0.00E+00	--	--	--
Te-127m	ITB-	109 d	0.00E+00	0.00E+00	--	--	--

Table A-6. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste (Calendar Year = 12033) (continued)

Radionuclide			WIPP TRU Waste				
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)		Release Limit [c]		Potential Release [d] (EPA Units)
			CH	RH	(Ci/UW)	(Ci)	
Th-227	A	18.68 d	1.43E+01	3.52E-01	--	--	--
Th-228	A	1.9116 y	9.60E-02	2.26E-02	--	--	--
Th-229	A	7.34E+3 y	6.63E+01	1.03E+01	100	330	2.32E-01
Th-230	A	7.538E+4 y	7.05E+01	3.59E+00	10	33	2.24E+00
Th-231	B-	25.52 h	1.20E+01	1.89E+00	--	--	--
Th-232	A	1.405E10 y	9.60E-02	2.26E-02	10	33	3.59E-03
Th-234	B-	24.10 d	3.92E+01	3.13E+00	--	--	--
Tl-204	B-EC	3.78 y	0.00E+00	0.00E+00	--	--	--
Tl-206	B-	4.200 m	7.25E-05	4.63E-06	--	--	--
Tl-207	B-	4.77 m	1.45E+01	3.56E-01	--	--	--
Tl-208	B-	3.053 m	3.45E-02	8.12E-03	--	--	--
Tl-209	B-	2.161 m	1.39E+00	2.17E-01	--	--	--
Tm-170	B-EC	128.6 d	0.00E+00	0.00E+00	--	--	--
Tm-171	B-	1.92 y	0.00E+00	0.00E+00	--	--	--
U-232	A	68.9 y	0.00E+00	0.00E+00	100	330	0.00E+00
U-233	A	1.592E+5 y	1.16E+02	1.69E+01	100	330	4.02E-01
U-234	A	2.455E+5 y	7.91E+02	1.73E+01	100	330	2.45E+00
U-235	A	7.04E+8 y	1.20E+01	1.89E+00	100	330	4.21E-02
U-236	A	2.342E+7 y	5.82E+01	8.47E-01	100	330	1.79E-01
U-237	B-	6.75 d	3.64E-05	2.44E-04	--	--	--
U-238	ASF	4.468E+9 y	3.92E+01	3.13E+00	100	330	1.28E-01
U-240	B-	14.1 h	5.83E-03	2.83E-02	--	--	--
V-49	EC	330 d	0.00E+00	0.00E+00	--	--	--
W-181	EC	121.2 d	0.00E+00	0.00E+00	--	--	--
Y-90	B-	64.10 h	0.00E+00	0.00E+00	--	--	--
Zn-65	ECB+	244.06 d	0.00E+00	0.00E+00	--	--	--
Zr-93	B-	1.53E+6 y	1.37E-03	2.43E-01	1000	3302	7.40E-05
Total:	--	--	7.66E+05	6.04E+03	--	--	2331

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.
(b) Decayed radionuclide inventory information taken from Van Soest (2018).
(c) Release limits are determined in accordance with 40 CFR 191 (Appendix B, Table B-1). Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(c) of Table 1, Appendix A, 40 CFR 191). Right column corresponds to release limit obtained for 3.30 units of waste. The 3.30 value for the unit of waste corresponds to the units of waste present at repository closure in 2033.
(d) Potential release is defined as the total inventory (CH + RH) in Ci divided by the release limit in Ci. Those isotopes without defined release limits have no potential release.

APPENDIX B – 40 CFR 191 Release Limits and Unit of Waste for WIPP-Scale TRU Waste

Table B-1. 40 CFR 191 Release Limits for Containment Requirements [a]

[Cumulative releases to the accessible environment for 10,000 years after disposal]	
Radionuclide	**Release Limit per 1,000 metric tons of heavy metal or other unit of waste [(b)] (see notes) [(c)] (curies)**
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or –232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000
NOTE **1**: *Units of Waste*. The Release Limits in Table 1 [of Appendix A of 40 CFR 191] apply to the amount of wastes in any one of the following: (e) An amount of transuranic wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.	

(a) Based on Table 1 of Appendix A of 40 CFR 191.
(b) Notes 1(a) through 1(d) of Table 1 from Appendix A of 40 CFR 191 do not apply to TRU waste and are not shown here. Only TRU wastes are allowed in the WIPP facility, thus only Note 1(e) should be used for identification of the "unit of waste" value. Also, alpha, beta and gamma emitting radionuclides with half-lives greater than 20 years all contribute to the "release limits".
(c) Notes 2 through 6 of Table 1 from Appendix A of 40 CFR191 are not shown here.

Table B-2. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste

Radionuclide			WIPP TRU Waste							
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)						Transuranic Inventory [c] (Ci)	% of Unit of Waste
			2033	2133	2383	3033	7033	12033	2033	2033
Ac-225	A	10.0 d	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Ac-227	B-A	21.772 y	2.59E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--
Ac-228	B-	6.15 h	1.36E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	--	--
Ag-108	B-ECB+	2.37 m	5.29E-03	3.07E-03	7.83E-04	2.26E-05	7.44E-15	1.05E-26	--	--
Ag-108m	ECIT	418 y	6.08E-02	3.52E-02	9.00E-03	2.59E-04	8.55E-14	1.20E-25	--	--
Ag-109m	IT	39.6 s	1.10E-03	1.88E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Ag-110	B-EC	24.6 s	8.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Ag-110m	B-IT	249.76 d	6.59E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Am-241	**A**	**432.2 y**	**1.14E+06**	**1.03E+06**	**6.89E+05**	**2.43E+05**	**4.18E+02**	**1.19E+01**	**1.14E+06**	**34.61%**
Am-242	B-EC	16.02 h	9.18E+00	5.62E+00	1.64E+00	6.73E-02	1.94E-10	4.11E-21	--	--
Am-242m	**ITA**	**141 y**	**9.23E+00**	**5.64E+00**	**1.65E+00**	**6.76E-02**	**1.95E-10**	**4.13E-21**	**9.23E+00**	**0.00%**
Am-243	**A**	**7.37E+3 y**	**4.35E+02**	**4.31E+02**	**4.21E+02**	**3.96E+02**	**2.72E+02**	**1.70E+02**	**4.35E+02**	**0.01%**
Am-245	B-	2.05 h	6.18E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Am-246	B-	39 m	6.18E-07	6.15E-07	6.09E-07	5.93E-07	5.06E-07	4.15E-07	--	--
Ar-39	B-	269 y	4.78E-02	3.69E-02	1.94E-02	3.63E-03	1.21E-07	3.07E-13	--	--
Ar-42	B-	32.9 y	8.75E-02	1.06E-02	5.48E-05	6.16E-11	0.00E+00	0.00E+00	--	--
At-217	A	3.23E-2 s	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Ba-133	EC	10.52 y	3.88E+00	5.33E-03	3.74E-10	9.39E-29	0.00E+00	0.00E+00	--	--
Ba-137m	IT	2.552 m	2.37E+05	2.35E+04	7.29E+01	2.18E-05	0.00E+00	0.00E+00	--	--
Be-10	B-	1.51E+6 y	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.02E-05	--	--
Bi-210	B-A	5.013 d	1.55E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Bi-211	A B-	2.14 m	2.60E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--
Bi-212	B-A	60.55 m	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Bi-213	B-A	45.59 m	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Bi-214	B-A	19.9 m	2.02E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Bk-249	B-A	330 d	4.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Bk-250	B-	3.212 h	3.46E-07	3.44E-07	3.41E-07	3.32E-07	2.83E-07	2.32E-07	--	--
C-14	B-	5.70E+3 y	5.34E+01	5.28E+01	5.12E+01	4.73E+01	2.92E+01	1.59E+01	--	--
Ca-45	B-	162.67 d	1.05E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Cd-109	EC	461.4 d	1.10E-03	1.88E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Cd-113	B-	7.7E+15 y	1.16E-17	1.86E-17	1.86E-17	1.86E-17	1.86E-17	1.86E-17	--	--
Cd-113m	B-IT	14.1 y	3.33E+00	2.44E-02	1.12E-07	1.48E-21	0.00E+00	0.00E+00	--	--
Ce-139	EC	137.641 d	1.02E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Ce-144	B-	284.91 d	6.76E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Cf-249	**ASF**	**351 y**	**4.83E+01**	**3.96E+01**	**2.42E+01**	**6.68E+00**	**2.45E-03**	**1.24E-07**	**4.83E+01**	**0.00%**
Cf-250	ASF	13.08 y	1.29E+02	6.43E-01	1.48E-06	3.32E-07	2.83E-07	2.32E-07	--	--
Cf-251	**A**	**900 y**	**8.49E+00**	**7.86E+00**	**6.48E+00**	**3.93E+00**	**1.79E-01**	**3.77E-03**	**8.49E+00**	**0.00%**
Cf-252	ASF	2.645 y	2.26E+00	9.40E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Cl-36	B-ECB+	3.01E+5 y	2.02E-07	2.02E-07	2.02E-07	2.02E-07	2.00E-07	1.98E-07	--	--
Cm-242	ASF	162.8 d	7.60E+00	4.65E+00	1.36E+00	5.57E-02	1.61E-10	3.41E-21	--	--
Cm-243	**AEC**	**29.1 y**	**3.87E+01**	**3.40E+00**	**7.77E-03**	**1.06E-09**	**0.00E+00**	**0.00E+00**	**3.87E+01**	**0.00%**

Table B-2. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste (continued)

Radionuclide			WIPP TRU Waste							
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)						Transuranic Inventory [c] (Ci)	% of Unit of Waste
			2033	2133	2383	3033	7033	12033	2033	2133
Cm-244	ASF	18.10 y	3.94E+04	8.55E+02	5.94E-02	9.18E-13	0.00E+00	0.00E+00	--	--
Cm-245	**ASF**	**8.5E+3 y**	**2.44E+01**	**2.46E+01**	**2.47E+01**	**2.42E+01**	**1.76E+01**	**1.17E+01**	**2.44E+01**	**0.00%**
Cm-246	**ASF**	**4.76E+3 y**	**5.10E+02**	**5.02E+02**	**4.84E+02**	**4.40E+02**	**2.45E+02**	**1.18E+02**	**5.10E+02**	**0.02%**
Cm-247	**A**	**1.56E+7 y**	**3.75E-01**	**3.75E-01**	**3.75E-01**	**3.75E-01**	**3.75E-01**	**3.75E-01**	**3.75E-01**	**0.00%**
Cm-248	**ASF**	**3.48E+5 y**	**1.77E+00**	**1.77E+00**	**1.77E+00**	**1.77E+00**	**1.75E+00**	**1.73E+00**	**1.77E+00**	**0.00%**
Cm-250	**AB-SF**	**8300 y**	**2.47E-06**	**2.46E-06**	**2.44E-06**	**2.37E-06**	**2.02E-06**	**1.66E-06**	**2.47E-06**	**0.00%**
Co-60	B-	5.2713 y	3.80E+02	7.36E-04	3.84E-18	0.00E+00	0.00E+00	0.00E+00	--	--
Cs-134	B-EC	2.0648 y	1.08E+01	2.72E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Cs-135	B-	2.3E+6 y	6.48E-02	6.48E-02	6.48E-02	6.48E-02	6.47E-02	6.46E-02	--	--
Cs-137	B-	30.1671 y	2.51E+05	2.49E+04	7.71E+01	2.31E-05	0.00E+00	0.00E+00	--	--
Dy-159	EC	144.4 d	4.60E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Es-254	A B-SF	275.7 d	4.19E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Eu-149	EC	93.1 d	6.03E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Eu-152	ECB+B-	13.537 y	8.67E+01	4.78E-01	1.08E-06	2.24E-21	0.00E+00	0.00E+00	--	--
Eu-154	B-EC	8.593 y	2.31E+03	7.23E-01	1.25E-09	0.00E+00	0.00E+00	0.00E+00	--	--
Eu-155	B-	4.7611 y	1.84E+02	6.81E-05	5.65E-21	0.00E+00	0.00E+00	0.00E+00	--	--
Fe-55	EC	2.737 y	6.46E+01	6.05E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Fr-221	A	4.9 m	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Fr-223	B-A	22.00 m	3.58E-01	2.25E-01	2.18E-01	2.17E-01	2.09E-01	2.05E-01	--	--
Gd-152	A	1.08E+14 y	5.13E-12	8.10E-12	8.12E-12	8.12E-12	8.12E-12	8.12E-12	--	--
Gd-153	EC	240.4 d	8.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
H-3	B-	12.32 y	3.59E+04	1.30E+02	1.02E-04	1.38E-20	0.00E+00	0.00E+00	--	--
Ho-166m	B-	1.20E+3 y	1.09E-03	1.03E-03	8.93E-04	6.14E-04	6.09E-05	3.39E-06	--	--
I-129	B-	1.57E+7 y	8.35E-01	8.35E-01	8.35E-01	8.35E-01	8.35E-01	8.35E-01	--	--
In-113m	IT	1.6579 h	1.01E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
In-115	B-	4.41E+14 y	1.33E-16	1.33E-16	1.33E-16	1.33E-16	1.33E-16	1.33E-16	--	--
Ir-194	B-	19.28 h	1.02E-02	9.74E-08	2.77E-20	0.00E+00	0.00E+00	0.00E+00	--	--
K-40	B-ECB+	1.251E+9 y	4.00E-02	4.00E-02	4.00E-02	4.00E-02	4.00E-02	4.00E-02	--	--
K-42	B-	12.360 h	8.75E-02	1.06E-02	5.48E-05	6.16E-11	0.00E+00	0.00E+00	--	--
Kr-85	B-	10.756 y	5.35E+02	8.32E-01	7.94E-08	4.42E-26	0.00E+00	0.00E+00	--	--
La-137	EC	6.0E+4 y	8.71E-07	8.70E-07	8.68E-07	8.61E-07	8.22E-07	7.76E-07	--	--
Lu-177	B-	6.647 d	2.66E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Lu-177m	B-IT	160.4 d	1.21E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Mn-54	ECB+B-	312.12 d	4.19E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Mo-93	EC	4.0E+3 y	5.47E-01	5.37E-01	5.11E-01	4.49E-01	2.03E-01	7.55E-02	--	--
Na-22	ECB+	2.6019 y	3.39E-02	9.11E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Nb-91	ECB+	680 y	7.12E-02	6.43E-02	4.99E-02	2.57E-02	4.36E-04	2.66E-06	--	--
Nb-92	EC	3.47E+7 y	6.52E-08	6.52E-08	6.52E-08	6.52E-08	6.52E-08	6.52E-08	--	--
Nb-93m	IT	16.13 y	3.66E+00	7.28E-01	6.66E-01	6.15E-01	4.12E-01	3.07E-01	--	--
Nb-94	B-	2.03E+4 y	4.35E+00	4.33E+00	4.29E+00	4.20E+00	3.66E+00	3.09E+00	--	--
Nd-144	A	2.29E+15 y	8.68E-12	8.68E-12	8.68E-12	8.68E-12	8.68E-12	8.68E-12	--	--
Ni-59	ECB+	1.01E+5 y	5.16E+02	5.15E+02	5.14E+02	5.11E+02	4.93E+02	4.70E+02	--	--

Table B-2. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste (continued)

Radionuclide			WIPP TRU Waste							
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)						Transuranic Inventory [c] (Ci)	% of Unit of Waste
			2033	2133	2383	3033	7033	12033	2033	2133
Ni-63	B-	100.1 y	8.72E+02	4.36E+02	7.73E+01	8.57E-01	8.01E-13	7.35E-28	--	--
Np-235	ECA	396.1 d	2.57E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Np-237	**A**	**2.144E+6 y**	**3.44E+01**	**7.01E+01**	**1.39E+02**	**2.29E+02**	**2.77E+02**	**2.77E+02**	**3.44E+01**	**0.00%**
Np-238	B-	2.117 d	4.15E-02	2.54E-02	7.43E-03	3.04E-04	8.78E-13	1.86E-23	--	--
Np-239	B-	2.3565 d	4.35E+02	4.31E+02	4.21E+02	3.96E+02	2.72E+02	1.70E+02	--	--
Np-240	B-	61.9 m	4.08E-05	4.08E-05	4.08E-05	4.08E-05	4.09E-05	4.10E-05	--	--
Np-240m	B-IT	7.22 m	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.41E-02	3.41E-02	--	--
Os-185	EC	93.6 d	1.77E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Os-194	B-	6.0 y	1.02E-02	9.74E-08	2.76E-20	0.00E+00	0.00E+00	0.00E+00	--	--
Pa-231	A	3.276E+4 y	1.59E+01	1.59E+01	1.58E+01	1.57E+01	1.51E+01	1.48E+01	--	--
Pa-233	B-	26.967 d	3.44E+01	7.01E+01	1.39E+02	2.29E+02	2.77E+02	2.77E+02	--	--
Pa-234	B-	6.70 h	5.50E-02	5.50E-02	5.50E-02	5.50E-02	5.50E-02	5.50E-02	--	--
Pa-234m	B-IT	1.17 m	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	--	--
Pb-209	B-	3.253 h	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Pb-210	B-A	22.20 y	1.55E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Pb-211	B-	36.1 m	2.60E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--
Pb-212	B-	10.64 h	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Pb-214	B-	26.8 m	2.02E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Pd-107	B-	6.5E+6 y	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	--	--
Pm-145	ECA	17.7 y	1.61E+00	3.21E-02	1.80E-06	1.58E-17	0.00E+00	0.00E+00	--	--
Pm-146	ECB-	5.53 y	5.26E-01	1.89E-06	4.64E-20	0.00E+00	0.00E+00	0.00E+00	--	--
Pm-147	B-	2.6234 y	2.59E+01	8.66E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Po-210	A	138.376 d	1.55E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Po-211	A	0.516 s	7.14E-02	4.48E-02	4.35E-02	4.32E-02	4.17E-02	4.08E-02	--	--
Po-212	A	2.99E-7 s	2.94E+02	1.09E+02	9.19E+00	9.03E-02	7.60E-02	7.60E-02	--	--
Po-213	A	4.2E-6 s	1.23E+00	2.31E+00	4.96E+00	1.16E+01	4.54E+01	7.50E+01	--	--
Po-214	A	1.643E-4 s	2.02E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Po-215	A	1.781E-3 s	2.60E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--
Po-216	A	0.145 s	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Po-218	A B-	3.10 m	2.03E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Pr-144	B-	17.28 m	6.76E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Pr-144m	ITB-	7.2 m	9.46E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Pu-236	ASF	2.858 y	6.65E-02	2.77E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Pu-238	**ASF**	**87.7 y**	**9.64E+05**	**4.38E+05**	**6.07E+04**	**3.57E+02**	**4.35E-10**	**9.06E-21**	**9.64E+05**	**29.21%**
Pu-239	**A**	**2.411E+4 y**	**8.74E+05**	**8.72E+05**	**8.65E+05**	**8.49E+05**	**7.57E+05**	**6.56E+05**	**8.74E+05**	**26.47%**
Pu-240	**ASF**	**6564 y**	**3.19E+05**	**3.16E+05**	**3.08E+05**	**2.88E+05**	**1.88E+05**	**1.11E+05**	**3.19E+05**	**9.67%**
Pu-241	B-A	14.35 y	1.87E+06	1.49E+04	2.49E+01	2.42E+01	1.77E+01	1.18E+01	--	--
Pu-242	**ASF**	**3.75E+5 y**	**1.64E+02**	**1.64E+02**	**1.64E+02**	**1.64E+02**	**1.65E+02**	**1.66E+02**	**1.64E+02**	**0.00%**
Pu-243	B-	4.956 h	3.75E-01	3.75E-01	3.75E-01	3.75E-01	3.75E-01	3.75E-01	--	--
Pu-244	**ASF**	**8.00E+7 y**	**3.40E-02**	**3.40E-02**	**3.40E-02**	**3.41E-02**	**3.41E-02**	**3.42E-02**	**3.40E-02**	**0.00%**
Pu-246	B-	10.84 d	6.18E-07	6.15E-07	6.09E-07	5.93E-07	5.06E-07	4.15E-07	--	--
Ra-223	A	11.43 d	2.60E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--

Table B-2. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste (continued)

Radionuclide			WIPP TRU Waste							
ID	Decay Mode [a]	Half-Life [a]	Total Inventory [b] (Ci)						Transuranic Inventory [c] (Ci)	% of Unit of Waste
			2033	2133	2383	3033	7033	12033	2033	2133
Ra-224	A	3.66 d	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Ra-225	B-	14.9 d	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Ra-226	A	1600 y	2.03E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Ra-228	B-	5.75 y	1.36E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	--	--
Rb-87	B-	4.923E10 y	1.29E-06	1.29E-06	1.29E-06	1.29E-06	1.29E-06	1.29E-06	--	--
Rh-102	ECB+B-	207 d	1.30E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Rh-106	B-	29.80 s	2.12E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Rn-219	A	3.96 s	2.60E+01	1.63E+01	1.58E+01	1.57E+01	1.51E+01	1.49E+01	--	--
Rn-220	A	55.6 s	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Rn-222	A	3.8235 d	2.03E+01	1.95E+01	1.79E+01	1.54E+01	2.63E+01	5.85E+01	--	--
Ru-106	B-	373.59 d	2.12E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
S-35	B-	87.51 d	6.34E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sb-125	B-	2.75856 y	1.52E+01	1.42E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sb-126	B-	12.35 d	8.05E-03	8.05E-03	8.03E-03	8.00E-03	7.78E-03	7.51E-03	--	--
Sb-126m	B-IT	19.15 m	1.22E-01	1.22E-01	1.21E-01	1.21E-01	1.18E-01	1.14E-01	--	--
Sc-46	B-	83.79 d	6.10E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Se-75	EC	119.779 d	1.05E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Se-79	B-	2.95E+5 y	1.80E-01	1.80E-01	1.80E-01	1.80E-01	1.78E-01	1.76E-01	--	--
Sm-145	EC	340 d	1.08E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sm-146	A	1.03E+8 y	6.18E-08	7.13E-08	7.13E-08	7.13E-08	7.13E-08	7.13E-08	--	--
Sm-147	A	1.060E11 y	9.52E-08	9.59E-08	9.59E-08	9.59E-08	9.59E-08	9.59E-08	--	--
Sm-148	A	7E+15 y	2.66E-16	2.66E-16	2.66E-16	2.66E-16	2.66E-16	2.66E-16	--	--
Sm-151	B-	90 y	1.54E+02	7.13E+01	1.04E+01	6.96E-02	2.89E-15	5.43E-32	--	--
Sn-113	EC	115.09 d	1.01E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sn-119m	IT	293.1 d	5.50E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sn-121	B-	27.03 h	3.42E+00	9.69E-01	4.15E-02	1.15E-05	0.00E+00	0.00E+00	--	--
Sn-121m	ITB-	43.9 y	4.40E+00	1.25E+00	5.35E-02	1.48E-05	0.00E+00	0.00E+00	--	--
Sn-123	B-	129.2 d	1.37E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Sn-126	B-	2.30E+5 y	1.22E-01	1.22E-01	1.21E-01	1.21E-01	1.18E-01	1.14E-01	--	--
Sr-90	B-	28.79 y	1.97E+05	1.68E+04	3.55E+01	3.97E-06	0.00E+00	0.00E+00	--	--
Ta-182	B-	114.43 d	9.08E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Tb-157	EC	71 y	1.84E-01	1.16E-01	3.66E-02	1.82E-03	1.70E-11	1.57E-21	--	--
Tc-97	EC	2.6E+6 y	1.69E-06	1.69E-06	1.69E-06	1.69E-06	1.69E-06	1.68E-06	--	--
Tc-97m	IT	90.1 d	2.46E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Tc-98	B-	4.2E+6 y	3.39E-07	3.39E-07	3.39E-07	3.39E-07	3.39E-07	3.38E-07	--	--
Tc-99	B-	2.111E+5 y	5.79E+02	5.79E+02	5.78E+02	5.77E+02	5.70E+02	5.60E+02	--	--
Te-121	EC	19.16 d	4.02E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Te-121m	ITEC	154 d	4.04E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Te-123	EC	6.00E+14 y	3.41E-14	3.41E-14	3.41E-14	3.41E-14	3.41E-14	3.41E-14	--	--
Te-123m	IT	119.25 d	2.57E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Te-125m	IT	57.40 d	3.71E+00	3.48E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Te-127	B-	9.35 h	9.30E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--

Table B-2. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste (continued)

Radionuclide			WIPP TRU Waste							
ID	Decay Mode[a]	Half-Life[a]	Total Inventory[b] (Ci)						Transuranic Inventory[c] (Ci)	% of Unit of Waste
			2033	2133	2383	3033	7033	12033	2033	2133
Te-127m	ITB-	109 d	9.49E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Th-227	A	18.68 d	2.56E+01	1.61E+01	1.56E+01	1.55E+01	1.49E+01	1.46E+01	--	--
Th-228	A	1.9116 y	4.59E+02	1.70E+02	1.44E+01	1.41E-01	1.19E-01	1.19E-01	--	--
Th-229	A	7.34E+3 y	1.25E+00	2.36E+00	5.07E+00	1.18E+01	4.64E+01	7.66E+01	--	--
Th-230	A	7.538E+4 y	2.66E+00	3.20E+00	4.94E+00	9.83E+00	3.92E+01	7.40E+01	--	--
Th-231	B-	25.52 h	6.41E+00	6.50E+00	6.71E+00	7.26E+00	1.04E+01	1.39E+01	--	--
Th-232	A	1.405E10 y	1.19E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	1.19E-01	--	--
Th-234	B-	24.10 d	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	--	--
Tl-204	B-EC	3.78 y	1.32E-08	1.43E-16	1.77E-36	0.00E+00	0.00E+00	0.00E+00	--	--
Tl-206	B-	4.200 m	2.04E-05	2.58E-05	2.37E-05	2.03E-05	3.47E-05	7.72E-05	--	--
Tl-207	B-	4.77 m	2.59E+01	1.62E+01	1.58E+01	1.57E+01	1.51E+01	1.48E+01	--	--
Tl-208	B-	3.053 m	1.65E+02	6.13E+01	5.16E+00	5.07E-02	4.26E-02	4.26E-02	--	--
Tl-209	B-	2.161 m	2.63E-02	4.95E-02	1.06E-01	2.49E-01	9.75E-01	1.61E+00	--	--
Tm-170	B-EC	128.6 d	3.99E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Tm-171	B-	1.92 y	7.37E-03	1.55E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
U-232	A	68.9 y	4.47E+02	1.66E+02	1.38E+01	2.18E-02	1.22E-19	0.00E+00	--	--
U-233	A	1.592E+5 y	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.30E+02	1.33E+02	--	--
U-234	A	2.455E+5 y	4.86E+02	6.74E+02	8.08E+02	8.28E+02	8.20E+02	8.09E+02	--	--
U-235	A	7.04E+8 y	6.41E+00	6.50E+00	6.71E+00	7.26E+00	1.04E+01	1.39E+01	--	--
U-236	A	2.342E+7 y	6.77E-01	1.62E+00	3.93E+00	9.65E+00	3.74E+01	5.91E+01	--	--
U-237	B-	6.75 d	4.47E+01	3.57E-01	5.94E-04	5.78E-04	4.22E-04	2.81E-04	--	--
U-238	ASF	4.468E+9 y	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	4.23E+01	--	--
U-240	B-	14.1 h	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.41E-02	3.41E-02	--	--
V-49	EC	330 d	1.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
W-181	EC	121.2 d	1.77E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Y-90	B-	64.10 h	1.97E+05	1.68E+04	3.55E+01	3.97E-06	0.00E+00	0.00E+00	--	--
Zn-65	ECB+	244.06 d	6.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	--	--
Zr-93	B-	1.53E+6 y	2.45E-01	2.45E-01	2.45E-01	2.45E-01	2.45E-01	2.44E-01	--	--
Total (Ci)	--	--	**6.14E+06**	**2.76E+06**	**1.93E+06**	**1.38E+06**	**9.50E+05**	**7.72E+05**	**3.30E+06**	**100%**
								WUF =	**3.30**	

(a) Decay mode and half-life information taken from the International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life units include s = second, m = minute, h = hour, d = day, and y = year.

(b) Decayed radionuclide inventory information taken from Van Soest (2018). The inventory information given has been decayed through 2033.

(c) Transuranic inventory data corresponds to the activity (Ci) data only for radionuclides that are categorized as "transuranic waste" per definitions in 40 CFR 191.

APPENDIX C – Decay Heat Contributions to Radiolysis

From the screening analysis (see Section 4), it is determined that the decay heat from only five radionuclides is sufficient to account for over 96% of the total decay heat at closure and over 99% at 100 years past closure and beyond (Table C-1). Four radionuclides (^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu) account for nearly all of the total decay at a given time. ^{242}Pu is added so that all tracked Pu isotopes are included for a correct isotope fraction calculation. Note that ^{241}Pu is not included because it has a half-life less than 20 years and it is not a regulated isotope. The heat generated by the progeny of the five selected radionuclides is neglected because each decays to a long-lived radionuclide, and those daughters have much smaller molar powers. Radionuclide disintegration energy, decay heat specific power, and specific activity used in the screening analysis are given in Table C-2. Inventories given in the PAIR (Van Soest 2018) and calculated wattages at calendar years 2033, 2133, and 12033 are tabulated in Table C-3 through Table C-5.

Table C-1. Calculated Wattage Summary for Five Radionuclides

Radionuclide	Wattage Fraction by Calendar Year (%)		
	2033	2133	12033
Am-241	34.26	39.85	0.00
Pu-238	28.69	16.84	0.00
Pu-239	24.38	31.44	85.17
Pu-240	8.93	11.43	14.47
Pu-242	0.00	0.01	0.02
Total	**96.25**	**99.57**	**99.65**

NOTE: The calculation of wattage fraction is documented in Table C-3 through Table C-5.

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Ac-225	A	864000	225.0232286	5.9338	2.04E+03	5.80E+04
Ac-227	B-A	687057480	227.0277507	0.0853	3.66E-02	7.23E+01
Ac-228	B-	22140	228.0310198	1.3166	1.74E+04	2.23E+06
Ag-108	B-ECB+	142.2	107.9059503	0.6256	2.73E+06	7.35E+08
Ag-108m	ECIT	13190796740	107.9059503	1.6368	7.69E-02	7.93E+00
Ag-109m	IT	39.6	108.9047558	0.088	1.36E+06	2.62E+09
Ag-110	B-EC	24.6	109.9061107	1.2119	3.00E+07	4.17E+09
Ag-110m	B-IT	21579264	109.9061107	2.8363	8.00E+01	4.76E+03
Am-241	A	13638905146	241.0568274	5.6379	1.15E-01	3.43E+00
Am-242	B-EC	57672	242.0595474	0.1994	9.55E+02	8.08E+05
Am-242m	ITA	4449527130	242.0595474	0.0734	4.56E-03	1.05E+01

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Am-243	A	2.32575E+11	243.0613799	5.4402	6.44E-03	2.00E-01
Am-245	B-	7380	245.0664529	0.3198	1.18E+04	6.24E+06
Am-246	B-	2340	246.069774	1.4739	1.71E+05	1.96E+07
Ar-39	B-	8488814170	38.96431304	0.2188	4.42E-02	3.41E+01
Ar-42	B-	1038222997	41.96304574	0.2325	3.57E-01	2.59E+02
At-217	A	0.0323	217.0047178	7.2011	6.87E+10	1.61E+12
Ba-133	EC	331978903.6	132.9060073	0.4583	6.95E-01	2.56E+02
Ba-137m	IT	153.12	136.9058274	0.6617	2.11E+06	5.38E+08
Be-10	B-	4.7651E+13	10.0135347	0.2525	3.54E-05	2.36E-02
Bi-210	B-A	433123.2	209.9841202	0.3889	2.86E+02	1.24E+05
Bi-211	A B-	128.4	210.9872687	6.733	1.66E+07	4.16E+08
Bi-212	B-A	3633	211.991285	2.8247	2.45E+05	1.46E+07
Bi-213	B-A	2735.4	212.9943836	0.6963	7.99E+04	1.94E+07
Bi-214	B-A	1194	213.9987109	2.1436	5.61E+05	4.42E+07
Bk-249	B-A	28512000	249.0749832	0.0325	3.06E-01	1.59E+03
Bk-250	B-	11563.2	250.078315	1.1932	2.76E+04	3.90E+06
C-14	B-	1.79875E+11	14.00324199	0.0495	1.31E-03	4.48E+00
Ca-45	B-	14054688	44.95618633	0.0772	8.17E+00	1.79E+04
Cd-109	EC	39864960	108.9049867	0.1092	1.68E+00	2.60E+03
Cd-113	B-	2.42988E+23	112.9044081	0.0926	2.26E-16	4.11E-13
Cd-113m	B-IT	444952713	112.9044081	0.1848	2.46E-01	2.25E+02
Ce-139	EC	11892182.4	138.9066576	0.1954	7.91E+00	6.83E+03
Ce-144	B-	24616224	143.9136528	0.111	2.10E+00	3.18E+03
Cf-249	ASF	11076482430	249.0748505	6.2944	1.53E-01	4.09E+00
Cf-250	ASF	412764644.4	250.0764046	6.2897	4.08E+00	1.09E+02
Cf-251	A	28401237000	251.0795872	6.1754	5.79E-02	1.58E+00
Cf-252	ASF	83468079.85	252.0816265	12.8107	4.07E+01	5.36E+02
Cl-36	B-ECB+	9.49864E+12	35.96830682	0.2733	5.35E-05	3.30E-02
Cm-242	ASF	14065920	242.0588343	6.2156	1.22E+02	3.31E+03
Cm-243	AEC	918306663	243.0613874	6.1624	1.85E+00	5.05E+01
Cm-244	ASF	571180433	244.0627507	5.9014	2.83E+00	8.09E+01
Cm-245	ASF	2.68234E+11	245.0654911	5.6382	5.74E-03	1.72E-01
Cm-246	ASF	1.50211E+11	246.0672221	5.5285	1.00E-02	3.05E-01
Cm-247	A	4.92288E+14	247.0703527	5.3544	2.94E-06	9.28E-05
Cm-248	ASF	1.09818E+13	248.0723491	22.5608	5.54E-04	4.14E-03

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Cm-250	AB-SF	2.61923E+11	250.0783576	161.287	1.65E-01	1.72E-01
Co-60	B-	166346045.1	59.93381567	2.6007	1.74E+01	1.13E+03
Cs-134	B-EC	65158749.06	133.9067185	1.719	1.32E+01	1.29E+03
Cs-135	B-	7.25809E+13	134.9059772	0.0894	6.11E-07	1.15E-03
Cs-137	B-	951981063	136.9070895	0.1884	9.67E-02	8.66E+01
Dy-159	EC	12476160	158.925746	0.0587	1.98E+00	5.69E+03
Es-254	A B-SF	23820480	254.0880205	6.6179	7.31E+01	1.86E+03
Eu-149	EC	8043840	148.9179371	0.0902	5.04E+00	9.42E+03
Eu-152	ECB+B-	427186161.4	151.9217512	1.3045	1.34E+00	1.74E+02
Eu-154	B-EC	271168699.5	153.922986	1.5223	2.44E+00	2.70E+02
Eu-155	B-	150245699.4	154.9229001	0.1259	3.62E-01	4.85E+02
Fe-55	EC	86371317.41	54.93829128	0.0058	8.17E-02	2.38E+03
Fr-221	A	294	221.0142538	6.4582	6.65E+06	1.74E+08
Fr-223	B-A	1320	223.0197343	0.4415	1.00E+05	3.83E+07
Gd-152	A	3.40815E+21	151.9197988	2.2046	2.85E-13	2.18E-11
Gd-153	EC	20770560	152.9217574	0.1494	3.15E+00	3.55E+03
H-3	B-	388781377.6	3.016049282	0.0057	3.25E-01	9.62E+03
Ho-166m	B-	37868316000	165.9322901	1.7746	1.89E-02	1.80E+00
I-129	B-	4.95444E+14	128.9049837	0.0902	9.45E-08	1.77E-04
In-113m	IT	5968.44	112.9040604	0.3967	3.94E+04	1.67E+07
In-115	B-	1.39166E+22	114.9038788	0.1526	6.38E-15	7.06E-12
Ir-194	B-	69408	193.9650758	0.9015	4.48E+03	8.38E+05
K-40	B-ECB+	3.94777E+16	39.96399817	0.6785	2.88E-08	7.15E-06
K-42	B-	44496	41.96240231	1.709	6.12E+04	6.04E+06
Kr-85	B-	339426339.1	84.91252726	0.2529	5.87E-01	3.91E+02
La-137	EC	1.89342E+12	136.9064506	0.0315	8.13E-06	4.35E-02
Lu-177	B-	574300.8	176.9437637	0.183	1.20E+02	1.11E+05
Lu-177m	B-IT	13858560	176.9437637	1.2692	3.46E+01	4.60E+03
Mn-54	ECB+B-	26967168	53.94035643	0.8402	3.86E+01	7.76E+03
Mo-93	EC	1.26228E+11	92.90680877	0.0163	9.30E-05	9.62E-01
Na-22	ECB+	82107976.17	21.99443742	2.3866	8.84E+01	6.25E+03
Nb-91	ECB+	21458712400	90.90699027	0.0176	6.03E-04	5.78E+00
Nb-92	EC	1.09503E+15	91.90718857	1.5133	1.01E-06	1.12E-04
Nb-93m	IT	509013280.9	92.90637316	0.0314	4.44E-02	2.39E+02
Nb-94	B-	6.40606E+11	93.90727899	1.7265	1.92E-03	1.88E-01
Nd-144	A	7.22654E+22	143.9100929	1.9052	1.23E-14	1.08E-12

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Ni-59	ECB+	3.18725E+12	58.93434557	0.0069	2.46E-06	6.01E-02
Ni-63	B-	3158848693	62.92966914	0.0174	5.85E-03	5.68E+01
Np-235	ECA	34223040	235.0440616	0.0178	1.48E-01	1.40E+03
Np-237	A	6.76581E+13	237.0481717	4.9529	2.07E-05	7.03E-04
Np-238	B-	182908.8	238.0509447	0.8398	1.29E+03	2.59E+05
Np-239	B-	203601.6	239.0529376	0.4469	6.14E+02	2.32E+05
Np-240	B-	3714	240.0561638	1.5632	1.17E+05	1.27E+07
Np-240m	B-IT	433.2	240.0561638	1.0004	6.43E+05	1.08E+08
Os-185	EC	8087040	184.954046	0.7101	3.18E+01	7.54E+03
Os-194	B-	189341580	193.9651795	0.0498	9.07E-02	3.07E+02
Pa-231	A	1.03381E+12	231.0358826	5.158	1.44E-03	4.72E-02
Pa-233	B-	2329948.8	233.0402466	0.438	5.39E+01	2.08E+04
Pa-234	B-	24120	234.0433056	1.8755	2.22E+04	2.00E+06
Pa-234m	B-IT	70.2	234.0433056	0.8334	3.39E+06	6.87E+08
Pb-209	B-	11710.8	208.9810899	0.1974	5.39E+03	4.61E+06
Pb-210	B-A	700563846	209.9841883	0.0457	2.08E-02	7.67E+01
Pb-211	B-	2166	210.9887354	0.5187	7.59E+04	2.47E+07
Pb-212	B-	38304	211.991896	0.3217	2.65E+03	1.39E+06
Pb-214	B-	1608	213.9998038	0.5481	1.07E+05	3.28E+07
Pd-107	B-	2.0512E+14	106.9051281	0.0096	2.93E-08	5.14E-04
Pm-145	ECA	558557661	144.9127558	0.0441	3.64E-02	1.39E+02
Pm-146	ECB-	174509822.9	145.9147023	0.8453	2.22E+00	4.43E+02
Pm-147	B-	82786450.16	146.9151446	0.0619	3.40E-01	9.28E+02
Po-210	A	11955686.4	209.9828736	5.4075	1.44E+02	4.49E+03
Po-211	A	0.516	210.9866531	7.5944	4.67E+09	1.04E+11
Po-212	A	0.000000299	211.9888679	8.9541	9.45E+15	1.78E+17
Po-213	A	0.0000042	212.9928571	8.537	6.38E+14	1.26E+16
Po-214	A	0.0001643	213.9952012	7.8335	1.49E+13	3.21E+14
Po-215	A	0.001781	214.9994185	7.5263	1.31E+12	2.95E+13
Po-216	A	0.145	216.0019135	6.9064	1.47E+10	3.60E+11
Po-218	A B-	186	218.0089715	6.1135	1.01E+07	2.78E+08
Pr-144	B-	1036.8	143.9133108	1.2373	5.55E+05	7.56E+07
Pr-144m	ITB-	432	143.9133108	0.0608	6.54E+04	1.81E+08
Pu-236	ASF	90189705.94	236.0460568	5.8674	1.84E+01	5.30E+02
Pu-238	ASF	2767542761	238.0495583	5.593	5.68E-01	1.71E+01
Pu-239	A	7.60838E+11	239.0521617	5.2442	1.93E-03	6.20E-02

Table C-2. D Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Pu-240	ASF	2.0714E+11	240.0538118	5.2559	7.07E-03	2.27E-01
Pu-241	B-A	452841945.5	241.0568497	0.0054	3.31E-03	1.03E+02
Pu-242	ASF	1.18338E+13	242.058741	4.9855	1.16E-04	3.94E-03
Pu-243	B-	17841.6	243.0620021	0.1988	3.07E+03	2.60E+06
Pu-244	ASF	2.52455E+15	244.0642044	4.9094	5.33E-07	1.83E-05
Pu-246	B-	936576	246.0702042	0.259	7.52E+01	4.90E+04
Ra-223	A	987552	223.0185007	5.9895	1.82E+03	5.12E+04
Ra-224	A	316224	224.0202105	5.7893	5.47E+03	1.59E+05
Ra-225	B-	1287360	225.0236106	0.1194	2.76E+01	3.89E+04
Ra-226	A	50491088000	226.0254085	4.8716	2.85E-02	9.89E-01
Ra-228	B-	181452347.5	228.0310687	0.0163	2.63E-02	2.73E+02
Rb-87	B-	1.55355E+18	86.90918053	0.1154	5.72E-11	8.36E-08
Rh-102	ECB+B-	17884800	101.9068343	0.6777	2.49E+01	6.19E+03
Rh-106	B-	29.8	105.9072859	1.6172	3.43E+07	3.57E+09
Rn-219	A	3.96	219.0094788	6.9456	5.36E+08	1.30E+10
Rn-220	A	55.6	220.0113925	6.4047	3.50E+07	9.22E+08
Rn-222	A	330350.4	222.0175763	5.5903	5.10E+03	1.54E+05
Ru-106	B-	32278176	105.9073282	0.01	1.96E-01	3.30E+03
S-35	B-	7560864	34.96903232	0.0487	1.23E+01	4.27E+04
Sb-125	B-	87051684.82	124.905253	0.5383	3.31E+00	1.04E+03
Sb-126	B-	1067040	125.907253	3.1097	1.55E+03	8.40E+04
Sb-126m	B-IT	1149	125.907253	2.1805	1.01E+06	7.80E+07
Sc-46	B-	7239456	45.95516749	2.1217	4.27E+02	3.39E+04
Se-75	EC	10348905.6	74.92252287	0.4034	3.48E+01	1.46E+04
Se-79	B-	9.30929E+12	78.91849925	0.0529	4.82E-06	1.54E-02
Sm-145	EC	29376000	144.9134172	0.095	1.49E+00	2.65E+03
Sm-146	A	3.25036E+15	145.9130469	2.529	3.57E-07	2.38E-05
Sm-147	A	3.34503E+18	146.9149041	2.3105	3.14E-10	2.30E-08
Sm-148	A	2.20899E+23	147.914829	1.986	4.07E-15	3.45E-13
Sm-151	B-	2840123700	150.9199391	0.02	3.12E-03	2.63E+01
Sn-113	EC	9943776	112.9051758	0.03	1.79E+00	1.00E+04
Sn-119m	IT	25323840	118.9033112	0.0932	2.07E+00	3.75E+03
Sn-121	B-	97308	120.9042428	0.1156	6.57E+02	9.59E+05
Sn-121m	ITB-	1385349227	120.9042428	0.0405	1.62E-02	6.74E+01
Sn-123	B-	11162880	122.9057254	0.5296	2.58E+01	8.22E+03
Sn-126	B-	7.25809E+12	125.9076588	0.1949	1.43E-05	1.23E-02

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
Sr-90	B-	908524014.7	89.90773089	0.1957	1.60E-01	1.38E+02
Ta-182	B-	9886752	181.9501554	1.5023	5.59E+01	6.27E+03
Tb-157	EC	2240542030	156.9240323	0.0114	2.17E-03	3.21E+01
Tc-97	EC	8.2048E+13	96.90636072	0.0169	1.42E-07	1.42E-03
Tc-97m	IT	7784640	96.90636072	0.0964	8.55E+00	1.50E+04
Tc-98	B-	1.32539E+14	97.90721121	1.5542	8.01E-06	8.69E-04
Tc-99	B-	6.66167E+12	98.90624968	0.1013	1.03E-05	1.71E-02
Te-121	EC	1655424	120.9049425	0.5872	1.96E+02	5.64E+04
Te-121m	ITEC	13305600	120.9049425	0.2993	1.24E+01	7.01E+03
Te-123	EC	1.89342E+22	122.9042697	0.0031	8.91E-17	4.85E-12
Te-123m	IT	10303200	122.9042697	0.2467	1.30E+01	8.91E+03
Te-125m	IT	4959360	124.9044299	0.1451	1.57E+01	1.82E+04
Te-127	B-	33660	126.9052257	0.2294	3.59E+03	2.64E+06
Te-127m	ITB-	9417600	126.9052257	0.0937	5.24E+00	9.44E+03
Th-227	A	1613952	227.0277026	6.1955	1.13E+03	3.08E+04
Th-228	A	60324227.39	228.0287398	5.5202	2.68E+01	8.20E+02
Th-229	A	2.31628E+11	229.0317614	5.1772	6.53E-03	2.13E-01
Th-230	A	2.37876E+12	230.0331324	4.7702	5.83E-04	2.06E-02
Th-231	B-	91872	231.0363029	0.1891	5.96E+02	5.32E+05
Th-232	A	4.43375E+17	232.0380537	4.0829	2.65E-09	1.10E-07
Th-234	B-	2082240	234.0435999	0.0728	9.99E+00	2.31E+04
Tl-204	B-EC	119285195.4	203.9738633	0.2385	6.56E-01	4.64E+02
Tl-206	B-	252	205.97611	0.5399	6.96E+05	2.17E+08
Tl-207	B-	286.2	206.9774186	0.4975	5.62E+05	1.90E+08
Tl-208	B-	183.18	207.982018	3.9716	6.97E+06	2.96E+08
Tl-209	B-	129.66	208.9853518	2.8302	6.99E+06	4.16E+08
Tm-170	B-EC	11111040	169.9358065	0.3321	1.18E+01	5.97E+03
Tm-171	B-	60589305.6	170.9364351	0.0261	1.69E-01	1.09E+03
U-232	A	2174272477	232.0371549	5.4135	7.18E-01	2.24E+01
U-233	A	5.02386E+12	233.0396344	4.9085	2.80E-04	9.64E-03
U-234	A	7.74723E+12	234.0409504	4.8587	1.79E-04	6.22E-03
U-235	A	2.22161E+16	235.0439282	4.6891	6.01E-08	2.16E-06
U-236	A	7.39063E+14	236.0455662	4.5723	1.75E-06	6.47E-05
U-237	B-	583200	237.0487284	0.3433	1.66E+02	8.16E+04
U-238	ASF	1.40996E+17	238.050787	4.2691	8.51E-09	3.36E-07
U-240	B-	50760	240.0565924	0.1374	7.54E+02	9.26E+05

Table C-2. Disintegration Energy, Decay Heat Specific Power, and Specific Activity for 195 Radionuclides (continued)

Radionuclide	Decay Mode[1]	Half-life[1] (s)	Atomic Weight[2] (g/mol)	Disintegration Energy[1] (MeV)	Decay Heat Specific Power[3] (W/g)	Specific Activity[3] (Ci/g)
V-49	EC	28512000	48.94851075	0.0045	2.16E-01	8.08E+03
W-181	EC	10471680	180.9482189	0.0533	1.88E+00	5.95E+03
Y-90	B-	230760	89.9071448	0.9331	3.01E+03	5.44E+05
Zn-65	ECB+	21086784	64.92924053	0.5888	2.88E+01	8.24E+03
Zr-93	B-	4.82821E+13	92.90647065	0.0194	2.89E-07	2.52E-03

[1] International Commission on Radiological Protection (ICRP 2008, Table A.1). Note that decay modes include A = alpha, B- = beta minus, B+ = beta plus, EC = electron capture, IT = isomeric transition, and SF = spontaneous fission. Half-life is converted to seconds.
[2] Wang et al. (2017, Table I).
[3] Decay heat specific power is calculated using Equation 10 and specific activity is calculated using Equation 9.

Table C-3. Calculated Wattage at 2033

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2] (W)	Wattage Fraction (selected) (%)
	CH	RH	Total		
Ac-225	3.80E-01	8.74E-01	1.25E+00	4.41E-02	
Ac-227	2.47E+01	1.19E+00	2.59E+01	1.31E-02	
Ac-228	9.03E-02	4.56E-02	1.36E-01	1.06E-03	
Ag-108	1.45E-04	5.15E-03	5.29E-03	1.96E-05	
Ag-108m	1.67E-03	5.92E-02	6.08E-02	5.90E-04	
Ag-109m	4.49E-08	1.10E-03	1.10E-03	5.76E-07	
Ag-110	1.02E-09	7.94E-09	8.96E-09	6.44E-11	
Ag-110m	7.50E-08	5.84E-07	6.59E-07	1.11E-08	
Am-241	1.13E+06	1.30E+04	1.14E+06	3.82E+04	34.26
Am-242	4.46E+00	4.72E+00	9.18E+00	1.09E-02	
Am-242m	4.48E+00	4.74E+00	9.23E+00	4.01E-03	
Am-243	2.24E+01	4.12E+02	4.35E+02	1.40E+01	
Am-245	1.88E-09	5.99E-08	6.18E-08	1.17E-10	
Am-246	2.91E-08	5.88E-07	6.18E-07	5.40E-09	
Ar-39	0.00E+00	4.78E-02	4.78E-02	6.20E-05	
Ar-42	0.00E+00	8.75E-02	8.75E-02	1.21E-04	
At-217	3.80E-01	8.74E-01	1.25E+00	5.35E-02	
Ba-133	2.31E-03	3.88E+00	3.88E+00	1.05E-02	
Ba-137m	5.82E+02	2.36E+05	2.37E+05	9.30E+02	
Be-10	0.00E+00	1.03E-05	1.03E-05	1.54E-08	
Bi-210	9.79E-01	1.45E+01	1.55E+01	3.57E-02	

Table C-3. Calculated Wattage at 2033 (continued)

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	(Watt)	(%)	(W)	(%)
Bi-211	2.48E+01	1.19E+00	2.60E+01	1.04E+00	
Bi-212	4.49E+02	9.23E+00	4.59E+02	7.68E+00	
Bi-213	3.80E-01	8.74E-01	1.25E+00	5.18E-03	
Bi-214	1.78E+00	1.85E+01	2.02E+01	2.57E-01	
Bk-249	1.30E-04	4.13E-03	4.26E-03	8.21E-07	
Bk-250	1.63E-08	3.30E-07	3.46E-07	2.45E-09	
C-14	2.27E-02	5.34E+01	5.34E+01	1.57E-02	
Ca-45	2.42E-21	1.05E-11	1.05E-11	4.81E-15	
Cd-109	4.49E-08	1.10E-03	1.10E-03	7.15E-07	
Cd-113	2.35E-22	1.16E-17	1.16E-17	6.36E-21	
Cd-113m	8.45E-05	3.33E+00	3.33E+00	3.65E-03	
Ce-139	1.82E-17	1.02E-12	1.02E-12	1.18E-15	
Ce-144	6.62E-07	6.76E-03	6.76E-03	4.45E-06	
Cf-249	1.10E+01	3.73E+01	4.83E+01	1.80E+00	
Cf-250	3.26E+00	1.26E+02	1.29E+02	4.80E+00	
Cf-251	1.01E-01	8.39E+00	8.49E+00	3.11E-01	
Cf-252	5.07E-01	1.76E+00	2.26E+00	1.72E-01	
Cl-36	2.02E-07	0.00E+00	2.02E-07	3.28E-10	
Cm-242	3.69E+00	3.91E+00	7.60E+00	2.80E-01	
Cm-243	2.54E+00	3.61E+01	3.87E+01	1.41E+00	
Cm-244	6.19E+03	3.32E+04	3.94E+04	1.38E+03	
Cm-245	2.97E+00	2.15E+01	2.44E+01	8.17E-01	
Cm-246	5.44E+01	4.55E+02	5.10E+02	1.67E+01	
Cm-247	3.34E-01	4.08E-02	3.75E-01	1.19E-02	
Cm-248	4.63E-01	1.31E+00	1.77E+00	2.37E-01	
Cm-250	1.17E-07	2.35E-06	2.47E-06	2.36E-06	
Co-60	3.10E-01	3.79E+02	3.80E+02	5.86E+00	
Cs-134	2.80E-03	1.08E+01	1.08E+01	1.10E-01	
Cs-135	1.67E-04	6.47E-02	6.48E-02	3.44E-05	
Cs-137	6.16E+02	2.50E+05	2.51E+05	2.80E+02	
Dy-159	0.00E+00	4.60E-13	4.60E-13	1.60E-16	
Es-254	0.00E+00	4.19E-10	4.19E-10	1.64E-11	
Eu-149	0.00E+00	6.03E-20	6.03E-20	3.23E-23	
Eu-152	1.29E+01	7.38E+01	8.67E+01	6.71E-01	
Eu-154	6.85E+00	2.30E+03	2.31E+03	2.08E+01	
Eu-155	1.33E+00	1.83E+02	1.84E+02	1.38E-01	
Fe-55	1.03E-03	6.46E+01	6.46E+01	2.22E-03	

Table C-3. Calculated Wattage at 2033 (continued)

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Fr-221	3.80E-01	8.74E-01	1.25E+00	4.80E-02	
Fr-223	3.41E-01	1.64E-02	3.58E-01	9.36E-04	
Gd-152	5.91E-13	4.54E-12	5.13E-12	6.70E-14	
Gd-153	5.08E-09	7.77E-08	8.28E-08	7.33E-11	
H-3	2.87E+04	7.18E+03	3.59E+04	1.21E+00	
Ho-166m	1.06E-03	2.94E-05	1.09E-03	1.15E-05	
I-129	5.02E-03	8.30E-01	8.35E-01	4.47E-04	
In-113m	2.14E-28	1.01E-14	1.01E-14	2.38E-17	
In-115	0.00E+00	1.33E-16	1.33E-16	1.20E-19	
Ir-194	0.00E+00	1.02E-02	1.02E-02	5.44E-05	
K-40	4.00E-02	0.00E+00	4.00E-02	1.61E-04	
K-42	0.00E+00	8.75E-02	8.75E-02	8.86E-04	
Kr-85	2.41E-01	5.35E+02	5.35E+02	8.03E-01	
La-137	0.00E+00	8.71E-07	8.71E-07	1.63E-10	
Lu-177	0.00E+00	2.66E-14	2.66E-14	2.88E-17	
Lu-177m	0.00E+00	1.21E-13	1.21E-13	9.12E-16	
Mn-54	4.62E-08	4.19E-03	4.19E-03	2.09E-05	
Mo-93	0.00E+00	5.47E-01	5.47E-01	5.29E-05	
Na-22	3.13E-02	2.56E-03	3.39E-02	4.79E-04	
Nb-91	0.00E+00	7.12E-02	7.12E-02	7.43E-06	
Nb-92	0.00E+00	6.52E-08	6.52E-08	5.85E-10	
Nb-93m	1.38E-03	3.65E+00	3.66E+00	6.80E-04	
Nb-94	1.97E-03	4.34E+00	4.35E+00	4.45E-02	
Nd-144	1.54E-13	8.52E-12	8.68E-12	9.80E-14	
Ni-59	2.53E-02	5.16E+02	5.16E+02	2.11E-02	
Ni-63	5.25E+00	8.67E+02	8.72E+02	9.00E-02	
Np-235	0.00E+00	2.57E-04	2.57E-04	2.71E-08	
Np-237	2.75E+01	6.96E+00	3.44E+01	1.01E+00	
Np-238	2.02E-02	2.14E-02	4.15E-02	2.07E-04	
Np-239	2.24E+01	4.12E+02	4.35E+02	1.15E+00	
Np-240	6.95E-06	3.38E-05	4.08E-05	3.78E-07	
Np-240m	5.79E-03	2.82E-02	3.40E-02	2.02E-04	
Os-185	0.00E+00	1.77E-21	1.77E-21	7.47E-24	
Os-194	0.00E+00	1.02E-02	1.02E-02	3.00E-06	
Pa-231	1.59E+01	1.04E-03	1.59E+01	4.85E-01	
Pa-233	2.75E+01	6.96E+00	3.44E+01	8.94E-02	
Pa-234	5.09E-02	4.07E-03	5.50E-02	6.12E-04	

Table C-3. Calculated Wattage at 2033 (continued)

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Pa-234m	3.92E+01	3.13E+00	4.23E+01	2.09E-01	
Pb-209	3.80E-01	8.74E-01	1.25E+00	1.47E-03	
Pb-210	9.79E-01	1.45E+01	1.55E+01	4.19E-03	
Pb-211	2.48E+01	1.19E+00	2.60E+01	7.98E-02	
Pb-212	4.49E+02	9.23E+00	4.59E+02	8.75E-01	
Pb-214	1.78E+00	1.85E+01	2.02E+01	6.58E-02	
Pd-107	3.30E-06	1.70E-02	1.70E-02	9.70E-07	
Pm-145	0.00E+00	1.61E+00	1.61E+00	4.21E-04	
Pm-146	6.32E-07	5.26E-01	5.26E-01	2.63E-03	
Pm-147	4.40E-01	2.54E+01	2.59E+01	9.50E-03	
Po-210	9.79E-01	1.45E+01	1.55E+01	4.96E-01	
Po-211	6.81E-02	3.27E-03	7.14E-02	3.21E-03	
Po-212	2.88E+02	5.91E+00	2.94E+02	1.56E+01	
Po-213	3.72E-01	8.55E-01	1.23E+00	6.21E-02	
Po-214	1.78E+00	1.85E+01	2.02E+01	9.40E-01	
Po-215	2.48E+01	1.19E+00	2.60E+01	1.16E+00	
Po-216	4.49E+02	9.23E+00	4.59E+02	1.88E+01	
Po-218	1.78E+00	1.85E+01	2.03E+01	7.34E-01	
Pr-144	6.62E-07	6.76E-03	6.76E-03	4.96E-05	
Pr-144m	9.27E-09	9.46E-05	9.46E-05	3.41E-08	
Pu-236	8.69E-12	6.65E-02	6.65E-02	2.31E-03	
Pu-238	9.42E+05	2.25E+04	9.64E+05	3.20E+04	28.69
Pu-239	8.70E+05	4.22E+03	8.74E+05	2.72E+04	24.38
Pu-240	3.16E+05	3.16E+03	3.19E+05	9.95E+03	8.93
Pu-241	1.82E+06	4.53E+04	1.87E+06	5.98E+01	
Pu-242	1.48E+02	1.59E+01	1.64E+02	4.84E+00	0.00
Pu-243	3.34E-01	4.08E-02	3.75E-01	4.42E-04	
Pu-244	5.80E-03	2.82E-02	3.40E-02	9.91E-04	
Pu-246	2.91E-08	5.88E-07	6.18E-07	9.48E-10	
Ra-223	2.48E+01	1.19E+00	2.60E+01	9.22E-01	
Ra-224	4.49E+02	9.23E+00	4.59E+02	1.57E+01	
Ra-225	3.80E-01	8.74E-01	1.25E+00	8.88E-04	
Ra-226	1.78E+00	1.85E+01	2.03E+01	5.85E-01	
Ra-228	9.03E-02	4.55E-02	1.36E-01	1.31E-05	
Rb-87	1.80E-10	1.29E-06	1.29E-06	8.82E-10	
Rh-102	0.00E+00	1.30E-08	1.30E-08	5.22E-11	
Rh-106	9.91E-05	2.11E-02	2.12E-02	2.03E-04	

Table C-3. Calculated Wattage at 2033 (continued)

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Rn-219	2.48E+01	1.19E+00	2.60E+01	1.07E+00	
Rn-220	4.49E+02	9.23E+00	4.59E+02	1.74E+01	
Rn-222	1.78E+00	1.85E+01	2.03E+01	6.71E-01	
Ru-106	9.91E-05	2.11E-02	2.12E-02	1.26E-06	
S-35	1.50E-30	6.34E-22	6.34E-22	1.83E-25	
Sb-125	5.70E-03	1.52E+01	1.52E+01	4.84E-02	
Sb-126	1.18E-06	8.05E-03	8.05E-03	1.48E-04	
Sb-126m	1.71E-05	1.22E-01	1.22E-01	1.57E-03	
Sc-46	0.00E+00	6.10E-22	6.10E-22	7.67E-24	
Se-75	1.19E-32	1.05E-15	1.05E-15	2.52E-18	
Se-79	6.91E-05	1.80E-01	1.80E-01	5.66E-05	
Sm-145	0.00E+00	1.08E-05	1.08E-05	6.10E-09	
Sm-146	1.70E-13	6.18E-08	6.18E-08	9.26E-10	
Sm-147	1.23E-09	9.40E-08	9.52E-08	1.30E-09	
Sm-148	1.75E-16	9.12E-17	2.66E-16	3.13E-18	
Sm-151	1.27E+01	1.41E+02	1.54E+02	1.83E-02	
Sn-113	2.14E-28	1.01E-14	1.01E-14	1.80E-18	
Sn-119m	3.38E-24	5.50E-06	5.50E-06	3.04E-09	
Sn-121	7.50E-05	3.42E+00	3.42E+00	2.34E-03	
Sn-121m	9.66E-05	4.40E+00	4.40E+00	1.06E-03	
Sn-123	0.00E+00	1.37E-13	1.37E-13	4.31E-16	
Sn-126	1.71E-05	1.22E-01	1.22E-01	1.41E-04	
Sr-90	8.18E+02	1.96E+05	1.97E+05	2.28E+02	
Ta-182	3.50E-25	9.08E-13	9.08E-13	8.09E-15	
Tb-157	0.00E+00	1.84E-01	1.84E-01	1.25E-05	
Tc-97	0.00E+00	1.69E-06	1.69E-06	1.69E-10	
Tc-97m	0.00E+00	2.46E-20	2.46E-20	1.41E-23	
Tc-98	0.00E+00	3.39E-07	3.39E-07	3.12E-09	
Tc-99	4.56E+01	5.33E+02	5.79E+02	3.48E-01	
Te-121	0.00E+00	4.02E-12	4.02E-12	1.40E-14	
Te-121m	0.00E+00	4.04E-12	4.04E-12	7.17E-15	
Te-123	6.98E-22	3.41E-14	3.41E-14	6.28E-19	
Te-123m	1.61E-28	2.57E-15	2.57E-15	3.76E-18	
Te-125m	1.39E-03	3.70E+00	3.71E+00	3.19E-03	
Te-127	0.00E+00	9.30E-16	9.30E-16	1.26E-18	
Te-127m	0.00E+00	9.49E-16	9.49E-16	5.27E-19	
Th-227	2.44E+01	1.17E+00	2.56E+01	9.40E-01	

Table C-3. Calculated Wattage at 2033 (continued)

Radionuclide	Inventory in Year 2033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Th-228	4.49E+02	9.23E+00	4.59E+02	1.50E+01	
Th-229	3.80E-01	8.74E-01	1.25E+00	3.85E-02	
Th-230	3.98E-01	2.26E+00	2.66E+00	7.51E-02	
Th-231	4.56E+00	1.85E+00	6.41E+00	7.19E-03	
Th-232	9.60E-02	2.26E-02	1.19E-01	2.87E-03	
Th-234	3.92E+01	3.13E+00	4.23E+01	1.83E-02	
Tl-204	1.32E-08	0.00E+00	1.32E-08	1.86E-11	
Tl-206	1.29E-06	1.91E-05	2.04E-05	6.54E-08	
Tl-207	2.47E+01	1.19E+00	2.59E+01	7.64E-02	
Tl-208	1.61E+02	3.32E+00	1.65E+02	3.88E+00	
Tl-209	7.98E-03	1.83E-02	2.63E-02	4.42E-04	
Tm-170	0.00E+00	3.99E-15	3.99E-15	7.86E-18	
Tm-171	0.00E+00	7.37E-03	7.37E-03	1.14E-06	
U-232	4.38E+02	8.87E+00	4.47E+02	1.44E+01	
U-233	1.10E+02	1.72E+01	1.27E+02	3.70E+00	
U-234	4.77E+02	9.70E+00	4.86E+02	1.40E+01	
U-235	4.56E+00	1.85E+00	6.41E+00	1.78E-01	
U-236	4.24E-01	2.53E-01	6.77E-01	1.84E-02	
U-237	4.36E+01	1.08E+00	4.47E+01	9.10E-02	
U-238	3.92E+01	3.13E+00	4.23E+01	1.07E+00	
U-240	5.79E-03	2.82E-02	3.40E-02	2.77E-05	
V-49	0.00E+00	1.26E-04	1.26E-04	3.36E-09	
W-181	0.00E+00	1.77E-16	1.77E-16	5.60E-20	
Y-90	8.19E+02	1.96E+05	1.97E+05	1.09E+03	
Zn-65	2.40E-10	6.10E-08	6.12E-08	2.14E-10	
Zr-93	1.37E-03	2.44E-01	2.45E-01	2.82E-05	
Total	**5.12E+06**	**1.01E+06**	**6.14E+06**	**1.11E+05**	**96.25**

[1] Van Soest 2018, Tables 5-3 and 5-4.
[2] Wattage is calculated using Equation 5.

Table C-4. Calculated Wattage at 2133

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Ac-225	1.34E+00	1.02E+00	2.36E+00	8.29E-02	
Ac-227	1.62E+01	5.29E-02	1.63E+01	8.23E-03	
Ac-228	9.60E-02	2.26E-02	1.19E-01	9.26E-04	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(Watt)	(%)
Ag-108	8.41E-05	2.98E-03	3.07E-03	1.14E-05	
Ag-108m	9.66E-04	3.43E-02	3.52E-02	3.42E-04	
Ag-109m	7.54E-32	1.88E-27	1.88E-27	9.80E-31	
Ag-110	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ag-110m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Am-241	1.02E+06	1.24E+04	1.03E+06	3.43E+04	39.85
Am-242	2.73E+00	2.89E+00	5.62E+00	6.64E-03	
Am-242m	2.74E+00	2.90E+00	5.64E+00	2.46E-03	
Am-243	2.22E+01	4.09E+02	4.31E+02	1.39E+01	
Am-245	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Am-246	2.90E-08	5.86E-07	6.15E-07	5.37E-09	
Ar-39	0.00E+00	3.69E-02	3.69E-02	4.79E-05	
Ar-42	0.00E+00	1.06E-02	1.06E-02	1.47E-05	
At-217	1.34E+00	1.02E+00	2.36E+00	1.01E-01	
Ba-133	3.18E-06	5.33E-03	5.33E-03	1.45E-05	
Ba-137m	5.77E+01	2.35E+04	2.35E+04	9.22E+01	
Be-10	0.00E+00	1.03E-05	1.03E-05	1.54E-08	
Bi-210	1.71E+00	1.78E+01	1.95E+01	4.50E-02	
Bi-211	1.62E+01	5.30E-02	1.63E+01	6.50E-01	
Bi-212	1.67E+02	3.40E+00	1.70E+02	2.85E+00	
Bi-213	1.34E+00	1.02E+00	2.36E+00	9.72E-03	
Bi-214	1.73E+00	1.78E+01	1.95E+01	2.48E-01	
Bk-249	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Bk-250	1.63E-08	3.28E-07	3.44E-07	2.44E-09	
C-14	2.24E-02	5.27E+01	5.28E+01	1.55E-02	
Ca-45	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cd-109	7.63E-32	1.88E-27	1.88E-27	1.22E-30	
Cd-113	4.13E-22	1.86E-17	1.86E-17	1.02E-20	
Cd-113m	6.19E-07	2.44E-02	2.44E-02	2.67E-05	
Ce-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ce-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cf-249	9.00E+00	3.06E+01	3.96E+01	1.48E+00	
Cf-250	1.63E-02	6.27E-01	6.43E-01	2.40E-02	
Cf-251	9.31E-02	7.77E+00	7.86E+00	2.88E-01	
Cf-252	2.10E-12	7.30E-12	9.40E-12	7.14E-13	
Cl-36	2.02E-07	0.00E+00	2.02E-07	3.28E-10	
Cm-242	2.26E+00	2.39E+00	4.65E+00	1.71E-01	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Cm-243	2.23E-01	3.17E+00	3.40E+00	1.24E-01	
Cm-244	1.35E+02	7.21E+02	8.55E+02	2.99E+01	
Cm-245	3.02E+00	2.16E+01	2.46E+01	8.22E-01	
Cm-246	5.36E+01	4.49E+02	5.02E+02	1.65E+01	
Cm-247	3.34E-01	4.09E-02	3.75E-01	1.19E-02	
Cm-248	4.62E-01	1.31E+00	1.77E+00	2.37E-01	
Cm-250	1.16E-07	2.34E-06	2.46E-06	2.35E-06	
Co-60	6.01E-07	7.35E-04	7.36E-04	1.13E-05	
Cs-134	7.03E-18	2.72E-14	2.72E-14	2.77E-16	
Cs-135	1.67E-04	6.47E-02	6.48E-02	3.44E-05	
Cs-137	6.11E+01	2.48E+04	2.49E+04	2.78E+01	
Dy-159	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Es-254	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-149	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-152	7.12E-02	4.07E-01	4.78E-01	3.70E-03	
Eu-154	2.14E-03	7.20E-01	7.23E-01	6.52E-03	
Eu-155	4.92E-07	6.76E-05	6.81E-05	5.08E-08	
Fe-55	9.70E-15	6.05E-10	6.05E-10	2.08E-14	
Fr-221	1.34E+00	1.02E+00	2.36E+00	9.02E-02	
Fr-223	2.24E-01	7.30E-04	2.25E-01	5.88E-04	
Gd-152	1.03E-12	7.07E-12	8.10E-12	1.06E-13	
Gd-153	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
H-3	1.04E+02	2.60E+01	1.30E+02	4.39E-03	
Ho-166m	1.00E-03	2.77E-05	1.03E-03	1.09E-05	
I-129	5.02E-03	8.30E-01	8.35E-01	4.47E-04	
In-113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
In-115	0.00E+00	1.33E-16	1.33E-16	1.20E-19	
Ir-194	0.00E+00	9.74E-08	9.74E-08	5.21E-10	
K-40	4.00E-02	0.00E+00	4.00E-02	1.61E-04	
K-42	0.00E+00	1.06E-02	1.06E-02	1.08E-04	
Kr-85	3.74E-04	8.32E-01	8.32E-01	1.25E-03	
La-137	0.00E+00	8.70E-07	8.70E-07	1.63E-10	
Lu-177	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Lu-177m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Mn-54	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Mo-93	0.00E+00	5.37E-01	5.37E-01	5.19E-05	
Na-22	8.42E-14	6.89E-15	9.11E-14	1.29E-15	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Nb-91	0.00E+00	6.43E-02	6.43E-02	6.71E-06	
Nb-92	0.00E+00	6.52E-08	6.52E-08	5.85E-10	
Nb-93m	1.37E-03	7.26E-01	7.28E-01	1.35E-04	
Nb-94	1.97E-03	4.33E+00	4.33E+00	4.43E-02	
Nd-144	1.54E-13	8.52E-12	8.68E-12	9.80E-14	
Ni-59	2.53E-02	5.15E+02	5.15E+02	2.11E-02	
Ni-63	2.62E+00	4.34E+02	4.36E+02	4.50E-02	
Np-235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Np-237	6.27E+01	7.39E+00	7.01E+01	2.06E+00	
Np-238	1.23E-02	1.31E-02	2.54E-02	1.26E-04	
Np-239	2.22E+01	4.09E+02	4.31E+02	1.14E+00	
Np-240	6.95E-06	3.38E-05	4.08E-05	3.78E-07	
Np-240m	5.79E-03	2.82E-02	3.40E-02	2.02E-04	
Os-185	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Os-194	0.00E+00	9.74E-08	9.74E-08	2.88E-11	
Pa-231	1.59E+01	4.94E-03	1.59E+01	4.85E-01	
Pa-233	6.27E+01	7.39E+00	7.01E+01	1.82E-01	
Pa-234	5.09E-02	4.07E-03	5.50E-02	6.12E-04	
Pa-234m	3.92E+01	3.13E+00	4.23E+01	2.09E-01	
Pb-209	1.34E+00	1.02E+00	2.36E+00	2.76E-03	
Pb-210	1.71E+00	1.78E+01	1.95E+01	5.29E-03	
Pb-211	1.62E+01	5.30E-02	1.63E+01	5.01E-02	
Pb-212	1.67E+02	3.40E+00	1.70E+02	3.25E-01	
Pb-214	1.73E+00	1.78E+01	1.95E+01	6.34E-02	
Pd-107	3.30E-06	1.70E-02	1.70E-02	9.70E-07	
Pm-145	0.00E+00	3.21E-02	3.21E-02	8.39E-06	
Pm-146	2.27E-12	1.89E-06	1.89E-06	9.47E-09	
Pm-147	1.47E-12	8.51E-11	8.66E-11	3.18E-14	
Po-210	1.71E+00	1.78E+01	1.95E+01	6.26E-01	
Po-211	4.46E-02	1.46E-04	4.48E-02	2.02E-03	
Po-212	1.07E+02	2.18E+00	1.09E+02	5.80E+00	
Po-213	1.31E+00	9.96E-01	2.31E+00	1.17E-01	
Po-214	1.73E+00	1.78E+01	1.95E+01	9.06E-01	
Po-215	1.62E+01	5.30E-02	1.63E+01	7.26E-01	
Po-216	1.67E+02	3.40E+00	1.70E+02	6.98E+00	
Po-218	1.73E+00	1.78E+01	1.95E+01	7.07E-01	
Pr-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Pr-144m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pu-236	3.62E-22	2.77E-12	2.77E-12	9.62E-14	
Pu-238	4.27E+05	1.02E+04	4.38E+05	1.45E+04	16.84
Pu-239	8.67E+05	4.21E+03	8.72E+05	2.71E+04	31.44
Pu-240	3.13E+05	3.22E+03	3.16E+05	9.85E+03	11.43
Pu-241	1.45E+04	3.83E+02	1.49E+04	4.78E-01	
Pu-242	1.48E+02	1.60E+01	1.64E+02	4.84E+00	0.01
Pu-243	3.34E-01	4.09E-02	3.75E-01	4.42E-04	
Pu-244	5.80E-03	2.82E-02	3.40E-02	9.91E-04	
Pu-246	2.90E-08	5.86E-07	6.15E-07	9.44E-10	
Ra-223	1.62E+01	5.30E-02	1.63E+01	5.78E-01	
Ra-224	1.67E+02	3.40E+00	1.70E+02	5.85E+00	
Ra-225	1.34E+00	1.02E+00	2.36E+00	1.67E-03	
Ra-226	1.73E+00	1.78E+01	1.95E+01	5.64E-01	
Ra-228	9.60E-02	2.26E-02	1.19E-01	1.15E-05	
Rb-87	1.80E-10	1.29E-06	1.29E-06	8.82E-10	
Rh-102	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Rh-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Rn-219	1.62E+01	5.30E-02	1.63E+01	6.70E-01	
Rn-220	1.67E+02	3.40E+00	1.70E+02	6.47E+00	
Rn-222	1.73E+00	1.78E+01	1.95E+01	6.47E-01	
Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
S-35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sb-125	5.34E-14	1.42E-10	1.42E-10	4.54E-13	
Sb-126	1.18E-06	8.05E-03	8.05E-03	1.48E-04	
Sb-126m	1.70E-05	1.22E-01	1.22E-01	1.57E-03	
Sc-46	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Se-75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Se-79	6.91E-05	1.80E-01	1.80E-01	5.65E-05	
Sm-145	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sm-146	1.81E-13	7.13E-08	7.13E-08	1.07E-09	
Sm-147	1.24E-09	9.46E-08	9.59E-08	1.31E-09	
Sm-148	1.75E-16	9.12E-17	2.66E-16	3.13E-18	
Sm-151	5.88E+00	6.54E+01	7.13E+01	8.46E-03	
Sn-113	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-119m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-121	2.13E-05	9.69E-01	9.69E-01	6.64E-04	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Sn-121m	2.74E-05	1.25E+00	1.25E+00	3.00E-04	
Sn-123	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-126	1.70E-05	1.22E-01	1.22E-01	1.41E-04	
Sr-90	6.97E+01	1.67E+04	1.68E+04	1.94E+01	
Ta-182	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tb-157	0.00E+00	1.16E-01	1.16E-01	7.85E-06	
Tc-97	0.00E+00	1.69E-06	1.69E-06	1.69E-10	
Tc-97m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tc-98	0.00E+00	3.39E-07	3.39E-07	3.12E-09	
Tc-99	4.56E+01	5.33E+02	5.79E+02	3.48E-01	
Te-121	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-123	6.98E-22	3.41E-14	3.41E-14	6.28E-19	
Te-123m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-125m	1.30E-14	3.47E-11	3.48E-11	2.99E-14	
Te-127	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-127m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Th-227	1.60E+01	5.23E-02	1.61E+01	5.90E-01	
Th-228	1.67E+02	3.40E+00	1.70E+02	5.58E+00	
Th-229	1.34E+00	1.02E+00	2.36E+00	7.23E-02	
Th-230	9.31E-01	2.27E+00	3.20E+00	9.04E-02	
Th-231	4.65E+00	1.85E+00	6.50E+00	7.28E-03	
Th-232	9.60E-02	2.26E-02	1.19E-01	2.87E-03	
Th-234	3.92E+01	3.13E+00	4.23E+01	1.83E-02	
Tl-204	1.43E-16	0.00E+00	1.43E-16	2.02E-19	
Tl-206	2.25E-06	2.35E-05	2.58E-05	8.24E-08	
Tl-207	1.62E+01	5.29E-02	1.62E+01	4.79E-02	
Tl-208	6.01E+01	1.22E+00	6.13E+01	1.44E+00	
Tl-209	2.81E-02	2.14E-02	4.95E-02	8.30E-04	
Tm-170	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tm-171	0.00E+00	1.55E-18	1.55E-18	2.40E-22	
U-232	1.62E+02	3.29E+00	1.66E+02	5.32E+00	
U-233	1.10E+02	1.72E+01	1.27E+02	3.70E+00	
U-234	6.60E+02	1.41E+01	6.74E+02	1.94E+01	
U-235	4.65E+00	1.85E+00	6.50E+00	1.81E-01	
U-236	1.36E+00	2.62E-01	1.62E+00	4.38E-02	
U-237	3.48E-01	9.16E-03	3.57E-01	7.27E-04	

Table C-4. Calculated Wattage at 2133 (continued)

Radionuclide	Inventory in Year 2133 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
U-238	3.92E+01	3.13E+00	4.23E+01	1.07E+00	
U-240	5.79E-03	2.82E-02	3.40E-02	2.77E-05	
V-49	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
W-181	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Y-90	6.97E+01	1.67E+04	1.68E+04	9.27E+01	
Zn-65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Zr-93	1.37E-03	2.44E-01	2.45E-01	2.82E-05	
Total	**2.64E+06**	**1.16E+05**	**2.76E+06**	**8.62E+04**	**99.57**

[1] Van Soest 2018, Tables 5-3 and 5-4.
[2] Wattage is calculated using Equation 5.

Table C-5. Calculated Wattage at 12033

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Ac-225	6.63E+01	1.03E+01	7.66E+01	2.70E+00	
Ac-227	1.45E+01	3.57E-01	1.49E+01	7.51E-03	
Ac-228	9.60E-02	2.26E-02	1.19E-01	9.26E-04	
Ag-108	2.87E-28	1.02E-26	1.05E-26	3.88E-29	
Ag-108m	3.30E-27	1.17E-25	1.20E-25	1.17E-27	
Ag-109m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ag-110	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ag-110m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Am-241	1.65E+00	1.02E+01	1.19E+01	3.97E-01	0.00
Am-242	2.00E-21	2.11E-21	4.11E-21	4.85E-24	
Am-242m	2.00E-21	2.12E-21	4.13E-21	1.80E-24	
Am-243	8.94E+00	1.61E+02	1.70E+02	5.48E+00	
Am-245	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Am-246	1.96E-08	3.95E-07	4.15E-07	3.62E-09	
Ar-39	0.00E+00	3.07E-13	3.07E-13	3.99E-16	
Ar-42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
At-217	6.63E+01	1.03E+01	7.66E+01	3.27E+00	
Ba-133	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ba-137m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Be-10	0.00E+00	1.02E-05	1.02E-05	1.53E-08	
Bi-210	5.50E+01	3.51E+00	5.85E+01	1.35E-01	

Table C-5. Calculated Wattage at 12033 (continued)

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Bi-211	1.45E+01	3.57E-01	1.49E+01	5.93E-01	
Bi-212	9.60E-02	2.26E-02	1.19E-01	1.99E-03	
Bi-213	6.63E+01	1.03E+01	7.66E+01	3.16E-01	
Bi-214	5.50E+01	3.51E+00	5.85E+01	7.43E-01	
Bk-249	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Bk-250	1.10E-08	2.21E-07	2.32E-07	1.64E-09	
C-14	6.77E-03	1.59E+01	1.59E+01	4.67E-03	
Ca-45	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cd-109	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cd-113	4.14E-22	1.86E-17	1.86E-17	1.02E-20	
Cd-113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ce-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ce-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cf-249	2.82E-08	9.59E-08	1.24E-07	4.63E-09	
Cf-250	1.10E-08	2.21E-07	2.32E-07	8.66E-09	
Cf-251	4.47E-05	3.73E-03	3.77E-03	1.38E-04	
Cf-252	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cl-36	1.98E-07	0.00E+00	1.98E-07	3.20E-10	
Cm-242	1.66E-21	1.75E-21	3.41E-21	1.26E-22	
Cm-243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cm-244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cm-245	1.52E+00	1.02E+01	1.17E+01	3.92E-01	
Cm-246	1.26E+01	1.05E+02	1.18E+02	3.86E+00	
Cm-247	3.34E-01	4.13E-02	3.75E-01	1.19E-02	
Cm-248	4.53E-01	1.28E+00	1.73E+00	2.32E-01	
Cm-250	7.83E-08	1.58E-06	1.66E-06	1.59E-06	
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Cs-135	1.66E-04	6.45E-02	6.46E-02	3.43E-05	
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Dy-159	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Es-254	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-149	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-152	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-154	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Eu-155	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Fe-55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Table C-5. Calculated Wattage at 12033 (continued)

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Fr-221	6.63E+01	1.03E+01	7.66E+01	2.93E+00	
Fr-223	2.00E-01	4.93E-03	2.05E-01	5.37E-04	
Gd-152	1.04E-12	7.08E-12	8.12E-12	1.06E-13	
Gd-153	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ho-166m	3.30E-06	9.10E-08	3.39E-06	3.56E-08	
I-129	5.02E-03	8.30E-01	8.35E-01	4.46E-04	
In-113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
In-115	0.00E+00	1.33E-16	1.33E-16	1.20E-19	
Ir-194	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
K-40	4.00E-02	0.00E+00	4.00E-02	1.61E-04	
K-42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Kr-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
La-137	0.00E+00	7.76E-07	7.76E-07	1.45E-10	
Lu-177	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Lu-177m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Mn-54	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Mo-93	0.00E+00	7.55E-02	7.55E-02	7.29E-06	
Na-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Nb-91	0.00E+00	2.66E-06	2.66E-06	2.78E-10	
Nb-92	0.00E+00	6.52E-08	6.52E-08	5.85E-10	
Nb-93m	1.37E-03	3.05E-01	3.07E-01	5.71E-05	
Nb-94	1.40E-03	3.09E+00	3.09E+00	3.16E-02	
Nd-144	1.54E-13	8.52E-12	8.68E-12	9.80E-14	
Ni-59	2.31E-02	4.70E+02	4.70E+02	1.92E-02	
Ni-63	4.42E-30	7.30E-28	7.35E-28	7.58E-32	
Np-235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Np-237	2.67E+02	9.91E+00	2.77E+02	8.14E+00	
Np-238	9.02E-24	9.55E-24	1.86E-23	9.24E-26	
Np-239	8.94E+00	1.61E+02	1.70E+02	4.50E-01	
Np-240	6.99E-06	3.40E-05	4.10E-05	3.80E-07	
Np-240m	5.83E-03	2.83E-02	3.41E-02	2.02E-04	
Os-185	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Os-194	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pa-231	1.45E+01	3.57E-01	1.48E+01	4.54E-01	
Pa-233	2.67E+02	9.91E+00	2.77E+02	7.20E-01	
Pa-234	5.09E-02	4.07E-03	5.50E-02	6.12E-04	

Table C-5. Calculated Wattage at 12033 (continued)

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Pa-234m	3.92E+01	3.13E+00	4.23E+01	2.09E-01	
Pb-209	6.63E+01	1.03E+01	7.66E+01	8.97E-02	
Pb-210	5.50E+01	3.51E+00	5.85E+01	1.58E-02	
Pb-211	1.45E+01	3.57E-01	1.49E+01	4.57E-02	
Pb-212	9.60E-02	2.26E-02	1.19E-01	2.26E-04	
Pb-214	5.50E+01	3.51E+00	5.85E+01	1.90E-01	
Pd-107	3.30E-06	1.70E-02	1.70E-02	9.69E-07	
Pm-145	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pm-146	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pm-147	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Po-210	5.50E+01	3.51E+00	5.85E+01	1.87E+00	
Po-211	3.99E-02	9.82E-04	4.08E-02	1.84E-03	
Po-212	6.15E-02	1.45E-02	7.60E-02	4.03E-03	
Po-213	6.49E+01	1.01E+01	7.50E+01	3.80E+00	
Po-214	5.50E+01	3.51E+00	5.85E+01	2.71E+00	
Po-215	1.45E+01	3.57E-01	1.49E+01	6.63E-01	
Po-216	9.60E-02	2.26E-02	1.19E-01	4.86E-03	
Po-218	5.50E+01	3.51E+00	5.85E+01	2.12E+00	
Pr-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pr-144m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pu-236	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Pu-238	4.40E-21	4.66E-21	9.06E-21	3.01E-22	0.00
Pu-239	6.52E+05	3.23E+03	6.56E+05	2.04E+04	85.17
Pu-240	1.10E+05	1.13E+03	1.11E+05	3.46E+03	14.47
Pu-241	1.52E+00	1.02E+01	1.18E+01	3.76E-04	
Pu-242	1.45E+02	2.00E+01	1.66E+02	4.89E+00	0.02
Pu-243	3.34E-01	4.13E-02	3.75E-01	4.42E-04	
Pu-244	5.84E-03	2.83E-02	3.42E-02	9.95E-04	
Pu-246	1.96E-08	3.95E-07	4.15E-07	6.37E-10	
Ra-223	1.45E+01	3.57E-01	1.49E+01	5.27E-01	
Ra-224	9.60E-02	2.26E-02	1.19E-01	4.07E-03	
Ra-225	6.63E+01	1.03E+01	7.66E+01	5.43E-02	
Ra-226	5.50E+01	3.51E+00	5.85E+01	1.69E+00	
Ra-228	9.60E-02	2.26E-02	1.19E-01	1.15E-05	
Rb-87	1.80E-10	1.29E-06	1.29E-06	8.82E-10	
Rh-102	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Rh-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Table C-5. Calculated Wattage at 12033 (continued)

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Rn-219	1.45E+01	3.57E-01	1.49E+01	6.12E-01	
Rn-220	9.60E-02	2.26E-02	1.19E-01	4.50E-03	
Rn-222	5.50E+01	3.51E+00	5.85E+01	1.94E+00	
Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
S-35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sb-125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sb-126	1.10E-06	7.51E-03	7.51E-03	1.39E-04	
Sb-126m	1.59E-05	1.14E-01	1.14E-01	1.47E-03	
Sc-46	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Se-75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Se-79	6.75E-05	1.76E-01	1.76E-01	5.52E-05	
Sm-145	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sm-146	1.81E-13	7.13E-08	7.13E-08	1.07E-09	
Sm-147	1.24E-09	9.46E-08	9.59E-08	1.31E-09	
Sm-148	1.75E-16	9.12E-17	2.66E-16	3.13E-18	
Sm-151	4.48E-33	4.99E-32	5.43E-32	6.44E-36	
Sn-113	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-119m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-121	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-123	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Sn-126	1.59E-05	1.14E-01	1.14E-01	1.31E-04	
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Ta-182	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tb-157	0.00E+00	1.57E-21	1.57E-21	1.06E-25	
Tc-97	0.00E+00	1.68E-06	1.68E-06	1.69E-10	
Tc-97m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tc-98	0.00E+00	3.38E-07	3.38E-07	3.12E-09	
Tc-99	4.41E+01	5.16E+02	5.60E+02	3.36E-01	
Te-121	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-123	6.98E-22	3.41E-14	3.41E-14	6.28E-19	
Te-123m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-125m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-127	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Te-127m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Th-227	1.43E+01	3.52E-01	1.46E+01	5.38E-01	

Table C-5. Calculated Wattage at 12033 (continued)

Radionuclide	Inventory in Year 12033 (Ci)[1]			Wattage[2]	Wattage Fraction (selected)
	CH	RH	Total	(W)	(%)
Th-228	9.60E-02	2.26E-02	1.19E-01	3.88E-03	
Th-229	6.63E+01	1.03E+01	7.66E+01	2.35E+00	
Th-230	7.05E+01	3.59E+00	7.40E+01	2.09E+00	
Th-231	1.20E+01	1.89E+00	1.39E+01	1.56E-02	
Th-232	9.60E-02	2.26E-02	1.19E-01	2.87E-03	
Th-234	3.92E+01	3.13E+00	4.23E+01	1.83E-02	
Tl-204	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tl-206	7.25E-05	4.63E-06	7.72E-05	2.47E-07	
Tl-207	1.45E+01	3.56E-01	1.48E+01	4.37E-02	
Tl-208	3.45E-02	8.12E-03	4.26E-02	1.00E-03	
Tl-209	1.39E+00	2.17E-01	1.61E+00	2.70E-02	
Tm-170	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Tm-171	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
U-232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
U-233	1.16E+02	1.69E+01	1.33E+02	3.86E+00	
U-234	7.91E+02	1.73E+01	8.09E+02	2.33E+01	
U-235	1.20E+01	1.89E+00	1.39E+01	3.86E-01	
U-236	5.82E+01	8.47E-01	5.91E+01	1.60E+00	
U-237	3.64E-05	2.44E-04	2.81E-04	5.72E-07	
U-238	3.92E+01	3.13E+00	4.23E+01	1.07E+00	
U-240	5.83E-03	2.83E-02	3.41E-02	2.78E-05	
V-49	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
W-181	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Y-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Zn-65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Zr-93	1.37E-03	2.43E-01	2.44E-01	2.81E-05	
Total	**7.66E+05**	**6.04E+03**	**7.72E+05**	**2.39E+04**	**99.65**

[1] Van Soest 2018, Tables 5-3 and 5-4.
[2] Wattage is calculated using Equation 5.

APPENDIX D – Parameter Data Entry Tables

The following tables identify parameter value changes associated with the inventory provided by PAIR-2018 (Van Soest 2018). The data found in Table D-1 through Table D-6 support Parameter Data Entry form NP 9-2-1 for changing parameters affected by this document. The data in Table D-2 and Table D-4 are provided directly from PAIR-2018 (Van Soest 2018). The data in Table D-1, Table D-3, and Table D-5 are calculated within this report using inputs provided by PAIR-2018. The data in Table D-6 are provided directly from ICRP 2008, Table A.1.

Table D-1. Waste Unit Factor (WUF) Parameter Change

Material	Property	Value / Median	Units	Distribution	Source
BOREHOLE	WUF	3.30	NONE	Constant	Appendix B, Table B-2

NOTE: The WUF parameter is used by PA codes EPAUNI, NUTS, PANEL, and PRECCDFGF.

Table D-2. Radionuclide Parameter Changes

Material	Property	Value / Median	Units	Distribution	Source
AM241	INVCHD	1.13E+06	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
AM241	INVRHD	1.30E+04	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
AM243	INVCHD	2.24E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
AM243	INVRHD	4.12E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CF252	INVCHD	5.07E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
CF252	INVRHD	1.76E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CM243	INVCHD	2.54E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
CM243	INVRHD	3.61E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CM244	INVCHD	6.19E+03	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)

Table D-2. Radionuclide Parameter Changes (continued)

Material	Property	Value / Median	Units	Distribution	Source
CM244	INVRHD	3.32E+04	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CM245	INVCHD	2.97E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
CM245	INVRHD	2.15E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CM248	INVCHD	4.63E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
CM248	INVRHD	1.31E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
CS137	INVCHD	6.16E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
CS137	INVRHD	2.50E+05	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
NP237	INVCHD	2.75E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
NP237	INVRHD	6.96E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PA231	INVCHD	1.59E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PA231	INVRHD	1.04E-03	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PB210	INVCHD	9.79E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PB210	INVRHD	1.45E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PM147	INVCHD	4.40E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PM147	INVRHD	2.54E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PU238	INVCHD	9.42E+05	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU238	INVRHD	2.25E+04	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)

Table D-2. Radionuclide Parameter Changes (continued)

Material	Property	Value / Median	Units	Distribution	Source
PU239	INVCHD	8.70E+05	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU239	INVRHD	4.22E+03	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PU240	INVCHD	3.16E+05	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU240	INVRHD	3.16E+03	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PU241	INVCHD	1.82E+06	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU241	INVRHD	4.53E+04	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PU242	INVCHD	1.48E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU242	INVRHD	1.59E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
PU244	INVCHD	5.80E-03	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
PU244	INVRHD	2.82E-02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
RA226	INVCHD	1.78E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
RA226	INVRHD	1.85E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
RA228	INVCHD	9.03E-02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
RA228	INVRHD	4.55E-02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
SM147	INVCHD	1.23E-09	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
SM147	INVRHD	9.40E-08	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)

Table D-2. Radionuclide Parameter Changes (continued)

Material	Property	Value / Median	Units	Distribution	Source
SR90	INVCHD	8.18E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
SR90	INVRHD	1.96E+05	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
TH229	INVCHD	3.80E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
TH229	INVRHD	8.74E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
TH230	INVCHD	3.98E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
TH230	INVRHD	2.26E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
TH232	INVCHD	9.60E-02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
TH232	INVRHD	2.26E-02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
U233	INVCHD	1.10E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
U233	INVRHD	1.72E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
U234	INVCHD	4.77E+02	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
U234	INVRHD	9.70E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
U235	INVCHD	4.56E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
U235	INVRHD	1.85E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)
U236	INVCHD	4.24E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
U236	INVRHD	2.53E-01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)

Table D-2. Radionuclide Parameter Changes (continued)

Material	Property	Value / Median	Units	Distribution	Source
U238	INVCHD	3.92E+01	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-3)
U238	INVRHD	3.13E+00	Ci	Constant	PAIR-2018 (Van Soest 2018, Table 5-4)

NOTES: INVCHD and INVRHD refer to contact-handled waste and remote-handled waste, respectively. These inventory parameters are used by PA code PANEL.

Table D-3. Lumped Radionuclide Parameter Changes

Material	Property	Value / Median	Units	Distribution	Source
AM241L	INVCHD	1.19E+06	Ci	Constant	Section 5.3, Table 7
AM241L	INVRHD	1.45E+04	Ci	Constant	Section 5.3, Table 7
TH230L	INVCHD	7.78E-01	Ci	Constant	Section 5.3, Table 7
TH230L	INVRHD	3.13E+00	Ci	Constant	Section 5.3, Table 7
PU238L	INVCHD	9.42E+05	Ci	Constant	Section 5.3, Table 7
PU238L	INVRHD	2.25E+04	Ci	Constant	Section 5.3, Table 7
U234L	INVCHD	5.86E+02	Ci	Constant	Section 5.3, Table 7
U234L	INVRHD	2.69E+01	Ci	Constant	Section 5.3, Table 7
PU239L	INVCHD	1.19E+06	Ci	Constant	Section 5.3, Table 7
PU239L	INVRHD	7.63E+03	Ci	Constant	Section 5.3, Table 7

NOTES: INVCHD and INVRHD refer to contact-handled waste and remote-handled waste, respectively. These lumped inventory parameters are used by PA code PANEL.

Table D-4. Waste Material Parameter Changes

Material	Property [b]	Description	Value / Median	Units	Distribution	Source
WAS_AREA	IRONCHW	Mass of iron-based material in CH waste	1.41E+07	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	IRONRHW	Mass of iron-based material in RH waste	1.33E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	IRNCCHW	Mass of iron containers, CH waste	3.12E+07	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	IRNCRHW	Mass of iron containers, RH waste	1.65E+07	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	CELLCHW	Mass of cellulosics in CH waste	4.10E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	CELLRHW	Mass of cellulosics in RH waste	1.70E+05	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	CELCCHW	Mass of cellulosics in CH waste container materials	1.47E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	CELCRHW	Mass of cellulosics in RH waste container materials	0.00E+00	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	CELECHW	Mass of cellulosics in CH waste emplacement materials	2.24E+05	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-7)
WAS_AREA	CELERHW	Mass of cellulosics in RH waste emplacement materials	0.00E+00 [a]	kg	Constant	Assumed based on PAIR-2018 data. See Note a
WAS_AREA	PLASCHW	Mass of plastics in CH waste	5.32E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	PLASRHW	Mass of plastics in RH waste	4.14E+05	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	PLSCCHW	Mass of plastic liners, CH waste	2.83E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	PLSCRHW	Mass of plastic liners, RH waste	4.68E+05	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	PLSECHW	Mass of plastic in CH waste emplacement materials	1.55E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-7)

Table D-4. Waste Material Parameter Changes (continued)

Material	Property [b]	Description	Value / Median	Units	Distribution	Source
WAS_AREA	PLSERHW	Mass of plastic in RH waste emplacement materials	0.00E+00 [a]	kg	Constant	Assumed based on PAIR-2018 data. See Note a
WAS_AREA	RUBBCHW	Mass of rubber in CH waste	1.09E+06	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	RUBBRHW	Mass of rubber in RH waste	5.12E+04	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	RUBCCHW	Mass of rubber in CH waste container materials	7.28E+04	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	RUBCRHW	Mass of rubber in RH waste container materials	5.73E+03	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-5)
WAS_AREA	RUBECHW	Mass of rubber in CH waste emplacement materials	4.79E+03	kg	Constant	PAIR-2018 (Van Soest 2018, Table 5-7)
WAS_AREA	RUBERHW	Mass of rubber in RH waste emplacement materials	0.00E+00 [a]	kg	Constant	Assumed based on PAIR-2018 data. See Note a

NOTES: [a] The emplacement materials identified by Van Soest (2018, Table 5-7) are for CH waste only. Currently, no cellulosic, plastic, or rubber emplacement materials are used for RH waste emplacement.
[b] The waste material parameters are used by PA code BRAGFLO.

Table D-5. Oxyanion Parameter Changes

Material	Property	Value / Median	Units	Distribution	Source
NITRATE	QINIT	2.72E+07	mol	Constant	Section 6
SULFATE	QINIT	4.73E+06	mol	Constant	Section 6

NOTE: The oxyanion parameters are used by PA code BRAGFLO.

Table D-6. Radiolysis and Decay Parameter Changes

Material	Property	Description	Value / Median	Units	Distribution	Source
AM241	DECAYNRG	Radionuclide disintegration energy	5.6379	MeV	Constant	ICRP 2008, Table A.1
PU238	DECAYNRG	Radionuclide disintegration energy	5.593	MeV	Constant	
PU239	DECAYNRG	Radionuclide disintegration energy	5.2442	MeV	Constant	
PU240	DECAYNRG	Radionuclide disintegration energy	5.2559	MeV	Constant	
PU242	DECAYNRG	Radionuclide disintegration energy	4.9855	MeV	Constant	

NOTE: The radiolysis and decay parameters are used by PA code BRAGFLO.

APPENDIX E – Generation of EPAUNI Input Files

This appendix provides information on the Microsoft® Excel® 2016 file used to generate EPAUNI input files. The Excel file, *CRA-2019_ScreeningAnalysisR0.xlsx*, was developed on a PC workstation running Windows 10 Enterprise and is included as a machine readable (CD ROM) supplement to this report.

The Excel file, *CRA-2019_ScreeningAnalysisR0.xlsx*, was created to select the radionuclides of interest from the inventory data provided by LANL. LANL provided scaled waste stream volumes (in m^3) and inventory of radionuclides on a waste stream basis for both CH- and RH-TRU waste, supplied in curies and decayed to the year 2033, for a set of radionuclides (Van Soest 2018, Tables 5-1 and 5-2). The inventory data include 510 CH waste streams and 97 RH waste streams. LANL also provided an Excel file (*PAIR-2018 Tables.xlsx*) containing this data, which is also included on the CD-ROM supplement to this report. LANL data (Van Soest 2018, Tables 5-1 and 5-2) were copied into the Excel file, *CRA-2019_ScreeningAnalysisR0.xlsx*, worksheets "CH 2033" and "RH 2033". Radionuclides of interest from worksheets "CH 2033" and "RH 2033" were copied into worksheets "EPAUNI CH" and "EPAUNI RH." Also, any spaces in the waste stream names were replaced with dashes. The data in worksheets "EPAUNI CH" and "EPAUNI RH" were copied into a text editor, saved as ASCII files *epu_CRA19_ch.inp* and *epu_CRA19_rh.inp*, and formatted for use by EPAUNI.

The development of the EPAUNI input files was verified by comparing selected values in the data in the files to the data in the spreadsheet and verifying that the files had the same number of records as in the spreadsheet. The worksheets "CH 2033" and "RH 2033" were used for these comparisons. For example, the spreadsheet for CH waste is shown in Figure E-1.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	CH Volume and Activity By Waste Stream and Radionuclide Decayed through 2033												
2	Site	Waste Stream ID	Scaled Volume (m^3)	Am-241	Am-243	Cm-244	Cs-137	Np-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
3	AE	AE-T001	133.12	2.71E+01	9.76E-01	7.18E+01	1.57E+01	3.94E-02	1.10E+00	1.46E+01	6.69E+00	1.32E+01	8.04E-02
4	AE	AE-T003	17.70	1.91E+00	5.02E-02	5.09E-03	2.31E-01	2.85E-03	3.83E+00	2.06E+00	1.88E+00	6.86E+00	4.64E-03
5	AE	WP-AECHDM	102.33	5.42E+01	1.88E+00	4.30E-02	9.73E-01	1.23E-01	5.20E+01	8.54E+01	6.45E+01	2.56E+01	2.62E-02
6	AE	WP-AECHHM	13.95	1.41E+01	5.13E-03	--	7.63E-04	1.83E-03	3.62E+00	4.13E+01	1.64E+01	2.96E-10	2.02E-03
7	AE	WP-MU-W002	4.50	6.72E+00	1.13E-03	--	9.16E-07	3.91E-03	--	2.27E-02	--	--	--
8	AW	AW-5649N	0.21	6.51E-04	--	--	--	4.13E-09	5.98E-06	3.07E-03	5.98E-04	4.87E-03	--
9	AW	AW-N027.531	5.73	5.75E+01	7.77E-09	--	3.46E-04	2.82E-03	--	1.87E+00	--	--	--
10	AW	AW-T033.1325	34.78	7.27E+01	1.58E-02	9.10E-01	8.98E-01	1.28E-01	3.89E+00	1.24E+01	1.65E-01	--	1.34E-04

Readme | CH 2033 | RH 2033 | CH_Data | RH_Data | Waste and Packaging Materials | WUF Calculation | W

	A	B	C	N	O	P	Q	R	S	T	U	V	W
1	CH Volume and Activity By Waste Stream and Radionuclide Decayed through 2033												
2	Site	Waste Stream ID	Scaled Volume (m^3)	Pu-244	Sr-90	Th-229	Th-230	Th-232	U-233	U-234	U-235	U-236	U-238
3	AE	AE-T001	133.12	2.63E-05	1.22E+01	1.04E-04	5.53E-04	3.92E-04	2.03E-02	3.30E-01	3.68E-04	6.75E-06	9.85E-03
4	AE	AE-T003	17.70	4.14E-07	1.11E-01	5.13E-07	3.47E-04	8.83E-05	2.64E-04	1.33E-02	6.80E-06	4.94E-06	3.26E-04
5	AE	WP-AECHDM	102.33	5.89E-16	9.71E-01	8.62E-03	2.23E-05	4.24E-14	4.20E-02	8.33E-02	1.50E-03	5.73E-05	4.41E-02
6	AE	WP-AECHHM	13.95	--	7.62E-04	3.21E-04	1.52E-06	1.08E-14	2.30E-07	5.67E-03	1.07E-04	1.46E-05	2.69E-03
7	AE	WP-MU-W002	4.50	--	9.15E-07	1.09E-03	2.02E-13	--	5.05E-07	1.46E-09	6.70E-10	--	1.73E-05
8	AW	AW-5649N	0.21	--	--	1.35E-16	5.54E-14	2.74E-19	1.98E-13	4.67E-10	7.56E-11	4.43E-10	--
9	AW	AW-N027.531	5.73	--	3.61E-04	1.27E-10	4.95E-13	--	1.84E-07	6.73E-09	2.13E-05	--	1.50E-04
10	AW	AW-T033.1325	34.78	--	8.51E-01	6.24E-09	3.55E-07	2.34E-15	8.87E-06	2.50E-03	1.46E-04	3.00E-06	6.87E-03

Readme | CH 2033 | RH 2033 ...

Figure E-1. Example CH Waste Data from Excel Spreadsheet *CRA-2019_ScreeningAnalysisR0.xlsx*

The data from the CH input file (*epu_CRA19_ch.inp*) that correspond to Figure E-1 are listed as follows:

```
StreamRH (Really CH) Volume(m3) Am-241 Cm-244 Pu-238 Pu-239 Pu-240 Pu-241 U-234
      Cs-137 Sr-90 U-233
AE-T001 1.33E+02 2.71E+01 7.16E+01 1.10E+00 1.46E+01 6.89E+00 1.32E+01 3.30E-01
      1.57E+01 1.22E+01 2.03E-02
AE-T003 1.77E+01 1.91E+00 5.09E-03 3.83E+00 2.06E+00 1.88E+00 6.86E+00 1.33E-02
      2.31E-01 1.11E-01 2.64E-04
WP-AECHDM 1.02E+02 5.42E+01 4.30E-02 5.20E+01 8.54E+01 6.45E+01 2.56E+01 8.33E-02
      9.73E-01 9.71E-01 4.20E-02
WP-AECHHM 1.40E+01 1.41E+01 0.00E+00 3.62E+00 4.13E+01 1.64E+01 2.96E-10 5.67E-03
      7.63E-04 7.62E-04 2.30E-07
WP-MU-W002 4.50E+00 6.72E+00 0.00E+00 0.00E+00 2.27E-02 0.00E+00 0.00E+00 1.46E-09
      9.16E-07 9.15E-07 5.05E-07
AW-5649N 2.10E-01 6.51E-04 0.00E+00 5.98E-06 3.07E-03 5.98E-04 4.87E-03 4.67E-10
      0.00E+00 0.00E+00 1.98E-13
AW-N027.531 5.73E+00 5.75E+01 0.00E+00 0.00E+00 1.87E+00 0.00E+00 0.00E+00 6.73E-09
      3.46E-04 3.61E-04 1.84E-07
AW-T033.1325 3.48E+01 7.27E+01 9.10E-01 3.89E+00 1.24E+01 1.65E-01 0.00E+00 2.50E-03
      8.98E-01 8.51E-01 8.87E-06
```

Note that the header specified the data as StreamRH (Really CH). The StreamRH title is used by EPAUNI to indicate that 10 radionuclides will be written into a logical record consisting of two physical records.

An example using the RH sheet is shown in Figure E-2.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	RH Volume and Activity By Waste Stream and Radionuclide Decayed through 2033												
2	Site	Waste Stream ID	Scaled Volume (m^3)	Am-241	Am-243	Cm-244	Cs-137	Np-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
3	AE	AE-T009	356.53	7.51E+02	1.88E+01	1.78E+02	6.36E+03	1.03E-02	6.11E+02	5.72E+02	3.38E+02	2.18E+03	2.60E-01
4	AE	WP-AERHDM	66.56	5.38E+02	2.37E-01	6.27E+02	5.40E+03	5.80E-03	6.92E+02	1.83E+02	1.48E+02	2.79E+03	3.49E-01
5	AW	AW-5410N	0.63	4.92E-02	1.96E-04	7.98E-07	1.66E-01	5.25E-06	1.85E-02	6.01E-03	9.03E-03	1.16E-01	2.45E-05
6	AW	AW-5882N	0.63	1.21E-01	--	--	1.33E-01	1.16E-06	--	--	--	--	--
7	AW	AW-T031.1322	285.11	8.93E+02	1.48E-01	2.11E+01	9.08E+03	9.11E-01	2.20E+02	2.56E+02	2.74E+01	1.80E+02	9.32E-02
8	AW	AW-W020.13	82.72	5.78E+02	2.71E-03	2.05E-02	1.77E+04	4.55E-02	1.90E+02	2.81E+02	9.29E+01	1.55E+03	1.63E-02
9	BT	BT-T001	192.48	6.19E-01	2.26E-03	--	7.50E+02	3.25E-03	2.21E+01	2.06E-02	--	1.59E+00	3.73E-04
10	BT	WP-BT-T001	3.15	9.40E-02	--	2.24E-02	7.96E+00	6.63E-07	1.02E+00	1.10E-02	1.55E-02	1.03E-01	6.56E-03
11	IN	IN-AE-AGHC-02	55.44	1.86E-01	--	5.63E-06	1.37E+04	9.96E-07	4.53E-02	4.26E+02	2.23E+02	3.99E-01	4.83E-05

Readme | CH 2033 | RH 2033 | CH_Data | RH_Data | Waste and Packaging Materials | WUF Calculation

Figure E-2. Example RH Waste Data from Excel Spreadsheet *CRA-2019_ScreeningAnalysisR0.xlsx*

The data from the RH input file (*epu_CRA19_rh.inp*) that correspond to Figure E-2 are listed as follows:

```
StreamRH Volume(m3) Am-241 Cm-244 Pu-238 Pu-239 Pu-240 Pu-241 U-234
      Cs-137 Sr-90 U-233
AE-T009 3.57E+02 7.51E+02 1.78E+02 6.11E+02 5.72E+02 3.38E+02 2.18E+03 1.78E-01
      6.36E+03 4.45E+03 4.98E-04
WP-AERHDM 6.66E+01 5.38E+02 6.27E+02 6.92E+02 1.83E+02 1.48E+02 2.79E+03 6.25E-01
      5.40E+03 3.19E+03 4.71E-02
AW-5410N 6.30E-01 4.92E-02 7.98E-07 1.85E-02 6.01E-03 9.03E-03 1.16E-01 3.05E-06
      1.66E-01 3.39E-01 5.27E-10
AW-5882N 6.30E-01 1.21E-01 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 9.05E-09
```

```
      1.33E-01 1.27E-01 7.37E-11
AW-T031.1322 2.85E+02 8.93E+02 2.11E+01 2.20E+02 2.56E+02 2.74E+01 1.80E+02 6.51E-01
      9.08E+03 1.38E+04 6.47E-05
AW-W020.13 8.27E+01 5.78E+02 2.05E-02 1.90E+02 2.81E+02 9.29E+01 1.55E+03 1.81E+00
      1.77E+04 8.96E+03 1.40E-01
BT-T001 1.92E+02 6.19E-01 0.00E+00 2.21E+01 2.06E-02 0.00E+00 1.59E+00 7.52E-03
      7.50E+02 7.24E+02 2.05E-01
WP-BT-T001 3.15E+00 9.40E-02 2.24E-02 1.02E+00 1.10E-02 1.55E-02 1.03E-01 2.35E-03
      7.96E+00 1.13E+01 7.38E-03
IN-AE-AGHC-02 5.54E+01 1.86E-01 5.83E-06 4.53E-02 4.26E+02 2.23E+02 3.99E-01 1.18E-03
      1.37E+04 2.09E+04 9.91E-09
```

The EPAUNI input files *epu_CRA19_ch_misc.inp* and *epu_CRA19_rh_misc.inp* contain two lines of data and provide control flags (line 1) and the WUF value (line 2). Because the control flags and WUF are the same for both CH and RH waste, these two input files are identical. The control flags include the following values:

- 0 (no diagnostic print statements)
- 2 (printout all files)
- 0 (read the input file with free format)
- 0 (data are read in as either CH or RH)
- 2033 (base year for the radionuclide inventory).

The WUF value in line 2 is 3.30 (as documented in Section 2.2).

The data files were subsequently transferred to the Sun Solaris cluster.