Radioactive and Nonradioactive Waste Intended for Disposal at the Waste Isolation Pilot Plant

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Abstract

Transuranic (TRU) waste generated by the handling of plutonium in research on or production of U.S. nuclear weapons will be disposed of in the Waste Isolation Pilot Plant (WIPP). This paper describes the physical and radiological properties of the TRU waste that will be deposited in the WIPP. This geologic repository will accommodate up to 175,564 m³ of TRU waste, corresponding to 168,485 m³ of contact-handled (CH-) TRU waste and 7,079 m³ of remote-handled (RH-) TRU waste. Approximately 35% of the TRU waste is currently packaged and stored (i.e., legacy) waste, with the remainder of the waste to be packaged or generated and packaged in activities before the year 2033, the closure time for the repository. These wastes were produced at 27 U.S. Department of Energy (DOE) sites in the course of generating defense nuclear materials. The radionuclide and nonradionuclide inventories for the TRU wastes described in this paper were used in the 1996 WIPP Compliance Certification Application (CCA) performance assessment calculations by Sandia National Laboratories/New Mexico (SNL/NM).

Key Words: Compliance certification application (CCA), contact-handled (CH-) transuranic (TRU) waste, containment requirements, performance assessment, radioactive waste, radionuclide inventory, release limits, remote-handled (RH-) TRU, source term, Waste Isolation Pilot Plant, 40 CFR 191.

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1. Introduction

The Waste Isolation Pilot Plant (WIPP) is being developed by the U.S. Department of Energy (DOE) for the deep geologic disposal of transuranic (TRU) waste[1]. The WIPP is located near Carlsbad, NM, in a large bedded salt deposit. The WIPP Land Withdrawal Act (WIPP LWA, Public Law 102-579)[2] allows up to 6.2 million ft³ (175,564 m³, approximately 845,000 55-gallon drum equivalents) of TRU waste to be disposed at the WIPP. This paper describes the key properties of the radioactive and nonradioactive constituents of the waste intended for disposal at the WIPP.

Transuranic isotopes have an atomic number greater than that of uranium (92), and the definition of TRU waste is given in the Code of Federal Regulations[3] as

“waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.”

The TRU waste category was introduced in 1970, when the U.S. Atomic Energy Commission decided that TRU wastes should be disposed in geologic repositories. Existing TRU wastes were generated at DOE sites where they resulted from the handling of plutonium in the research on or production of nuclear weapons. Prior to 1970, waste contaminated with transuranic isotopes was disposed with low-level wastes at waste generator sites in shallow landfills. This waste is referred to as buried waste and is not destined for placement in the WIPP. Only newly generated TRU waste and retrievably stored TRU waste will be disposed in the WIPP repository. The newly generated TRU wastes include only those TRU wastes that have been generated after a site's implementation of DOE's TRU Waste Characterization Quality Assurance Program Plan (QAPP)[4]. The retrievably stored TRU wastes are post-1970 TRU wastes generated before the implementation of the QAPP that have been segregated from other wastes and placed in retrievable storage. The volume of these existing TRU wastes equals approximately 35 percent of the design capacity for WIPP. The remaining 65 percent of the capacity is intended for projected TRU waste. It is anticipated that only a small portion of the projected waste will actually be produced in future years, as most of the generator sites are no longer producing nuclear materials. Thus, most of the projected waste will be TRU wastes that currently exist at the generator sites in the form of plutonium residues, decontamination debris, and so forth that have yet to be assayed and packaged. These projected TRU wastes are expected to have characteristics similar to the existing (legacy) waste.

Two types of transuranic radioactive waste will be disposed in WIPP: mixed waste that contains radionuclides along with hazardous substances, such as lead or solvents and non-mixed waste that contains only radioactive

substances. Only inventory information for the radioactive (i.e., nonhazardous) components of the waste were used in the 1996 performance assessment (PA) of the WIPP repository. The hazardous components were not modeled in the PA because their biological risks are believed to be insignificant in comparison to the radioactive risks. They are regulated separately as part of the Resource Conservation and Recovery Act permitting process implemented by the New Mexico Environment Department.

The TRU waste is subdivided into contact-handled (CH) and remote-handled (RH) waste on the basis of the dose equivalent rate at the surface of the waste container. If the dose rate is less than 200 millirem/hr (2 milliSievert/hr), the waste is categorized as CH-TRU waste; otherwise, the categorization is RH-TRU waste. Volumetric limits on these waste classes are set in the WIPP Land Withdrawal Act (LWA)[2] and the "Agreement for Consultation and Cooperation,"[5] with limits of 0.25 million ft³ (7,079 m³) of RH-TRU waste and 5.95 million ft³ (168,485 m³) of CH-TRU waste. Further limitations include

- Surface dose rate limits for the RH-TRU waste of 1,000 rem/hr (10 Sievert/hr), with no more than five percent by volume of RH-TRU waste exceeding 100 rem/hr (1 Sievert/hr)
- 23 curies (85.1×10^{10} Bq) per liter limit for RH-TRU waste (averaged over the volume of the canister)
- Total curies of RH-TRU waste of no more than 5.1 million curies ($\sim 18.9 \times 10^{16}$ Bq) at WIPP.

Most of the TRU waste to be disposed at the WIPP site is contaminated sludges and trash such as rags, tools, and protective clothing or equipment. The bulk of these wastes resulted from activities associated with the production of nuclear weapons during the Cold War, including plutonium fabrication and reprocessing, research and development (R&D), decontamination and decommissioning (D&D), and environmental restoration programs at various waste generator sites[6]. Examples of these operations include

- Production of nuclear products – reactor operation, radionuclide separation and finishing, and nuclear weapons fabrication and manufacturing.
- Plutonium recovery – recovery of plutonium from contaminated molds, metals, glass, plastics, rags, salts used in electrorefining, precipitates, firebrick, soot, and filters. Final waste forms include sludges and residues from evaporator and storage tanks that are typically solidified in Portland- or gypsum-based cements.
- R&D – projects involving actinide separations, metallurgical research, hot-cell or glove-box demonstration activities, chemical and physical properties determinations, and so forth.
- D&D – projects involving the decontamination and decommissioning of facilities and equipment that are no longer usable or needed. The resulting TRU wastes include scrap materials, cleaning agents, tools, piping,

filters, Plexiglas, gloveboxes, concrete rubble, asphalt, cinder blocks, and other building materials. This is the largest category by volume of the TRU wastes to be disposed in the WIPP repository.

2. CH- and RH-TRU Waste Inventories

The TRU wastes originated at 27 DOE generator sites (see Figure 1). Approximately 70 percent of the CH-TRU waste is scheduled to be packaged in 55-gallon (0.208 cubic meter) drums, with the remainder to be packaged in standard waste boxes (SWBs, each having an internal volume of 1.88 m³ and the capacity to contain four 55-gallon drums of CH-TRU waste)[6]. The RH-TRU waste will be packaged in R72B canisters,[7] each having an internal volume of 0.89 m³ and the capacity to contain three 55-gallon drums of RH-TRU waste.

The WIPP Compliance Certification Application (CCA)[8] provided a PA that showed conformity with Environmental Protection Agency (EPA) standards, 40 CFR 191 [3], which addresses the management and disposal of transuranic radioactive waste in the WIPP facility[9]. Information used in this WIPP PA was obtained from Rev. 3 of the Transuranic Waste Baseline Inventory Report (TWBIR)[6], which was developed from the best available information provided by the DOE TRU waste sites. The total waste volumes from the waste sites are listed in Table 1, and the waste material mass densities are listed in Table 2.

2.1 Normalized Units

The identification of the radionuclides that are important in the WIPP PA is dependent on the release limits defined in 40 CFR 191 (Table 3). These release limits are normalized to a unit of waste, which is the amount of waste containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years. At the projected closure of the WIPP in year 2033, the total radionuclide inventory contained in the WIPP is estimated to be 4.19×10^6 curies (15.5×10^{16} Bq) (Table 4). This includes 3.44×10^6 curies (12.7×10^{16} Bq) of transuranic radionuclides, thus resulting in 3.44 units of waste for the WIPP repository. The release limits for 3.44 units of waste are presented in Table 5. Also included in this table are the computed initial EPA units, which are multiples of the release limits associated with the inventory of radionuclides. Because these release limits are based on the relative biological importance of each radionuclide, the EPA units are a health dose surrogate[10]. For TRU waste, the total initial radioactive inventory is approximately equivalent to 10,000 EPA units. This is 10,000 units of α -emitters. The inclusion of other radionuclides (e.g., ¹³⁷Cs) slightly reduces the sum.

The allowable releases for 40 CFR 191 are probabilistic and specify that 1 EPA unit is allowed to be released over the entire 10,000 year regulatory timeframe with a probability of less than 1 chance in 10 and that 10 EPA units are allowed to be released over the same timeframe with a probability of less than 1 chance in 1000 [11]. For wastes that contain more than one radionuclide, the composite releases caused by a multitude of radionuclides is the sum of all the releases expressed by

$$R_j = \frac{1}{f_w} \left[\frac{Q_{1j}}{L_1} + \frac{Q_{2j}}{L_2} + \dots + \frac{Q_{nRj}}{L_{nR}} \right] = \sum_{i=1}^{nR} \frac{Q_{ij}}{f_w L_i} \quad (1)$$

where

f_w = waste unit factor = $\sum w_i / 10^6 Ci$; see Table 3 for units

w_i = activity in curies (Ci) for α -emitting TRU repository wastes having half-lives ($\tau_{1/2}$) of 20 years

L_i = the EPA release limit for radionuclide i (see Table 4 for examples and units)

nR = number of radionuclides contributing to the release

R_j = total normalized release (EPA sum) for the j th scenario

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

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 [11])

There are two different release pathways used in the 1996 WIPP performance assessment: (1) direct releases comprising (a) material brought to the surface by cuttings, cavings, and spillings[12], (b) brine under pressure that flows to the surface during a drilling intrusion through the repository[13]; and (2) indirect releases to the accessible environment in brine that moves through the subsurface, primarily the Culebra aquifer above the disposal region[14]. Other releases that have been estimated to be trivial are screened out as part of the features, events and processes screening arguments[15]. For indirect releases, information for the volumes, densities, and radioactivity of the TRU wastes are site-averaged (i.e., the properties for the total inventory of CH-TRU and RH-TRU wastes are averaged). For direct releases, the radioactivity information is needed in much greater detail because the model for direct releases [12] (cuttings and cavings only) includes the probability of penetrating individual drums of waste.

2.2 Waste Streams

The waste information in the TWBIR[6] is based on data obtained from each of the DOE sites in which they identify their inventory of legacy and projected wastes. Their information is grouped into waste streams, which are the smallest collections that have common waste characteristics. In total, there were 970 unique waste streams identified. This included 569 CH-TRU waste streams and 401 RH-TRU waste streams. In general, these waste streams come from different processes (e.g., actinide separation, nuclear weapons fabrication). Some of the DOE

sites have several hundred unique waste streams each. These waste stream inventories are summed to identify DOE site inventories and total WIPP inventories (which are used for indirect release calculations). It is the waste stream level of information that is used for the CH-TRU wastes in the direct release calculations for cuttings and cavings only. Thus, the indirect release calculations used information for all 569 CH-TRU waste streams. The RH-TRU was modeled as a single RH-TRU waste stream (actually a composite of all 401 RH-TRU waste streams) because of the insignificant contribution of the RH-TRU wastes to the inventory (Figure 2).

Because the CH-TRU waste streams are generated from a variety of activities, they result in a wide range for the concentration of EPA units. From Figure 3, it is evident that there are many waste streams that have thousands of drum volumes with very low concentrations of EPA units. Presentation of the CH-TRU waste stream data in complementary cumulative distribution function format at various post-closure times results in Figure 4. This distribution underlies the stochastic modeling of the WIPP PA direct releases for cuttings and cavings only[16].

2.3 Identification of Dominate Radionuclides

TRU waste can be quantitatively expressed in EPA units, which serve as a health dose surrogate measure for repository performance. A study of the WIPP TRU waste inventory[17] identified that four of the radionuclides listed in Table 5 (^{238}Pu , ^{239}Pu , ^{241}Am , and ^{240}Pu) are the significant radionuclides for repository releases and give rise to more than 99 percent of the total initial inventory in EPA units. This is logical because these actinide isotopes are the major transuranic isotopes that are generated in the production of nuclear weapon materials. The study also identified that because ^{238}Pu and ^{241}Am are short-lived, the total inventory of EPA units decays to one-third of initial value after 1,000 years (Figure 2). For the time period from 1,000 years to 10,000 years, when the majority of the human intrusions may occur, the EPA unit concentration in the TRU waste is low. Achieving an integrated release of 1 EPA unit would then require that hundreds of intact drum volumes be directly released to the accessible environment. These volumes are nearly two orders of magnitude greater than the volume from predicted mean releases[12].

3. Discussion

The key features of the TRU wastes to be disposed in the WIPP are the following: (1) the hazardous components of the TRU wastes are believed to have biological risks that are insignificant to the radioactive risks, (2) plutonium and americium radionuclides dominate the radionuclide inventory, and (3) the volumetric loading of the radionuclides, measured in EPA units, is low. The only way to alter these features would be for the future waste forms to have a significantly different composition from that of the legacy waste. This will not occur because the majority of the projected waste currently exists today and has yet to be packaged during future decommissioning and deactivation activities at the DOE sites.

An interesting feature of using EPA units as a health dose surrogate for repository performance assessment is that because this measure is normalized, the magnitude of the radioactivity does not matter. If the inventory source term is doubled, then the allowable releases are also doubled, but the number of EPA units would be the same (approximately 10,000 units for TRU waste dominated by plutonium and americium radionuclides). The only way to have an impact on the releases would be to require that the relative distribution of key transuranic radionuclides be altered (significant changes to the radionuclide inventory are not expected to occur). With respect to the repository regulations, all that matters is that 1 EPA unit of radioactivity is not released by any means to the biosphere during the regulatory time frame of 10,000 years with a probability of exceeding 10^{-1} . Nor should 10 EPA units be released with a corresponding probability of 10^{-3} . This normalized measure is very successful in that it is not possible to subvert to the intent of the regulatory standard.

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Figure Captions

Fig. 1. U.S. DOE transuranic waste sites (after [6]).

Fig. 2. Total EPA units as a function of time (after [17]).

Fig. 3. Number of CH-TRU drums (equiv.) versus EPA units/drum (time = 100 yr after closure) (after [17]).

Fig. 4. Distribution of radionuclide concentration (EPA units/m³) in CH-TRU waste streams at selected times (after [16]).

- Indicates Small Quantity Site
- * Indicates Major Site
- Waste Isolation Pilot Plant (WIPP)

AE Argonne National Laboratory-East
 AL Ames Laboratory
 AM ARCO Medical Products Company
 AW Argonne National Laboratory-West
 BC Battelle Columbus Laboratory
 BL Babcock & Wilcox-Lynchburg
 BT Bettis Atomic Power Laboratory
 ET Energy Technology Engineering Center
 IN Idaho National Engineering and Environmental Laboratory
 IT Inhalation Toxicology Research Institute
 KA Knolls Atomic Power Laboratory-Schenectady
 LA Los Alamos National Laboratory
 LB Lawrence Berkeley Laboratory

LL Lawrence Livermore National Laboratory
 MC U.S. Army Material Command
 MD Mound Plant
 MU University of Missouri Research Reactor
 NT Nevada Test Site
 OR Oak Ridge National Laboratory
 PA Paducah Gaseous Diffusion Plant
 PX Pantex Plant**
 RF Rocky Flats Environmental Technology Site
 RL Hanford (Richland) Site
 SA Sandia National Laboratories/New Mexico
 SR Savannah River Site
 TB Teledyne Brown Engineering**
 WV West Valley Demonstration Project

** Stored waste inventory has been shipped to other sites since issuance of last inventory report [s].

TRI-6342-6017-0

Fig. 1. U.S. DOE transuranic waste sites (after Ref. 6).

TRI-6342-6018-0

Fig. 2. Total EPA units as a function of time (after Ref. 17).

TRI-6342-6014-0

Fig. 3. Number of CH-TRU drums (equiv.) versus EPA units/drum (time = 100 yr after closure) (after Ref. 17).

TRI-6342-5210-0

Fig. 4. Distribution of radionuclide concentration (EPA units/m³) in CH-TRU waste streams at selected times (after Ref. 16).

Table 1. WIPP TRU Waste Anticipated Inventory by Site *

Storage/Generator Site	Stored Volumes (m ³)		Projected Volumes (m ³)	
	CH-TRU	RH-TRU	CH-TRU	RH-TRU
Ames Laboratory – Iowa State	0.0E+00		4.2E-01	
Argonne National Laboratory – East	1.1E+01		1.3E+02	
Argonne National Laboratory – West	6.5E+00	1.9E+01	7.4E+02	1.3E+03
Battelle Columbus Laboratories		5.8E+02		0.0E+00
Bettis Atomic Power Laboratory	0.0E+00	0.0E+00	1.2E+02	6.7E+00
Energy Technology Engineering Center	1.7E+00	8.9E-01	0.0E+00	0.0E+00
Hanford (Richland) Site	1.2E+04	2.0E+02	3.3E+04	2.2E+04
Idaho National Engineering Laboratory	2.9E+04	2.2E+02	0.0E+00	0.0E+00
Lawrence Livermore National Laboratory	2.3E+02		7.1E+02	
Los Alamos National Laboratory	1.1E+04	9.4E+01	7.4E+03	9.9E+01
Mound Plant	2.7E+02		0.0E+00	
Nevada Test Site	6.2E+02		9.0E+00	
Oak Ridge National Laboratory	1.3E+03	2.5E+03	2.6E+02	4.5E+02
Paducah Gaseous Diffusion Plant	0.0E+00		1.9E+00	
Pantex Plant	6.2E-01		0.0E+00	
Rocky Flats Environmental Technology Site	7.1E+02		4.4E-03	
Sandia National Laboratory – Albuquerque	6.7E+00		7.5E+00	
Savannah River Site	2.9E+03		6.8E+03	
Teledyne Brown Engineering	2.1E-01		0.0E+00	
U.S. Army Material Command	2.5E+00		0.0E+00	
University of Missouri Research Reactor	2.1E-01		8.3E-01	
Total CH & RH Volumes	5.8E+04	3.6E+03	5.4E+04	2.3E+04
Total TRU Waste Volumes	6.2E+04		7.7E+04	

* Data taken from Ref. 6.

Table 2. WIPP TRU Waste Material Parameter Average Mass Density *

Waste Material Parameters	Average Mass Density (Kg/m ³)	
	CH-TRU	RH-TRU
Iron Case Metal/Alloys	1.7E+02	1.0E+02
Aluminum Base Metal/Alloys	1.8E+01	7.1E+00
Other Metals/Alloys	6.7E+01	2.5E+02
Other Inorganic Materials	3.1E+01	6.4E+01
Vitrified	5.5E+01	4.7E+00
Cellulosics	5.4E+01	1.7E+01
Rubber	1.0E+01	3.3E+00
Plastics	3.4E+01	1.5E+01
Solidified Inorganic Material	5.4E+01	2.2E+01
Solidified Organic Material	5.6E+00	9.3E-01
Cement (Solidified)	5.0E+01	1.9E+01
Soils	4.4E+01	1.0E+00
<u>Container Materials</u>		
Steel	139	446
Plastic/Liners	26	3.1
Lead		465
Steel Plug		2145

* Data taken from Ref. 6.

Table 3. 40 CFR 191 Release Limits for Containment Requirements* [Cumulative releases to the accessible environment for 10,000 years after disposal]

Radionuclide	Release Limit per 1,000 MTHM or other unit of waste (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
Application of Table {Appendix A to Part 191 for Subpart B}	
<p>Note 1: Units of Waste. The release limits in Table 1 apply to the amount of wastes in any one of the following:[†]</p> <ul style="list-style-type: none"> a An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM; b The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM; c Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the NRC as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPB); d Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the NRC as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPB); or [‡] e An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years. 	

NRC - Nuclear Regulatory Commission

NWPB - National Waste Policy Act

* Source - [3], Subpart B, Appendix A, Table 1.

[†] Only Note 1 of this table is shown.

[‡] Only subnote e applies to WIPP and only TRU waste will be disposed at the facility.

Table 4. 40 CFR 191 Unit of Waste for WIPP-Scale TRU Waste^a

Nuclide			WIPP TRU Waste		
ID	Decay Mode	Half-Life	Total Inventory [Curies]	Transuranic Inventory [α -Curies]	% of Unit of Waste
Top 5 Radionuclides					Cum (%)
²³⁸ Pu	α, γ, SF	87.7 a	1.94E+06	1.94E+06	56.4
²³⁹ Pu	α, γ, SF	2.410E+04 a	7.95E+05	7.95E+05	79.5
²⁴¹ Am	α, γ, SF	432.7 a	4.88E+05	4.88E+05	93.7
²⁴⁰ Pu	α, γ, SF	6.56E+03 a	2.14E+05	2.14E+05	99.9
²⁴² Pu	α, γ, SF	3.75E+05 a	1.17E+03	1.17E+03	>99.9
others			7.52E+05	1.20E+02	3.49E-03
Sum =			4.19E+06	3.44E+06	100.00%

^a Radionuclide inventory information taken from Revision 3, Transuranic Waste Baseline Inventory Report (TWBIR, [6]) (in total, 135 radionuclides are inventoried in the TWBID). Unit of waste values taken from [17]. Inventory data for closure date, year 2033.

Table 5. 40 CFR 191 Release Limits and Source Term EPA Units for WIPP-Scale TRU Waste
(Calendar Year = 2033)^a

Nuclide			WIPP TRU Waste				
ID	Decay Mode ^b	Half-Life (yr)	Total Inventory [Curies]		Release Limits Inventory [Curies] ^c		Initial EPA Unit
			CH	RH	(Ci/UW)	(Ci)	Inventory
Top 10 Radionuclides							
²⁴¹ Am	α, γ, SF	432.7	4.78E+05	9.43E+03	100.	344.	1.42E+03
¹³⁷ Cs	β^{-}, γ	30.17	3.35E+03	8.98E+04	1000.	3440.	2.71E+01
²³⁷ Np	α, γ	2.14E+06	6.19E+01	2.95E+00	100.	344.	1.89E-01
²³⁸ Pu	α, γ, SF	87.7	1.93E+06	1.08E+03	100.	344.	5.64E+03
²³⁹ Pu	α, γ, SF	2.410E+04	7.85E+05	1.03E+04	100.	344.	2.31E+03
²⁴⁰ Pu	α, γ, SF	656E+03	2.09E+05	5.05E+03	100.	344.	6.22E+02
²⁴² Pu	α, γ, SF	3.75E+05	1.17E+03	1.50E-01	100.	344.	3.40E+00
⁹⁰ Sr	β^{-}	29.1	2.77E+03	8.45E+04	1000.	3440.	2.54E+01
²³³ U	α, γ, SF	1.592E+05	1.79E+03	1.58E+02	100.	344.	5.67E+00
²³⁴ U	α, γ, SF	2.46E+05	7.08E+02	4.29E+01	100.	344.	2.18E+00
others			3.92E+05	2.77E+05			3.98
Sum =			3.80E+06	3.93E+05			1.00E+04
			4.20E+06 ^d				

- a Radionuclide inventory information taken from Revision 3, Transuranic Waste Baseline Inventory Report (in total, 135 radionuclides are inventoried in the TWBIR [6] and were then decayed to the year 2033). EPA unit values taken from [17].
- b α - alpha emission, β -beta emission, γ - gamma emission, SF - spontaneous fission
- c Release limits are determined in accordance with 40 CFR 191 (Appendix A, Table 1) [3]. Left column corresponds to Table 3 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 [3]). Right column corresponds to release limit obtained for 3.44 units of waste (see Table 4 for calculation of the unit of waste).
- d For comparison, the Yucca Mountain Project [18] has approximately 12.4 billion curies of radioactive inventory (spent nuclear fuel—63,000 MTU $\times$ 1.57×10^5 Ci/MTU + vitrified high-level waste— 2.47×10^9 Ci).